Euro 6/VI Evaluation Study

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Executive summary

A. Introduction and objectives

This report presents the findings of the support study for the retrospective assessment of Euro 6/VI vehicle emission standards (henceforth the "Evaluation").

The evaluation study focuses on the vehicle emission standards[1] as set in Regulations 715/2007 for light duty vehicles (Euro 6) and 595/2009 for heavy duty vehicles (Euro VI). It also covers secondary implementing legislation related to the type approval process which introduced the new regulatory test implementing the World Harmonised Light Vehicle Test Procedure (WLTP) and the methodology for testing vehicle emissions in real-driving conditions (RDE). In the case of heavy-duty vehicles, it also includes the provisions related to the use of portable emission measurement systems (PEMS).

The study aims to:

- Establish evidence-based conclusions on the actual results and impacts of the Regulations and the factors that may have resulted in the interventions being more, or less successful than anticipated;
- Communicate the achievements and challenges of the Regulations; and
- Inform decisions in order to improve the design of any future revision of the standards.

The study focuses on the period since the entry into force of the standards, namely 2014 for Euro 6 and 2012 for Euro VI. Given that the evaluation is intended to be a backward-looking exercise the focus is on the impact up to now (2020). However, given that the impacts of the Euro 6/VI emissions limits are expected to last even after 2020, the analysis also considered the expected impacts of the already adopted measures in the future. Geographically, the focus of the evaluation is on the implementation of the Regulations in the European Union.

B. Evaluation methodology

The methodology followed the standard evaluation framework for an assessment of legislation and the key evaluation criteria related to effectiveness, efficiency, relevance, coherence and EU added value. An evaluation matrix was developed to analyse and operationalise the evaluation questions. Relevant indicators and judgement criteria and the appropriate data collection tools and sources were identified to support the analysis.

The research and analysis tools used included:

- Desk research/review of relevant documents and analysis of relevant available datasets (e.g. Eurostat, OECD, IHS Markit Database).
- A targeted stakeholder consultation combining an online questionnaire and follow up interviews of members of the Advisory Group on Vehicle Emission Standards (AGVES). These included national authorities (type approval authorities and

[1] Throughout the text we will use the term "emissions" or "pollutant emissions" to refer to tailpipe and evaporative emissions from vehicles that hazardous to health and the environment, that are regulated by the Euro 6/VI standards. Unless explicitly stated it will not refer to the emissions from vehicles that have an impact on climate (greenhouse gas emissions), although some of the pollutant emissions also have a climate change impact.

ministries/agencies with relevant responsibilities), technical services, industry representatives (including vehicle manufacturers and equipment suppliers and their representatives), representatives of the civil society (environmental and health NGOs, consumer representatives) and research organisations. They were supplemented with additional data requests to type approval authorities.

- Analysis of additional input provided by stakeholders on the context of the Public consultation organised by the Commission as well as relevant comments to the Inception Impact Assessment.
- The COPERT software[2] and SYBIL model[3] to support quantification of the impacts of the Euro 6/VI standards and the assessment of their effectiveness (i.e. impact on pollutant emissions) and efficiency (costs of implementation).

C. Main findings

A summary of the findings of the analysis for each evaluation criterion is presented in this section.

Effectiveness

Impact of Euro 6/VI on vehicle emissions and role of testing procedures

- Overall, the Euro 6/VI standards have had a positive contribution towards making vehicles cleaner by leading to significant reductions in emissions of key regulated air pollutants, albeit with certain ongoing limitations.
- In the case of **Euro 6**, the available evidence points to significant reductions in the levels of NOx emissions from new Light Duty Vehicles (LDVs) both in the initial stages (Euro 6b/c) as well as following the adoption of more demanding Real-Driving Emissions (RDE) testing procedures (Euro 6d-Temp and Euro 6d[4]). More specifically:
    i) The available data from the literature and emission factors, point to a 51% reduction in real world NOx emissions per vehicle for the initial version Euro 6 vehicles (Euro 6b/c) prior to the introduction of the RDE testing procedures. This is in comparison to 56% reduction in the emission limit values between Euro 5 and Euro 6. Euro 6d-Temp and Euro 6d vehicles (i.e. vehicles after the introduction of RDE testing) achieved further levels of reduction, with real-world emission factors eventually dropping by 92% compared to Euro 5.
    ii) There are also similarly sizeable reductions of other pollutants on the basis of currently available emission factors. In relation to CO, they reduced by 30% between Euro 5 and Euro 6d for Compression ignition (CI) passenger cars[5] and in the case of particles they reduced by 19% for CI passenger cars and 10% for positive ignition (PI)[6] passenger cars. In addition, emissions of exhaust particles

[2] https://copert.emisia.com/

[3] https://www.emisia.com/utilities/sibyl-baseline/

[4] We will use the term “Euro 6 RDE vehicles” when referring to vehicles complying with Euro 6d-temp or Euro 6d.

[5] Refers to all Internal combustion engines that can be fuelled by diesel fuel or biodiesel. It also refers to all types of hybrid diesel vehicles including plug-in hybrid.

[6] Refers to all Internal combustion engines that can be fuelled by gasoline fuel, gasoline fuel blended with oxygenates including methanol and/or ethanol, liquid petroleum gas or compressed natural gas. It also refers to all types of hybrid petrol vehicles including plug-in hybrid.

reduced by 86% for PI passenger cars. PI passenger cars also see large reductions in THC (62%) and NMHC (61%). All other regulated pollutants emission factors also reduced from Euro 5 to Euro 6d emissions.

- As such, we can conclude that Euro 6d-Temp and Euro 6d vehicles are significantly cleaner than Euro 5 vehicles.
- However, as they were only recently introduced in the market they still represent a small share of the total fleet (e.g. at the end of 2019, only 7.1% of the overall light-duty vehicle fleet in Germany complied with the Euro 6d-temp and 6d standards). As a result, the net impact on total pollutant emissions – and on air quality - from Euro 6 vehicles has, so far, been relatively limited. Thus, a more sizeable reduction in emissions is expected in coming years with the gradual increase in the share of Euro 6 RDE vehicles (78.1% reduction of NOx in the 2021-2050 period).

An important part of the reduction in emissions is due to the improvements in testing procedures. More specifically:

- The introduction of the Worldwide Harmonised Light Vehicles Test Procedure (WLTP) played a positive role by introducing a more representative driving cycle.
- The main contributor was the introduction of the RDE testing during type approval that defined a broad range of boundary conditions that cover normal driving conditions and accounted for differences in level of emissions under a broad range of driving conditions, including different ambient temperatures and different altitudes and included cold-start emissions.
- Within the boundary conditions set, the available evidence from various studies shows that RDE testing has led to additional significant reductions in real-world emissions of NOx, CO and PN that helped ensure that real world emissions are more in line with the emission limits.
- In-service conformity (ISC) requirements and market surveillance have also helped ensure that, at least within the context set by the RDE boundary conditions, use of defeat devices that deactivate emissions control equipment in the real world are not applied. TAAs are now responsible for re-testing through in-service conformity checks instead of relying on technical reporting by manufacturers. In the latest changes to the testing provisions that only recently came into force (RDE 4^{th} package), the Regulation further expands the effectiveness by including surveillance on in-use vehicle fleet by type approval authorities and other accredited independent laboratories. However, this only applies to vehicles up to 100,000km, which excludes an important part of the in-use fleet.

Having said that, some problematic aspects were also identified.

- The analysis shows that some level of emissions under real-world emissions still remains unaccounted for. RDE test boundaries exclude short trips, high mileage and high-altitude useuse, extensive stop-and-go driving during traffic jams, high or low accelerations and severe temperature conditions for LDVs. These operating conditions represent a small proportion of vehicle operations overall, but they include scenarios that are not that uncommon and that have been found to be associated with emission levels well above the limits. Furthermore, while the vehicle can be tested with a high payload, devices affecting the aerodynamics (including roof and rear mounted equipment and trailers, except for PEMS installation) are not included within RDE testing but can lead to higher level of emissions. As a result, while the RDE boundary conditions effectively capture the normal condition of use that still miss a part of total emissions produced by vehicles during untypical driving conditions.

- Introduced to account for potential measurement uncertainties for PEMS (Portable Emissions Measurement System) relative to laboratory measurements, conformity factors used up to now (the 2.1 for Euro 6d-Temp and 1.43 for Euro 6d for NOx, and 1.5 for PN) have allowed (at least for the first phase) additional emissions that may not be fully justified by PEMS measurement uncertainties in practice. This meant that vehicles were allowed to emit NOx emissions above the nominal Euro 6 limits.
- The presence of different implementation dates for vans may have had a negative impact on the stringency of the standards for these vehicles, even though they are likely to be more polluting given the likely driving conditions in which they are used (lower speed, more urban driving and more stop-start than cars) and the additional power required in comparison to cars due to their loads.
- Durability provisions currently only cover a proportion (approximately 50%) of the average lifetime of vehicles (in terms of age and mileage) and this share could be further reduced in the future if the trend for an increased lifetime is confirmed. Thus, the durability provisions appear to be not effective when it comes to capturing vehicles' real-world emissions over their useful lifetime.
- Existing on-board diagnostic (OBD) requirements do not appear to be robust enough to ensure that it is not possible to manipulate and to ensure detection of degradation or failure of emission control systems under all circumstances. This is because the OBD threshold is not set sufficiently low to ensure that all faults are detected. This results in a lack of monitoring of missing particle filters, increasing the risk that diesel particulate filters (DPFs) and gasoline particulate filters (GPFs) are illegally removed for cost saving once a vehicle is on sale in the EU.
- Defeat devices may still be possible to be used and not be identified outside the boundaries conditions set in the RDE test methodology. However, as the window outside the testing boundary conditions is smaller than in the past there is also reduced incentive in using them.

In the case of **Euro VI for Heavy Duty Vehicles (HDVs)**, the analysis points to similar positive impacts in terms of the reductions in pollutant emissions from Euro VI buses and lorries.

- The available data from the literature and emission factors, point to a level of reduction in real-world NOx emission factors of around 72% between Euro V and Euro VI vehicles. This translated into actual savings in NOx emissions in 2020 for the whole vehicle fleet of around 52% in comparison to a Euro V baseline[7].
- There are also similarly sizeable reductions in the pollutant emissions from HDVs as reflected in the changes to the emission factors. In relation to particles, exhaust emission factors reduced 90% between Euro V and Euro VI while CO emission factors have also largely decreased by the same level. There were also significant reductions for THCs (around 23.4%), CH4 (20.5%) and NMHC (23%). However, NH3 increased by 45.7%. .
- Overall, we conclude that Euro VI vehicles are significantly cleaner than Euro V vehicles. At the same time, as Euro VI vehicles already represent a significant share

[7] In the case of heavy-duty vehicles, the baseline scenario assumes a continuation of the Euro V standard. There would be no changes to the emission limits and test requirements as those already in place and that all new HDVs entering the market would be Euro V vehicles. Any changes to the testing procedures (including for example the OCE testing) is considered as part of the Euro VI.

of the total fleet (17.3% at the end of 2018), the analysis of the impacts on total fleet-wide emissions also suggests overall sizeable reductions.

The analysis also points to ongoing limitations of the existing testing procedures for Euro VI which mean that they can lead to misleading conclusions in terms of the actual level of emissions generated under normal conditions of use:

- The coverage of the engine test cycles for heavy duty vehicles (World Harmonised Transient Cycle (WHTC) and World Harmonised Stationary Cycle (WHSC)) remains insufficient and there is still potential for optimisation of a vehicle's engine to the test conditions. Similarly, the elimination of the "moving average window" results at less than 10% power from the PEMS test results can exclude significant real-world emissions generating scenarios from regulation.
- The applicable tests' boundaries exclude emissions measured at low loads, low speeds and during engine idling – i.e. the conditions that buses are mostly operating under in the real world. As such, the existing tests may not properly capture the emission levels in urban areas, or for the full range of HDV use, being more representative of medium-long haul trucks. Even with the recent changes to the power threshold from 20% to 10%, a significant proportion of pollutant emissions are not accounted for by the test procedures.
- In addition, the regulation allows for the deactivation of emission control systems control devices under specific conditions to protect the engine or aftertreatment system from damage. Although the requirements limit the occasions on which such deactivation of emissions controls can occur, there is potential for the allowance to be used to justify unnecessary deactivations.
- The above limitations are compounded by the fact that tampering is still possible, allowing some vehicle operators to disable aftertreatment systems on heavy duty vehicles. Unlike LDVs, no third-party verification is included in the legislation and in-service conformity (ISC) for HDVs is undertaken by manufacturers. Hence, it is possible that manufacturers may not pay appropriate attention to the security of their systems and may, unintentionally, allow for tampering to occur.
- Further to that, existing on-board diagnostic (OBD) requirements do not appear to be robust enough to ensure that it is not possible to manipulate and to ensure detection of degradation or failure of emission control systems under all circumstances. This is because the OBD threshold is not set sufficiently low to ensure that all faults are detected. For HDVs, OBD limits for CO, NOx and PN are even higher than the Euro VI emission limits. This results in a lack of monitoring of missing particle filters, increasing the risk that diesel particulate filters (DPFs) and gasoline particulate filters (GPFs) are illegally removed for cost saving once a vehicle is on sale in the EU.
- As in the case of Euro 6, durability provisions appear to be not effective when it comes to capturing vehicles' real-world emissions over their useful lifetimes. Current durability provisions under Euro VI currently cover around 60% of the average lifetime of heavy duty vehicles (in terms of age and mileage) and this share could be further reduced in the future if trends for an increased lifetime continue.

Ensuring effective functioning of the single market

- The Euro 6/VI standards appear to have largely achieved the objective of ensuring the effective functioning of the Single market and ensuring a harmonised approach when it comes to accessing the market. However, there are still outstanding distortions in the market due to discrepancies in testing procedures, with variations in technical expertise and resources available to type approval authorities (TAAs) leaving room for interpretation of the requirements.

- "Room for interpretation" is driven by inconsistent interpretation of the term "illegal defeat device", through different European TAAs, lack of clarity over the right to disable emission control devices to protect components, ongoing financial relationships between TAAs and manufacturers and the fact that the current type-approval procedure does not prevent manufacturers from requesting approval from a different Authority if its request has initially been rejected. This leads manufacturers to select the authority with the least stringent interpretation of existing rules. As a result, the market is not yet fully harmonised.

Provision of sufficient lead time to industry

- The notification timeframes of the EU standards (seven and four years for Euro 6 and Euro VI respectively) provided sufficient time for industry to develop the relevant technologies in advance of the legal compliance dates for the initial phases of the standards. The type of technology developments necessary to ensure compliance with the new emission limits typically require two-three years of lead time.
- The picture was different in the case of the introduction of the RDE testing regime. While also introduced in stages, it brought effective changes to the real performance of vehicles within a shorter period of time (2016-2019). However, from the point of view of the industry this meant that there was not sufficient lead time provided in view of the significant changes required, a point made by the majority of industry representatives (including OEMs and suppliers). It has been linked with substantial additional effort within a very short period of time. Nonetheless, given the seriousness of the situation with respect to the dieselgate scandal and the huge impact this had on consumer confidence in the automotive industry, it could be argued that the additional efforts required by the industry at short notice were proportionate to the nature and scale of the problem.

Impact of the complexity of the legal framework

- The current legal framework is particularly complex, characterised by a very long legal text with references to a large number of supporting legislation (including UNECE Regulations). It has been the result of a gradual evolutionary process with multiple additions and changes introduced without changes to the overall structure.
- Besides the implications to the costs (discussed below), this complexity makes both compliance with, and enforcement of, the legal framework challenging. It also provides room for different interpretations that can limit the effectiveness of the measures.

Contribution to innovation

The available evidence suggests that the introduction of Euro 6/VI standards and new testing requirements have had a positive role in the development of innovation.

- Euro 6/IV standards have been relevant to foster the development and, even more so, the market uptake of aftertreatment control technologies in a number of areas. Technologies like Selective Catalytic Reduction (SCR), which was first used for many HDV from Euro V and a handful of high-end LDV at Euro 5, has seen further R&D activity leading to more effective and lower-cost systems and widespread adoption. In other cases, (e.g. Gasoline Particulate Filters for Gasoline Direct Injection engines), the introduction of PN limits is directly credited with bringing the specific technology to the market. In parallel, while not the only driver of such developments, improvements in engine design, in-cylinder control technologies and engine management systems can be linked with the Euro standards while also improving performance, fuel efficiency and reducing CO_2 emissions.
- In that respect, the adoption of RDE testing as part of Euro 6 was much more important to incentivise innovation in relation to most of the above technologies than the changes

to the emission limit values. This is a common view of most stakeholders, and it is also evident by the evolution of the technologies fitted in the most recent Euro 6d-Temp and Euro 6d vehicles.

- Whether in reference to new or existing emission control technologies, the adoption of the standards was clearly relevant in terms of technology adoption by vehicle manufacturers. Voluntary adoption of emission control technologies, in the absence of these standards, was highly unlikely to have happened as technology is costly and the perceived value of improved pollutant emissions performance by customers is limited.
- Relevant R&D support mechanisms have been in place to support the development of new technologies related to Euro 6/VI both at the EU level (e.g. through Horizon 2020, investment support from the European Investment Bank (EIB) as well as via national support schemes. However, there is limited evidence on the role that these mechanisms have played to support OEMs and suppliers in the development of innovation.

Impact on the competitiveness of the sector

The impact on the international competitiveness of the sector is a result of the combined impact on profitability, innovative capacity and market access. Put together, we conclude that the impact of the implementation of the Euro 6/VI standards was positive but limited. Most probably they have not had a negative impact on competitiveness and that they may have even helped to ensure that they are in the forefront when it comes to the adoption of emission control technologies. More specifically:

- The standards led to an increase in production costs that have potential negative implication on the profitability of the automotive sector. However, as manufacturers are generally expected to pass costs to consumers, any such impact should be limited. Furthermore, given that the requirements (and the associated costs) apply to all vehicle manufacturers that place vehicles in the EU market, impacts on profit margins should not put EU OEMs at a disadvantage. Still, indirectly EU OEMs may be at a disadvantage as a result of the higher labour and other indirect costs when compared to competitors in lower cost countries. As such, the higher regulatory costs arising from Euro 6/VI legislation may have had a small and indirect negative effect on the profitability of some EU manufacturers.
- While this varies depending on the specific pollutant under consideration, the role of the Euro 6/VI standards has mainly been towards that the adoption of existing technologies and ensuring that manufacturers do not fall behind third country competitors. It had less of a role in the adoption of new breakthrough technologies which could provide an early technological advantage vis a vis their competitors based in other regions.
- It is difficult to tell if there is a direct impact from the adoption of Euro 6/VI standards in terms of international market access and, if so, how significant it is. This depends on the stringency of the requirements vis a vis those in other markets – which is high when considering the combination of limit values and testing procedures – but also on the extent that EU based manufacturers rely on sales in the EU (still more than 75%) and the extent of local production of vehicles sold in other markets (generally high). Overall, we conclude that the Euro 6/VI standards have probably had a positive but limited role in terms in supporting access to other markets.

Contribution to the achievement of the targets of other legislation

- The reduction in emissions also contributed to reducing the level of key pollutants (CO, NOx, PM) regulated under the National Emissions Ceilings Directive and, to a certain extent, towards the achievement of Member States' air quality targets under the

Ambient Air Quality Directive (Directive 2008/50/EC). However, while the absolute level of emissions from transport reduced (as already indicated), the relative contribution of the road transport sector to overall pollution at the EU-level remained the same due to annual increases in activity levels. In addition, a small increase in NH_3 emissions from CI LDVs as a side effect of the technologies used to limit NOx emissions (Lean NOx Traps and SCR) has been mitigated in the most recent Euro 6d vehicles while NH3 emissions from HDVs have increased.

- We have found no systematic evidence to suggest that that Euro 6/VI has led to an increase of CO_2 emissions. There is a potential impact on CO_2 emissions from the choice of specific emission control technologies which increase the backpressure required for filtration or SCR units, but these are rather the result of technology choices by OEMs and it is not necessarily caused by Euro 6/VI as the technology to improve CO_2 emissions and NOx emissions exists.

No evidence of sizeable impact on employment or public awareness of vehicle-related air pollution

- There are no indications of a significant impact – positive or negative – on the levels of employment that can be directly associated with the introduction of Euro 6/VI. A positive impact on employment can be expected linked to the increased R&D activity by OEMs for the development of new or updated technologies and for suppliers specialising in pollution control technologies as a result of the increased demand for such technologies. In addition, there has also been a demand for additional human resources in the relevant regulatory/homologation departments in response to the more demanding testing and type approval procedures introduced, particularly following the adoption of RDE.
- Finally, Euro 6 standards appear to have had a limited contribution towards raising awareness of vehicle-related air pollution and influencing public attitudes. Whilst society seems to be more aware of air pollution issues and the role of vehicles in creating these issues, this is mainly the result of other events/trends (such as the dieselgate scandal, the growing use of Low Emission Zones (LEZs) in cities, fiscal taxes and benefits). There is still an indirect link with the Euro 6/VI standards as these are used to determine access to fiscal incentives or access to LEZs. Still, it is probably the case that consumers associate the adoption of these instruments – rather than the Euro 6 standard itself – with any impact on air pollution.

Efficiency

The analysis of the efficiency of the Euro 6/VI standards assessed the total regulatory costs of the legislation (namely the substantive compliance, enforcement and administrative costs) and compared them with the respective benefits to society arising from the reduction of pollutant emissions. It has been based on the combination of input from industry representatives, technical services and type approval authorities, combined with information and data collected as part of the desk research and input from experts within the CLOVE consortium. In our quantification we considered the marginal costs incurred up to now in comparison to a Euro 5/V vehicles but also the marginal costs expected to be incurred up to 2050 in comparison to a Euro 5/V baseline out to 2050, by which time all ICE light duty vehicles in the fleet are expected to be Euro 6d vehicles. There is some uncertainty over some of the specific cost estimates due to limited data and, as a result, broad cost ranges have been used in some cases, we consider that the costs estimates properly reflect the scale of the costs and the relative share of different cost elements. In addition, they have been presented to industry stakeholders for comments for potential revision.

The following points summarise the conclusions of the analysis in relation to the costs incurred and the cots-effectiveness of the measures

Regulatory costs to industry

- The introduction of Euro 6 and Euro VI has led to significant additional regulatory costs for vehicle manufacturers. The total costs have been estimated in the range of €30.6-76.0 billion over the period 2013-2020, €21.1billion-€55.6billion linked to the introduction of Euro 6 and €9.5billion-€20.4 billion linked to Euro VI.
- While sizeable, the total costs represent a very small share of the industry turnover, estimated to be no more than 2% of the total turnover of the sector. Furthermore, it is generally expected that OEMs would eventually pass-through most of the costs to consumers.
- For the total period up to 2050, net compliance costs for Euro 6 are estimated in the range of €80.6 billion to €186.6 billion (discounted to 2013 base year with a social discount rate of 4%). The respective costs for Euro VI are estimated at €16.0 billion-€35.0 billion.
- Considering the specific cost drivers, hardware costs (i.e. costs of technology installed in the new vehicles) represent the most important part of these costs. The weighted average of the costs for the whole period were estimated in the range of €36-€59 per vehicle for PI engines and €307-€801 per vehicle for CI engines and 1,556-€3,635 per vehicle for HDVs. However, this cost increased over time for LDVs as a result of the introduction of Euro 6 RDE. Thus, the costs of hardware installed in the most recent Euro 6d vehicles is estimated at €402-€465 for PI and €751-€1,703 for CI vehicles.
- Total costs for compliance for diesel LDVs have been more significant up to now. However, Euro 6d requirements introduce additional costs for most PI vehicles. As a result, in the coming period, costs for compliance for PI (mainly petrol) vehicles should be expected to represent a higher share of the total costs for Euro 6 vehicles.
- The analysis also points to sizeable R&D and testing costs. Overall, the estimated non-hardware costs per vehicle represent 23%-27% of total costs for LDVs and 54%-58% for HDVs. We note that the current estimates of the R&D costs for HDVs based on input from OEMs are considered as high and possibly overstating the actual costs associated with the Euro VI. As such, it is possible that the actual share of non-hardware costs was smaller, along the lines of the respective costs for LDVs. Even if the case of these possibly overstated R&D costs, the total R&D expenditure (€8.5b-€21.3 bn was a relatively small share of the total R&D expenditure of the motor vehicles sector (NACE 29.1), 3.4%-8.5% of the total of ca. €250 billion over the same period (Eurostat).
- Other cost elements related to enforcement, fees and administrative costs represent a smaller amount for both Euro 6 (4-5% of the total) and Euro VI (1%). The only exception are the costs for Euro 6 PI , since there was no need for new technologies in the initial stages, the overall share of the other costs elements was higher (19%)
- Input from equipment suppliers suggests that most of them incurred additional costs for new product development and testing of new equipment. Those that were involved in type approval activities also incurred relevant certification costs. However, it is largely the case that costs for suppliers are ultimately covered by vehicle manufacturers, mainly through the cost of hardware fitted to vehicles.

Impact on type approval authorities and consumers

- Type approval authorities and technical services also incurred one-off costs. These included investment in new facilities and equipment (in a few cases) as well as preparatory action taken in the form of training, development of guidance documents or other system updates. They also included ongoing costs in the form of additional expert personnel to cover the increased time needed for witnessing the various tests and the increase demand for type approvals. However, large part of these costs (in the form of witnessing costs mentioned earlier and fees) have been covered by vehicle manufacturers.

- Concerning the impact on users of vehicles (consumers or businesses), any increase in regulatory costs to industry is expected to be eventually passed through in the form of higher prices. In that respect, the analysis suggests that, in most cases, the estimated regulatory costs are in the range of 1%-3% of the average vehicle price. The only exception is the costs for Euro 6d-CI vehicles where costs as high 6% of the average vehicle price for small size vehicles are expected. However, it is expected that OEMs distribute these costs across all vehicle categories.

Cost-effectiveness of the intervention

- The analysis of costs has been compared against the monetised benefits arising from the emission reductions. The comparison is based on examining the Net Present Values (NPVs) for both the costs and monetised benefits for the whole time period up to 2050 at which point all vehicles ICE vehicles are expected to be compliant with Euro 6d (LDVs) or Euro VI (HDVs) in order to properly capture the benefits arising from the standards. The monetised benefits have been calculated by multiplying the emission savings with the external damage costs air pollutants for transport extracted from the 2019 Handbook of External costs of transport developed on behalf of the European Commission DG MOVE. Benefits have been monetised for most regulated pollutants (NOx, NMVOC, PM) but, , not in relation to PN which is linked to the use of GPF technology in some PI Euro 6 vehicles due to absence of relevant emission factor for PN. It also does not cover CO, THC and CH_4. As a result, the analysis most probably underestimates the total benefits associated with Euro 6/VI.

- Considering the overall cost-effectiveness of the legislation, the analysis points to the overall high benefit to cost ratio for both Euro 6 and Euro VI standards when assessed against the expected monetised benefits to the society from the reduced emissions and resulting environmental and health impacts. This is also a point that is supported by the large majority of stakeholders that consider that the costs are justified by the benefits achieved.

- The ratio of net monetised benefits for the period up to 2050 against the expected net costs (in PV values) is in the range of 2.0-4.7 for Euro 6 depending on the cost scenario assumed. Compared against Euro 6 pre-RDE the ratio is smaller (1.6-3.1) reflecting the higher costs for compliance with Euro 6-RDE.

- Focusing on the CI (diesel) LDVs only, the ratio is higher (2.5-5.9 against Euro 5 and 2.5-4.7 against Euro 6 pre-RDE). In the case of PI engines the small emission savings (mainly in relation to PM) lead to overall costs that are higher than the respective benefits (negative overall net present value). However, as the analysis does not capture the health and environmental benefits resulting from the adoption of PN limits for petrol GDI engines (while it does include the associated costs of the introduction of these technologies) it underestimates the benefit/cost ratio. An earlier analysis on the expected effectiveness of the specific measure (introduction of GPF) suggested that the costs per vehicle would be relatively similar to the benefits. As such, the inclusion of the impacts on PN should be expected to lead to a positive NPV and a benefit-to-cost ratio higher than one.

- In the case of Euro VI, the analysis also points to a clearly positive benefit/cost ratio (15.0-32.8).

- While the additional costs resulting from the Euro 6/VI standards were significant, there is no indication that they are not affordable for industry. Furthermore, it is generally expected that OEMs would eventually pass-through most of the costs to consumers.

Simplification and unnecessary costs

- While being overall cost-effective, the legislation did not bring a simplification to the legal framework. Rather on the contrary, the legal framework for both LDVs and HDVs is characterised by the presence of multiple and complex tests and has become, over time, more complicated. In relative terms, Euro VI legislation is less complex than Euro 6, notwithstanding the changes to some of the testing requirements moving from Euro VI-A to Euro VI-E.
- The complexity of the legal framework has mainly increased as a result of the new and more demanding testing requirements and the multiple phases of implementation (stages) together with different dates for the introduction of various tests. These have been introduced within a short period – largely in response to the dieselgate "scandal". They were also introduced on an add-on basis without changes to the overall architecture of the legal framework, with an increasing number of references to other pieces of legislation (e.g. UNECE) without a clear overview. Such levels of complexity have contributed to increased enforcement and administrative costs. However, while not desirable, such additional complexity could be seen as partly justified within the context of the need to ensure that vehicles are clean on the basis of more demanding and rigorous testing and in-service conformity requirements and the need to restore consumer confidence.

Relevance

Overall, on the basis of the analysis we can conclude that objectives of Euro 6/VI to reduce pollutants emitted by the road transport sector and improve air quality appears to remain very relevant. These are the conclusions of the main drivers:

- Air quality issues associated to road transport remain a persistent issue in European urban areas and recent research suggests strong associations of air pollution with health effects even at low concentration levels, with no observable thresholds.
- Emission standards are relevant mechanisms to encourage reductions in vehicle emissions that could offset potential transport demand increases. Without standards forcing the adoption of new technologies there are simply no incentives for the development and deployment of emission control technologies, and it would not be possible to achieve significant reductions in emissions of air pollutants.
- The European Green Deal introduces a "zero-pollution ambition" and states that "transport should become drastically less polluting". While an important part of achieving this objective is linked with the increased uptake of electric vehicles and other traction options with zero tailpipe emissions, this also creates a need for more stringent air pollutant emissions standards for combustion-engine vehicles. ICEs, in particular for HDV, are expected to still represent a significant part of the fleet in the coming decades and reducing their overall impact on air pollution will still be necessary.
- At the same time, the adoption of aftertreatment systems in response to Euro 6/VI standards and trends in the use of fuels increasingly induce pollutant species that were already emitted by pre-Euro 6/VI vehicles. These pollutant species are not specifically regulated under current Euro 6/VI standards, but they are implicated in air quality and health issues. In particular:

- Ammonia (NH_3) emissions, which are not regulated for LDV, increase with the application of technologies (urea-based SCR systems or lean-NO_x traps) used to comply with Euro 6 (and Euro VI) for CI vehicles and have a significant role in the formation of secondary particles, increasing $PM_{2.5}$. This effect has been mitigated in more recent Euro 6d CI vehicles with the increased use of ammonia slip catalysts. However, particularly high NH_3 emissions have been observed on gasoline cars equipped with three-way catalysts, which appears to be the main outstanding issue.

- Formaldehyde (HCHO) emissions may increase with the potential increase of ethanol content in gasoline fuel blends. Formaldehyde is harmful for human health (e.g. it is carcinogenic) and to the environment (it is implicated in the formation of ground-level ozone) at low concentrations and thus the THC/NMOG limit is not regarded as sufficient for limiting formaldehyde.

- The standard sets limits on total NO_x emissions (comprising NO and NO_2) but does not include a separate limit for directly emitted NO_2, which is the most toxic component of total NO_x emissions. Aftertreatment systems that are used to comply with the Euro 6/VI standards may lead to an increase in the share of NO_2 in total NO_x emissions. However, this effect seems to have been mitigated in the later stages of Euro 6/VI.

- In addition, new measurement methodologies are being developed to help monitor and control nanoparticles (smaller than 23 nm) from tailpipe emissions, and tyre/brake wear particles. Such developments lead to questions on whether it is appropriate for components such as brakes and tyres to be excluded from the emissions standards for light and heavy-duty vehicles.

- The improvements in tailpipe emissions control mean that evaporative emissions represent an increasing share of VOC emitted from LDVs and HDVs. The existing requirements, while expected to bring certain improvements, do not appear to be sufficient to capture the expected increase in VOC as a result of the increasing frequency of high temperature and the increase in ethanol content.

- The evaluation also finds that increasingly complex emission control technologies require a more complete demonstration of durability. In this sense, new technologies in the field of on-board monitoring introduce the possible need for a more comprehensive monitoring approach provisions that will be better placed to capture the increasing complexity of the emission control systems.

Coherence

Overall, the analysis did not identify significant issues in terms of the internal coherence of the Euro 6/VI standards. Despite the complexity of the legal framework, the analysis concluded that the features of the Euro 6 and Euro VI standards work together sufficiently well. This was a conclusion supported by most stakeholders: 38 out of 48 stakeholders (including 15 out of 23 industry stakeholders) indicated that the industry is provided with a coherent framework to work with. Nonetheless, some potential inconsistencies were still identified on testing, the lack of fuel and technology neutrality, and differences in applicability for cars and vans:

- On testing, stakeholders pointed out several aspects (e.g. on instrumentation and error margins) in the testing procedures that they considered to be internal coherence issues within the testing procedures outlined in the Euro standards. No stakeholders indicated that any of these issues represented important inconsistencies or gaps.

- On the lack of fuel and technology neutrality, there are different requirements for CI and PI vehicles, and between different technologies available for each fuel. For example, port fuel injection (PFI) petrol engines have no limits for their PN emissions, in contrast to GDI engines (which have the same PN limit – $6x10^{11}$ #/km – as CI engines). Under Euro 6, CI vehicles also have higher limits for NOx than PI vehicles. While there might be practical reasons for the lack of neutrality in some specific instances, these could be considered as internal coherence issues.

- On the difference in the applicability of the Euro 6 standards for cars and vans, passenger cars and vans are treated by the regulations in terms of conformity factors[8] and the different deadlines for entry into force of specific testing procedures. There is no obvious justification for these differences. In practice, while the different deadlines have provided a more step-wise approach, this has made the framework more complicated while allowing vans to pollute more than comparable passenger cars.

The analysis also found that Euro 6 standards are consistent with other key legislation (including the vehicle CO_2 standards, AQD/NECD on air quality and emissions, and vehicle roadworthiness legislation) in terms of the overall objectives of achieving a higher level of environmental and health protection in the EU. Still, there are some inconsistencies with these pieces of legislation in terms of their provisions. More specifically:

- **Vehicle CO_2 standards**: An inconsistency was identified related to the use of criteria (reference mass (RM) or total permissible maximum laden mass (TPMLM)) to define the testing regime that a vehicle is subjected to, with some N2 vehicles with the same TPMLM that could be subjected to different testing regimes for their CO_2 emissions, depending on their RM. There was no indication that this has been particularly problematic for industry.
- **Air Quality Directive (AQD)/National Emissions Ceilings Directive (NECD)**: Different pollutants are covered by the different interventions, leading to lower effectiveness in reducing pollution. Specifically, AQD NO_2 vs automotive regulated NOx, and AQD particles ($PM_{2.5}$) vs automotive regulated particles. Many of the pollutants regulated in the air quality directives are present in such low concentrations in vehicle exhausts that it is reasonable that they are not regulated pollutants under the Euro standards. For some others practicality or cost/benefit considerations have, to date, meant they are not measured. These considerations are being revisited in other Tasks in this study.
- **Vehicle roadworthiness legislation**: Existing legislation on periodic testing and inspections (PTI) and roadside inspections (RSI) do not support compliance with emission limits as set out in the Euro standards. Still, this is likely more derived from the different nature of these interventions, with PTI and RSI based testing not being designed to ensure compliance with emission limits than, a coherence issue. Also, OBD checks under Euro 6 cannot effectively help when it comes to identify malfunctions and to support the PTI & RSI emissions tests. As more sensors are added to vehicles for emissions control, and checked as part of the vehicles' OBD system, it is likely that OBD checks become more able to support the type approval emissions standards in the future.

EU added value

The analysis concludes that there is clear added value from the action taken against air pollution from road vehicles at EU level and that action at national or international level would most probably be less effective and more costly.

[8] Class I N1 vehicles (those with a reference mass of 1,305 kg or less) have the same limits as M vehicles (passenger cars). N1 vehicles with higher reference masses (Class II and III) and N2 vehicles have higher limits.

- The trans-boundary nature of road transport and subsequent air pollution highlight the need and added value of EU interventions as it creates a level playing field across the Union, ensuring the proper functioning of the internal market.
- In the absence of EU action to deal with vehicle-related pollution, Member States or even regional/local authorities would generally be expected to take action at the national level to limit the impact on health from road transport emissions. This could include setting emission limits for vehicles at national level, promoting vehicles that fulfil stricter emission limits and establishing national compliance regimes. It is unlikely that a harmonised approach in terms of emission limits and testing would apply across Member States. It is more likely that there would be a fragmented approach across Member States, or, at best, within groups of Member States. Such a scenario would have a negative impact on the effectiveness of the emission limits and would also lead to increased costs of compliance and enforcement for stakeholders. It would also have a negative impact on the proper functioning of the internal market.
- If EU action was to be replaced with action at the international level under the auspices of UNECE, a less effective process in terms of reducing vehicle-related emissions would most probably arise. This is not only because UNECE generally delivers results at a slower pace but also because of the likely need to agree on a lower common denominator in terms of emission targets to reflect the different situations among UNECE members. Having said that, some industry stakeholders expressed scepticism with regard to the added value of EU action as opposed to that of UNECE considering that it can bring greater economies of scale (i.e. making such a global intervention more efficient with lower costs for industry) and create a more level playing field even outside of the EU. Establishing the extent that this can indeed be the case would require a more detailed assessment that is outside the scope of this study.

1. Introduction

1.1. Purpose of the evaluation

This evaluation study focuses on the vehicle emission standards as set in Regulations 715/2007 for light duty vehicles (Euro 6) and 595/2009 for heavy duty vehicles (Euro VI.

The overall objective of the evaluation is to assess to what extent the Euro 6/VI vehicle emission standards have achieved their objective of harmonising rules on pollutant emissions from vehicles and improving air quality by reducing pollutants emitted by the road transport sector.

In line with the Better Regulation Guidelines, the evaluation study examines the effectiveness, efficiency, relevance, coherence and EU-added value of the vehicle emission standards.

The study aims to:

- Establish evidence-based conclusions on the actual results and impacts of the Regulations and the factors that may have resulted in the interventions being more, or less successful than anticipated;
- Communicate the achievements and challenges of the Regulations; and
- Inform decisions in order to improve the design of any future revision of the standards.

1.2. Scope of the evaluation

The scope of the study (in terms of the legislation covered) is summarised in **Error! Reference source not found.** below. It includes the two core pieces of legislation in which the emission limits and the relevant obligations of manufacturers and authorities are being set. It also includes secondary implementing legislation related to the type approval process which introduced the new regulatory test implementing the World Harmonised Light Vehicle Test Procedure (WLTP) and the methodology for testing vehicle emissions in real-driving conditions (RDE). In the case of heavy-duty vehicles, it also includes the provisions related to the use of portable emission measurement systems (PEMS).

Table 1-1: Scope of the evaluation

	Light-Duty Vehicles[9]	Heavy-Duty Vehicles[10]
Core legislation	Regulations 715/2007	Regulation 595/2009
Implementing legislation	Implementing Regulation 2017/1151	Implementing Regulation (EU) No 582/2011

[9] The term Light Duty Vehicles covers passenger cars and light commercial vehicles (vans). According to the Regulation 715/2007, vehicle categories M1, M2, N1 and N2 (as defined in Annex II to Directive 70/156/EEC) with a reference mass not exceeding 2,610 kg fall within the scope of the Regulation.

[10] Heavy Duty Vehicles (HDVs) includes buses and lorries. Regulation 595/2009 applies to motor vehicles of categories M1, M2, N1 and N2 with a reference mass exceeding 2,610 kg and to all motor vehicles of categories M3 and N3.

In terms of the **period covered**, the study focuses on the period since the entry into force of the standards, namely 1/9/2014 for Euro 6 and 31/12/2012 for Euro VI. Given that the evaluation is intended to be a backward-looking exercise the focus is on the impact up to now (2020). However, given that the impact of the Euro 6/VI emissions limits are expected to last even after 2020, the analysis also considered the expected impacts of the already adopted measures in the future. This was due to the following important considerations:

- Euro 6/VI vehicles that entered the market during the period up to now are expected to remain in circulation for a significant period in the future. Examining only their impacts on emissions up to 2020 would significantly underestimate the impact of the standards. It would also exacerbate the relevant costs to meet the standards that have naturally occurred at the initial period.
- Further to that, in order to establish the full cost-effectiveness of the Euro 6 standards we assess how the costs and benefits would evolve over time after the measures have been entered into force and up to 2050. This is a point when, according to current projected vehicle replacement rates, the internal combustion engine (ICE) part of the vehicle fleet is expected to be composed of Euro 6/VI vehicles only. It does not take into consideration the recent announcement on the 2030 climate target plan (European Commission, 2020) that may eventually lead to the adoption of measures that may lead to an earlier withdrawal of new ICEs from the market. This will also provide the relevant counterfactual for the assessment of possible future changes to the standards, the topic of Task 3.3 of the study.

Geographically, the focus of the evaluation is on the implementation of the Regulations in the European Union (EU-28). However, the EU automotive sector is not an isolated sector: many of its manufacturers and suppliers operate globally. Similar requirements in terms of pollutant emissions are being placed on manufacturers in many other major global vehicle markets. This evaluation takes account of these issues where relevant.

1.3. Structure of this report

The report is structured as follows:

- **Section 2: Background to the Regulations**. This section covers the purpose of the Regulations, their history and evolution, as well as their objectives. This section also includes an analysis of the objectives, a presentation of the intervention logic for the Regulations and the baseline.
- **Section 3: Implementation/ state of play**. This section provides a detailed description of the Euro 6/VI standards and their implementation. It also analyses relevant market trends including the evolution of the sales of Euro 6/VI over time and the technologies used to meet.
- **Section 4: Research methodology**. This section outlines the methodological approaches used in terms of data collection, analysis and engagement with stakeholders. It also discusses the limitations of the research.
- **Section 5: Analysis of the evaluation questions**. The analysis for each of the evaluation questions is covered in this section, presented under the headings of relevance, effectiveness, efficiency, coherence and EU-added value.
- **Section 6: Conclusions and recommendations**. This section sets out the conclusions for each evaluation question, followed by recommendations for future actions.

2. Background to the Regulations

2.1. Purpose of the Regulations

Regulation 715/2007 concerning light duty vehicles (Euro 6) and Regulation 595/2009 concerning heavy duty vehicles (Euro VI) establish common technical requirements for the type approval of motor vehicles (and replacement parts) with regard to their emissions.

As indicated in the preamble of the two Regulations, their purpose was to contribute towards the reduction of emissions of air pollutants (such as particulate pollutants (PM) as well as ozone precursors such as nitrogen oxides (NOx) and hydrocarbons) from road transport to ensure a high level of environmental protection. At the same time, in view of the fact that the legal basis for the adoption of the Regulations is Article 95 of the Treaty[11], the Regulations should ensure that this was done in a harmonised way to avoid requirements that differ from one Member State to another and ensure the effective operation of the internal market. Finally, the Regulations were intended to provide clear information to industry on future limits, providing long-term planning security so that any requirements are met in a cost-effective way.

2.2. Brief history and evolution of measures for addressing air pollutant emissions

The pathway for the control of emissions from light duty vehicles (LDV) and heavy duty vehicles (HDVs) has evolved over the last 18 years, starting with Euro 1/I in 1992 and gradually progressing with ever more stringent provisions over time[12].

The current emission standards for LDVs (Euro 6) were adopted in 2007 under Regulation (EC) No. 715/2007 together with the earlier set of standards (Euro 5). Euro 5 standards entered into force in 2009 while the Euro 6 standards entered into force in September 2014. In comparison to Euro 5, Euro 6 introduced more demanding emission limits for some categories of pollutants (NOx, hydrocarbons (HC) and PM) while others remained at the same levels[13]. The simultaneous release of the Euro 5 and Euro 6 aimed to provide the automotive industry with greater certainty and a longer timeline to develop strategies for meeting the future emission limits.

Since the introduction of the Euro 6 standards in 2014 there have been significant changes to the testing procedures used as part of the type approval process that have been introduced in the form of separate implementing legislation. Changes to the testing procedures replacing the New European Driving Cycle (NEDC) with the Worldwide

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[11] Article 95, paragraph 1 provides that the Council shall adopt measures for the approximation of the provisions laid down by law, regulation or administrative action in Member States which have as their object the establishment and functioning of the internal market. Furthermore, according to paragraph 3, the Commission should, in its proposals envisaged in paragraph 1 concerning health, safety, environmental protection and consumer protection, will take as a base a high level of protection, taking account in particular of any new development based on scientific facts. The European Parliament and the Council will also seek to achieve this objective.

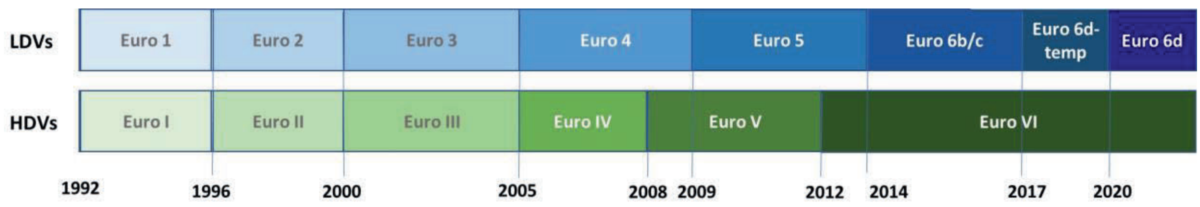
[12] Euro 1/I-4/IV standards were implemented by Directives, which had to be transposed into each Member State. Euro 5/V and 6/VI standards are issued by Regulations directly applicable to all EU Member States.

[13] The only exception was the three-year phase-in concerning the particle number limit for GDI engines and the reduction in NOx emission limits for diesel vehicles.

Harmonised Light Vehicles Test Cycle (WLTC) were introduced under Commission Regulation (EU) No 2017/1151 while the introduction of the RDE road based testing was introduced in stages, initially on a voluntary basis and eventually became mandatory under Regulation (EU) No 2016/427. They were both intended to reduce the gap between certification and real-world emissions. These changes to the testing procedures are reflected in the different stages of the Euro 6 standards, demarcated as Euro 6b, Euro 6c, Euro 6d-Temp and the more recent Euro 6d as indicated in Figure 2-1. Further details are provided in Section 3.2 of this report.

In the case of HDVs, the Euro VI emission limits were introduced by Regulation (EC) No. 595/2009 and entered into force in January 2013. Aspects related to the implementation of Euro VI, including provisions for off-cycle emissions (OCE) and in-service conformity (ISC) have been phased in over 5 stages, with stages A-C implemented by Regulation (EU) No 582/2011; stage D, which refines the requirement for in-service conformity testing of engines using PEMS, implemented by Regulation (EU) No 2016/1718; and implemented by Regulation (EU) No 2019/1939 (see Section 3.3).

Figure 2-1: Summary timeline of the development of standards for LDVs[14] (Euro 1-6) and HDVs (Euro I-VI)



2.3. Identified needs, objectives and expected outcomes of the Euro standards

2.3.1. Objectives

In order to define the objectives of the standards, we have reviewed the text of the relevant pieces of the legislation (including the Recitals and the relevant Articles) together with the Impact Assessments Staff Working Documents (SWD) that present the analysis that supported the adoption of the Euro 5 and 6 standards (European Commission, 2005a) and Euro VI (European Commission, 2007)[15]. As indicated in Section 1.2, the analysis covers both the core legislation (Regulation 715/2007 and 595/2009) as well as the related implementing legislation that primarily focused on the revision of the testing procedures.

Definition of the problem

The analysis of the relevant Impact Assessment (IA) SWDs pointed to the following problems that were expected to be addressed by the revision of the emission standards:

1. **Need for action to address the impacts of air pollution**: According to both IAs, Member States (MS) and their citizens were concerned about the significant risk to

[14] Dates indicated refer to the time of entry of requirements for passenger cars (M1) and some light commercial vehicles (N1 Class I). The entry of requirements for light commercial vehicles (N1 Class II, III and N2) has typically been one year later.

[15] Henceforth referred to as "IA SWDs".

human health and environment that results from air pollution. Although air quality had improved, there were still significant air quality problems throughout the EU, especially in urban areas and in densely populated regions. In that respect, road transport represented a significant source of pollution (according to the IA, responsible for 43% of total NO_X emissions and 27% of total volatile organic compounds (VOCs) emissions in 2002). Furthermore, road transport contributed 15% to the total emissions of acidifying substances in 2001 for EEA-31[16] and was the dominant source of ozone precursors (contributing to 36% of total ozone precursor emissions in 2001 in EEA-31).

The thematic strategy on air pollution adopted in 2005 (European Commission, 2005b) concluded that further reductions in emissions from the transport sector were needed to improve air quality and that reducing the in-use vehicle emissions was part of the overall strategy.

In that respect, in view of the role of emission standards that are designed to reduce pollutant emissions and reflecting the developments in automotive technology, the IA text identified the need to update the pollution emission standards for vehicles (which was addressed in the Regulations).

2. **Need for setting of common standards at EU level to ensure the functioning of the single market:** Both the IA support studies and Regulation pointed to the need to ensure that measures adopted would ensure the proper functioning of the single market in the EU. This requires the adoption of common standards limiting the emission of atmospheric pollutants from motor vehicles. Action at Community level should prevent varying product standards emerging across MS which could result in fragmentation of the internal market and imposition of unnecessary barriers to intra-Community trade. With no change in the policy of reducing emission levels for motor vehicles at the EU level, the risk that the functioning of the internal market would be impaired was identified in both the IA and the Regulations.
3. **Need to consider the implication of emission standards to competitiveness:** The Regulations also recognised the need to take into account the implications for competitiveness of markets and manufacturers, the direct and indirect costs imposed on business and the benefits that accrue in terms of stimulating innovation, improving air quality, reducing health costs and increasing life expectancy.
4. **Need to ensure that emissions are appropriately controlled under real driving conditions:** Regulation 715/2007 also pointed to the need that test procedures and cycles reflect changes in vehicle specification and driver behaviour and reflected on concerns that real world emissions did not correspond to type approval measurement. As such, while there was no provision for action at that time, it indicated the need to keep under review the need to revise the NEDC as the test procedure that provides the basis of European Commission (EC) type approval emissions regulations. The text of the Regulation already referred to the possible need to consider the use of PEMS and the introduction of the 'not-to-exceed' regulatory concept.

The subsequent implementing legislation (Regulations 646, 2017/1154) referred to research findings suggesting that emissions generated by real driving on the road of Euro 5/6 vehicles substantially exceeded the emissions measured on the

[16] European Economic Area 31: Includes the EU27 MS and the UK (up until 31/01/2020) the UK plus Lichtenstein, Norway and Iceland.

regulatory NEDC, in particular with respect to NOx emissions of CI vehicles. Thus, they pointed to the need for action to correct the observed limitations.

In the case of Euro VI standards, Regulation 595/2009 did not refer to issues concerning the emission measurements but still referred to the need to consider the use of emissions measurement systems to verify actual in-use emissions and to control off-cycle emissions. It also referred to the need to adopt the harmonised driving cycles.

Policy objectives

In response to the above needs, the two Regulations set a number of **policy objectives**. According to the IA SWDs, the proposed Regulations should pursue a set of key general and specific objectives focusing on **the need to ensure a proper functioning of the internal market** and **ensuring a high level of environmental protection**. The general and specific objectives stated were the same for both pieces of legislation.

In the case of the Euro 6 standards for LDVs that were adopted together with the Euro 5 standards, an additional objective that can be derived by the preambles of the Regulation was to **provide clear information on future limits and sufficient time for industry to prepare to meet more demanding emission limits**. Setting limit values at an early stage was considered necessary to provide long-term planning certainty and help meet requirements in a cost-effective manner. In the case of light duty vehicles, the Regulation refers to the need to meet ambitious targets in terms of NOx emissions reduction while maintaining the advantages of CI engines in terms of fuel consumption and hydrocarbon and carbon monoxide (CO) emissions.

Finally, in addition to these objectives, the adoption of the implementing legislation – and in particular the measures related to the test procedures – point to an additional specific objective to ensure that pollutant emission tests are robust and accurate to better reflect real world pollutant emissions.

Table 2-1: General and specific objectives of Euro 6 and Euro VI standards and of the implementing legislation

Objective level	Objective statement
General objectives	• Ensure proper functioning of the internal market; • Provide for a high level of environmental protection in the European Union.
Specific objectives	• Set harmonised rules on the construction of motor vehicles; • Improve air quality by reducing tailpipe and evaporative pollutants emissions of the road transport sector; • Provide time for industry to prepare to meet more demanding emission limits and ensure that limits are met in a cost-effective manner; • Ensure that pollutant emission tests are robust and accurate.

Source: Impact Assessment Staff Working Documents for Euro 5 and Euro 6 (European Commission, 2005a) *and Euro VI* (European Commission, 2007)

The IA SWD for Euro 6 does not identify a clear set of operational objectives for the two interventions[17]. As such, these have been developed reflecting on the policy options selected and the analysis of the preambles of the Regulations:

- Introducing/revising limits for pollutant emissions from LDVs and HDVs at EU level, revising/updating those applicable in the previous standards (Euro 5 and Euro V);
- Define appropriate and effective test procedures to be followed as part of the type approval process in order to increase accuracy and reduce the difference between type approval and real-world emissions under normal conditions of use.
- Limits to be set taking into account the implications on competitiveness, the costs imposed on business and the benefits that accrue in terms of stimulating innovation.

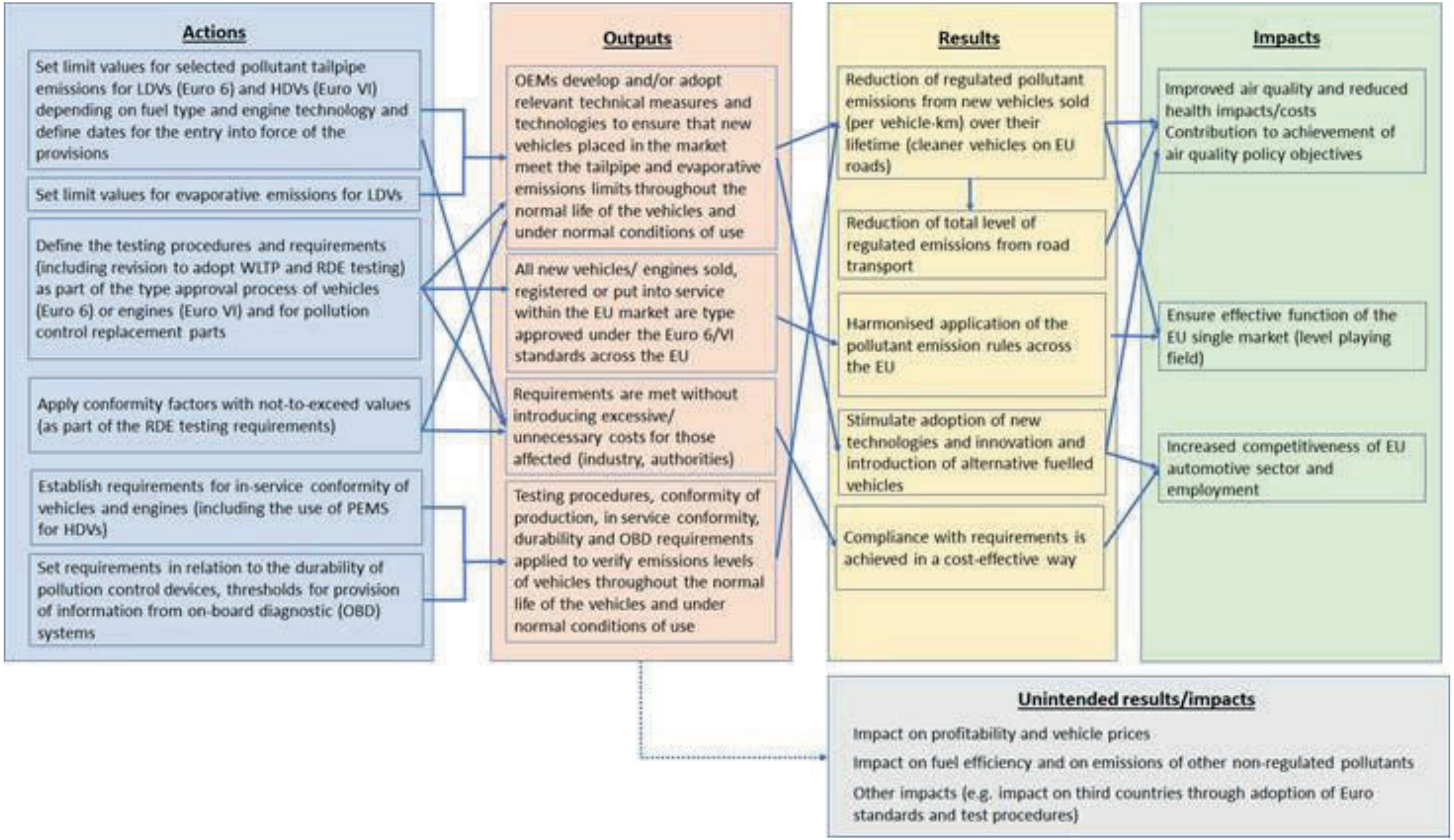
2.3.2. Expected outcomes of the Euro 6/VI standards

The implementation of the standards and the associated implementing legislation (actions) should lead to specific, short term outcomes (outputs) as well as longer term results and impacts, reflecting the objectives of the Regulations. The intervention diagram below depicts how specific actions (provisions and requirements as part of the implementation of the standards) are expected to lead to specific outputs and, in turn, how these are expected to lead to results and impacts. Expected results and impacts are closely linked with the specific and general objectives of the standards. While the impact on competitiveness was not identified as a general objective, we consider it as a potential long-term impact of the standards to the extent that they promote the adoption of new technologies or, as a minimum, ensure that the EU remains at the forefront of technological innovation in the sector.

Besides the expected impacts we also identify relevant, but arguably unintended, impacts of the standards that were considered in the IA SWDs and that we have considered as part of the analysis. These include the possible direct or indirect impacts on vehicle prices (affordability), the potential impact on fuel efficiency (particularly in relation to CI vehicles) as well as on the share of CI vehicles.

[17] In the case of the IA SWD for Euro 6 one operational objective is proposed: Setting the next stage of emission limit values for passenger cars and light-duty vehicles in a cost-effective way with specific focus on NOX, PM and HC.

Table 2-2: Expected outcomes of the Euro 6/VI standards and implementing legislation



2.3.2.1 *Specific targets*

The Regulations do not set specific performance targets/benchmarks against which to assess the effectiveness and efficiency of the intervention. Such benchmarks should, in principle, be derived from the IA SWDs that supported the adoption of the relevant measures and analysed the alternative options considered at that point. However, the information provided in the relevant IA SWDs– particularly in relation to Euro 6 standards for LDVs – is limited and covers only some key aspects. Relevant information (quantitative or qualitative) is summarised in the following paragraphs. It will be used as a reference point for the analysis of the evaluation questions in Section 5.

2.3.2.1.1 Targets for LDVs

The IA SWDs accompanying the joint proposal for the Euro 5 and 6 standards[18] (European Commission, 2005a) estimated that the implementation of the preferred option[19] would deliver an additional 24% reduction in overall NOx emissions in 2020, in comparison to Euro 5. According to the analysis conducted at that time it was also expected to increase the health benefits by approximately 60 – 90% relative to Euro 5. More specifically, it was expected that it would lead to a further reduction in premature deaths and life years lost as summarised in Table 2-3.

Table 2-3: Expected Health Impacts Associated with Euro 5 and 6 in 2020 – EU24[20]

Health impact parameter	***Acute Mortality (All ages)***	***Chronic Mortality (30yr +)***	***Chronic Mortality (All ages)***	***Restricted Activity Days (RADs 15-64yr)***
Pollutant	Ozone (O_3)	PM	PM	PM
Unit	Number of premature deaths	Number of premature deaths	Life years lost	Days
Reduction due to Euro 5	72	2,000	20,600	1,850,000
Combined Reduction Euro 5 & 6	112	3,800	35,900	3,180,000
Net impact of Euro 6	40	1800	15,300	1,330,000
Increase in benefit	57%	90%	74%	71%

Source: RAINS, Environment DG as reported in the Euro 6 IA SWD

Furthermore, it was expected that the compliance costs to manufacturers would increase by €213 per CI engine vehicle (2005 values; ca. €266 in 2020 values) relative to the Euro

[18] The initial Euro 5/6 IA SWD did not examine the scenario of the adoption of Euro 6 that was decided at a subsequent stage. An internal study conducted by the Commission on the basis of the initial analysis supported the adoption of the Euro 6. The identified values are based on the subsequent communication by the European Commission: Euro 5 and 6 will reduce emissions from cars, MEMO/06/409, https://ec.europa.eu/commission/presscorner/detail/en/MEMO_06_409

[19] The option considered in the IA included a NOx emissions limit to 75mg/km for diesel vehicles and 5 mg/km for PM. This deviated from the actual limits eventually adopted (80 mg/km for NOx and 4.5 mg/km for PM. We also note that this only refers to the limits and not the test procedures that were revised in subsequent stages with the introduction of RDE.

[20] The IA SWD refers to the impacts on all EU Member States. Given the time of the adoption we assume that this included EU24 (all EU27 except BG, RO and HR).

5[21]. These costs cover the costs of technology packages that would be needed to meet the requirements, including internal engine measures and aftertreatment technologies. However, the study authors considered that these costs were a conservative (i.e. pessimistic) scenario and that they probably overstated the expected costs. At the same time, other regulatory costs besides the substantive compliance costs (i.e. administrative or enforcement costs) were not assessed in the study and there are no indications as to how these were expected to develop.

The Euro IA SWD also indicated that there would be a very limited impact from Euro 6 vehicles on fuel efficiency and carbon dioxide (CO_2) emissions (<0.3% from the baseline in 2020)[22]. Related to that, very limited impact on the standards to the composition of the vehicle fleet with regard to fuel used was expected. The impact from Euro 6 on the share of CI vehicles was expected to be a reduction by less than 0.4%.

2.3.2.1.2 Targets for HDVs

In relation to HDVs, according to the relevant IA SWD (European Commission, 2007) the adoption of the Euro VI standards was expected to deliver an additional 37% reduction in overall NOx emissions and 22% reduction in PM emissions by 2020 in comparison to Euro V. The total external cost savings from the reduction of pollutant emissions in 2020 were estimated at a total of €3.9 billion. In comparison, the total compliance costs in 2020 were estimated at €954 million, of which €827 million were expected to be the production costs (i.e. the substantive compliance costs) for manufacturers with the remaining linked to impacts on the utility for consumers due to possible increase in prices and on public funds (linked to tax revenues)[23]. Depending on the engine displacement size (6,9 or 12 lt) and type, the compliance costs per vehicle were expected to range between €2,539 and €4,009 (2012 values)[24]. As in the case of LDVs, other regulatory costs (administrative, enforcement/monitoring) were not assessed.

Other aspects were only qualitatively assessed in the two IA support studies:

- In terms of the **impact on ensuring the harmonisation of the market**, the IA support studies concluded that harmonised emission limit values throughout the EU would have a positive impact on the competition in the internal market by sustaining a 'level playing field' for all automotive businesses.
- In terms of the **impact on the competitiveness of the industry**, the preferred options in the IA SWD were expected to have neutral direct impacts overall on the competitiveness of the EU automotive industry. Any increases in costs were not expected to affect the competitive position of the manufacturers within the EU (presumably, but not stated, because the requirements will apply to all manufacturers) and any cost impacts due to more expensive technology would be expected to diminish over time.
- Positive indirect impacts on the competitiveness were expected on the basis of more demanding emission standards. The automotive industry could become more competitive in markets outside the EU with strict environmental regulation in force, through being able to produce vehicles and engines equipped with advanced

[21] Costs for PI vehicles were not considered as no changes to limit values from Euro 5 limits were examined in the study.

[22] Baseline (no Euro 5 or 6): 543.5 m tonnes (2020), Euro 5: 547.5 m tonnes (2020), Euro 5 and 6: 547.2 m tonnes.

[23] There is no detailed information provided on the estimated impact.

[24] These are equivalent to €3,169-€5,004 in 2020 values.

environmental technologies and ensuring access to emerging markets. Furthermore, it was expected that encouraging the development of cleaner CI vehicle technology will have a positive impact on the international competitiveness of EU industry through expanding the size of the global clean CI market. Furthermore, the development of new environmental technologies would benefit indirectly the component suppliers in the automotive industry.

- In terms of the **impact on consumers**, any increase in costs would eventually have a negative impact by leading to an increase in consumer prices of new vehicles. However, according to the IA SWDs, consumers would also benefit from the proper functioning of the internal market indirectly through greater competition between manufacturers and the reduction in barriers to cross-border vehicle purchases[25] as well as from improved air quality and reduced health impacts (as indicated earlier). In the case of HDVs, the expectation was that an increase in the costs would be limited in comparison to the cost of a new lorry or bus. As such, the impact on businesses using HDVs would also be limited.

2.3.2.2 *Limitations of the IA benchmarks*

While informative and relevant, there are also certain important limitations of the IA support studies that should be taken into consideration:

- Both IA studies focused on emission limits and did not take into consideration the possible increase in divergence between lab tests and real driving emissions nor the possible impact of changes to the testing procedures that came at a later stage. As such, in the case of Euro 6 standards, the important impact of the adoption of the WLTP and the RDE was not taken into consideration and the same applies with the changes introduced in relation to PEMS testing requirements for Euro VI.
- This was to a certain extent addressed by the fact that the assessment of the impacts in terms of total emissions reduction and associated health impacts was based on an assumed reduction of real-world emissions proportionate to the level of reduction of the emission limits. Namely, in the case of Euro 6 it considered the impact from 200mg/km for Euro 5 and 75 mg/km for Euro 6 for NOx (62.5% reduction) (European Commission, 2005a). This was expected to lead to a proportionate reduction of real-world emissions between Euro 5 and Euro 6 vehicles estimated using relevant emission factors[26]. Thus, expected reduction levels can still be considered as indicative/relevant targets to consider in the analysis.
- There are also differences between the limit values considered as part of the studies and the actual limits adopted. The actual NOx emissions limits for CI vehicles actually adopted were higher, 180 mg/km for Euro 5 and 80 mg/km for Euro 6 (55.6% reduction).
- In that respect, with reference to Euro pre-RDE, the estimated impacts in the IA from Euro 5 to Euro 6 most probably represent an overestimate of the actual technology costs as well as the expected air quality and health impacts. However, overall, the

[25] While this is stated in the IA SWD, in practice the specific benefit would only apply if we were to assume that Member States would introduce specific measures at national level. Otherwise, under Euro 5, such a benefit would not arise.

26 Information collected as part of a discussion with the authors of the IA SWD that are also members of the CLOVE consortium (LAT, TNO, Ricardo).

costs should still be expected to be underestimates of the technology costs for the Euro RDE vehicles, in the absence of the WLTP and RDE changes in the IA SWD.

- In the case of Euro VI, the emission limits eventually adopted were in line with those identified as preferable in the IA SWD, namely an emission limit of 0.4 g/kWh for NOx (80% reduction) and 0.01 g/kWh particulate matter (66% reduction).

2.4. Relevant external parameters – context

In assessing the impact of the Euro 6/VI regulations we have also considered external parameters and broader context that may have played a direct or indirect role. This includes other EU and MS interventions that interact with the emission standards and other parameters or events (external factors) that have played a role (directly or indirectly).

2.4.1. Relevant EU policies

2.4.1.1 *Type approval legislation*

The implementation of legislation setting pollutant emission limits is linked with the type approval (TA) legal framework. This was initially established in Directive 2007/46/EC (now replaced by Regulation (EU) 2018/858) and determines the process for the introduction of vehicles into the market and subsequent steps to check compliance with all relevant legislation (e.g. including safety, security as well as environmental requirements). Ensuring that there is compliance with the Euro 6 and Euro VI pollutant limits is part of the broad range of requirements that need to be met for a vehicle to be granted a Whole Vehicle Type Approval. As such, there is interaction between the Euro standards and the TA legal framework, as the former cannot be properly implemented without an effective TA framework. In that respect, limitations of the type approval legal framework, namely on issues related to enforcement and market surveillance[27], can also negatively impact the effectiveness of the Euro standards. On the other hand, it is clear that when it comes to the reducing the level of pollutant emissions from vehicles and the procedures to test and verify compliance with these requirements, these are determined by the Euro 6/VI standards and the implementing legislation.

2.4.1.2 *Roadworthiness*

While the Euro emissions standards are assessed during the type approval stage, i.e., before the vehicle is in circulation, the roadworthiness legislation aims to assess if a vehicle already in circulation is over-polluting due to any technical defects. The relevant pieces of legislation include Directive 2014/45/EU, on periodical technical inspections (PTI), and Directive 2014/47/EU, on technical roadside inspections of commercial vehicles. Both the roadworthiness legislation and the Euro standards have complementary objectives of ensuring that the emission standards are complied with during the different stages of the life of the vehicle, ensuring the pollution levels are kept in check.

However, there are also large differences between the two testing regimes applicable (i.e. loaded transient driving simulation combined with real-driving-emissions tests at type approval in comparison to a swift unloaded test checking limited parameters for a stationary

[27] For more details see (Gieseke & Gerbrandy, 2017).

vehicle in the case of roadworthiness). This means that the latter is not effective in keeping in check the vehicle's overall emissions.

2.4.1.3 *Air quality legislation*

The Euro 6/VI standards were developed as part of a broader package of strategic measures developed in the early 2000s, which aimed to improve air quality across the EU. This strategy was first outlined in the 2001 Clean Air for Europe (CAFE) communication (European Commission, 2001), and was further developed in the coming years with Sixth Community Environment Action Programme (European Commission, 2002) and Thematic Strategy on Air Pollution (European Commission, 2005b).

As part of these strategies, Directives aimed at tackling the issue of air pollution were developed and/or revised. These include the Air Quality Directive (AQD, 2008/50/EC) and National Emissions Ceiling Directive (NECD, 2016/2284/EU) both of which were revised in the period since the adoption of the Euro 6 standards to set more demanding limits. These directives interact with the Euro standards, as they also aim to curb air pollution across the EU, including the pollution resulting from road vehicles (that may also include pollutants that are secondary product of primary emissions).

2.4.1.4 *Vehicle CO_2 standards*

The CO_2 emissions of new cars and vans have been regulated since 2009 and 2011, respectively, with Regulation (EU) 2019/631 being the most recent specifying emission targets for 2020, 2025 and 2030. For new HDVs, Regulation (EU) 2019/1242 sets the first CO_2 emissions performance standards for 2025 and 2030.

There is a fundamental difference in the overall approach between the pollutant emission and CO_2 standards:

- In the case of pollutant emissions, individual vehicles can only be placed on the market within the EU if their emissions for vehicles type (LDV) or engine type (HDV) meet the pollutant emission standards.
- In contrast, the CO_2 emissions of individual vehicles are determined, based on measurements for each vehicle type (LDV using WLTP) or vehicle build (HDV using Vehicle Energy Consumption calculation Tool (VECTO) and recorded but vehicles do not need to meet a specific CO_2 emission level in order to be placed on the market. The CO_2 emissions standards apply to manufacturers in relation to the average annual emissions of their EU-wide fleet of newly registered vehicles. For manufacturers exceeding the standards, there are financial penalties.

There are interlinkages when it comes to the measurement of the emission performance of LDVs, as the testing cycle used for determining CO_2 and pollutant emissions is the same, comprising chassis dynamometer testing, cold start WLTP. However, in the case of HDV, the approach is different, with HDVs' CO_2 emissions performance being modelled and involving a convolution of the engine's load/speed/fuel consumption map, and the VECTO model for the whole vehicle, while pollutant emissions are measured using an engine dynamometer using the WHTC and WHSC testing cycles. The small numbers of HDVs produced, the large number of power unit, drive train and body variants possible, and the small number of HD chassis dynamometers, make chassis dynamometer testing for HDVs disproportionate and impractical.

Another aspect of the CO_2 standards is the extent that the recently adopted targets may lead to a faster uptake of zero or low CO_2 emission vehicles (Battery or Fuel Cell electric vehicles or Plug-in hybrid electric vehicles) that, under the expected condition of use, also have low level of pollutants emissions. In this case, achieving cleaner vehicles on EU streets may come from such changes to the vehicle fleet and not as a result of the Euro 6/VI standards. However, in the context of our analysis the focus has been on the impact on the pollutant emissions from ICE vehicles. As such, the expected impact of the CO_2 Regulations on the total fleet composition does not play a direct role in the assessment of the impact of Euro 6/VI.

2.4.1.5 *Vehicle taxation and low emissions zones*

Environmental concerns, including pollutant emissions and explicit references to the Euro standards, have become a component of Member States' taxes on vehicle purchase/registration or vehicle ownership/circulation. Around 15% of MS use the Euro standards in the calculations of their purchase/registration taxes and around 20% of MS in their vehicle ownership/circulation taxes (CE Delft et al., 2019). Furthermore, as more local/city and regional authorities are imposing local restrictions (sometimes called "low emission zones") based on the Euro standards of the vehicle there are potential indirect impacts on the overall effectiveness of the standards. The existence of these varied taxes and local restrictions may shift the incentives that consumers face when deciding on what type of vehicles to purchase (i.e. move towards alternative fuelled vehicles). Furthermore, this variance might also have implications in the existence of a level playing field in the EU internal market, as it could impact the manufacturers' access to the market.

2.4.1.6 *Fuel quality standards*

The Euro standards stipulate the reference fuels to be used for the emissions tests. The requirements have evolved over time in line with the evolution of the fuel quality standards (as set in the Fuel Quality Directive, 2009/30/EC amending Directive 98/70/EC) to ensure that required emissions standards are possible to achieve (ICCT, 2016a).

2.4.1.7 *R&D and innovation support policies*

The automotive sector is the EU's number one investor in R&D, responsible for around 29% of the total R&D spending. At the same time, the EU automotive sector has benefitted from a significant level of support for the development of new technologies and innovation, including in relation to the development of clean technologies aiming for the reduction of pollutant emissions. At the EU level, this support came through the implementation of 7th Framework Programme for research and the subsequent Horizon 2020 programme. Within the context of the Smart, Green and Integrated Transport societal challenge where a total of 6.4 billion was allocated for the 2014-2020 period, specific funding was allocated to the development of new aftertreatment and improved engines in the context of the three multiannual work programmes[28].

2.4.2. External factors – relevant parameters

The impact of Euro standards has potentially been also affected by other external events. We consider how these may have played a role:

- **The "dieselgate" scandal** , where it was found that some manufacturers were using "defeat devices" during tests to artificially lower their vehicles' level of emissions. This scandal also had a potential impact on the level of trust of

[28] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/smart-green-and-integrated-transport

consumers towards the legal framework and the extent that information provided by manufacturers on the vehicles' environmental performance is actually correct. Changes to the testing procedures (RDE and WLTP), which were already underway, were expedited and came into force earlier than initially anticipated, in an effort to restore consumer confidence. Dieselgate has also had an impact on **consumer awareness** about the pollution resulting from CI vehicles which is also reflected in the decline in the market share of diesel (i.e. CI) passenger cars across the EU. Between 2015 and 2018, the share of CI vehicles sold in the EU (as a percentage of the total market for new passenger cars) declined from 52% to 36% (ACEA, 2019a)[29].

- **Technological developments** in the automotive sector, and more broadly, have affected the capacity and the associated costs for responding to the new requirements. These included developments related to new engine technologies, pollutant emissions control and sensors, all relevant for ensuring compliance with the new requirements. Some of these technologies were already in place or where developed irrespective of the standards, in some cases in response to more demanding requirements introduced in other markets (e.g. USA).
- **Evolution in the cost of raw materials** is also relevant in terms of the costs of emission control technologies. This is particularly the case for precious metals such as palladium or rhodium that are used in catalytic converters which have seen as significant increase in unit price since 2015[30]. This is relevant when it comes to determining the costs of compliance.
- **Macroeconomic trends:** The overall impact on the level of emissions is dependent on the rate by which the new cleaner vehicles enter the market, replacing older vehicles and increasing their share in the fleet. As such, broader macroeconomic developments that have an impact on purchasing power can also affect the overall level of demand for new vehicles and thus the rate of renewal of the fleet. In the period under investigation (2013-2020) the EU experienced a small but positive growth rate (in the range of 1.5%-3% per year)[31] following the decline during the financial crisis. In terms of vehicle purchases, the number of new vehicle registrations also increased on an annual basis since 2013 following the significant decline in the 2008-2013 period[32].

2.5. Intervention logic diagram

On the basis of the needs and objectives described earlier and the expected outcome, the diagram presented below (Figure 2-2) presents in a structured format the intervention logic of the Euro 6/VI standards. It describes, in graphical form, the links and causal relationships between the problems and/or needs, broader policy goals, the general, specific and operational objectives that the specific policy measure is designed to address, and the specific actions and inputs for addressing those problems and/or needs. It then indicates

[29] The role of dieselgate is further discussed in the baseline section (section 2.6).

[30] According to Trade Economics (https://tradingeconomics.com/commodity/palladium), the price of palladium in 2020 was four times higher than 2015. The price for rhodium has increased by more than 15 times since 2015.

[31] Eurostat, Real GDP growth rate - volume [TEC00115], https://ec.europa.eu/eurostat/databrowser/bookmark/4957bee3-8a16-4470-8c5e-68fcc1d9602a?lang=en

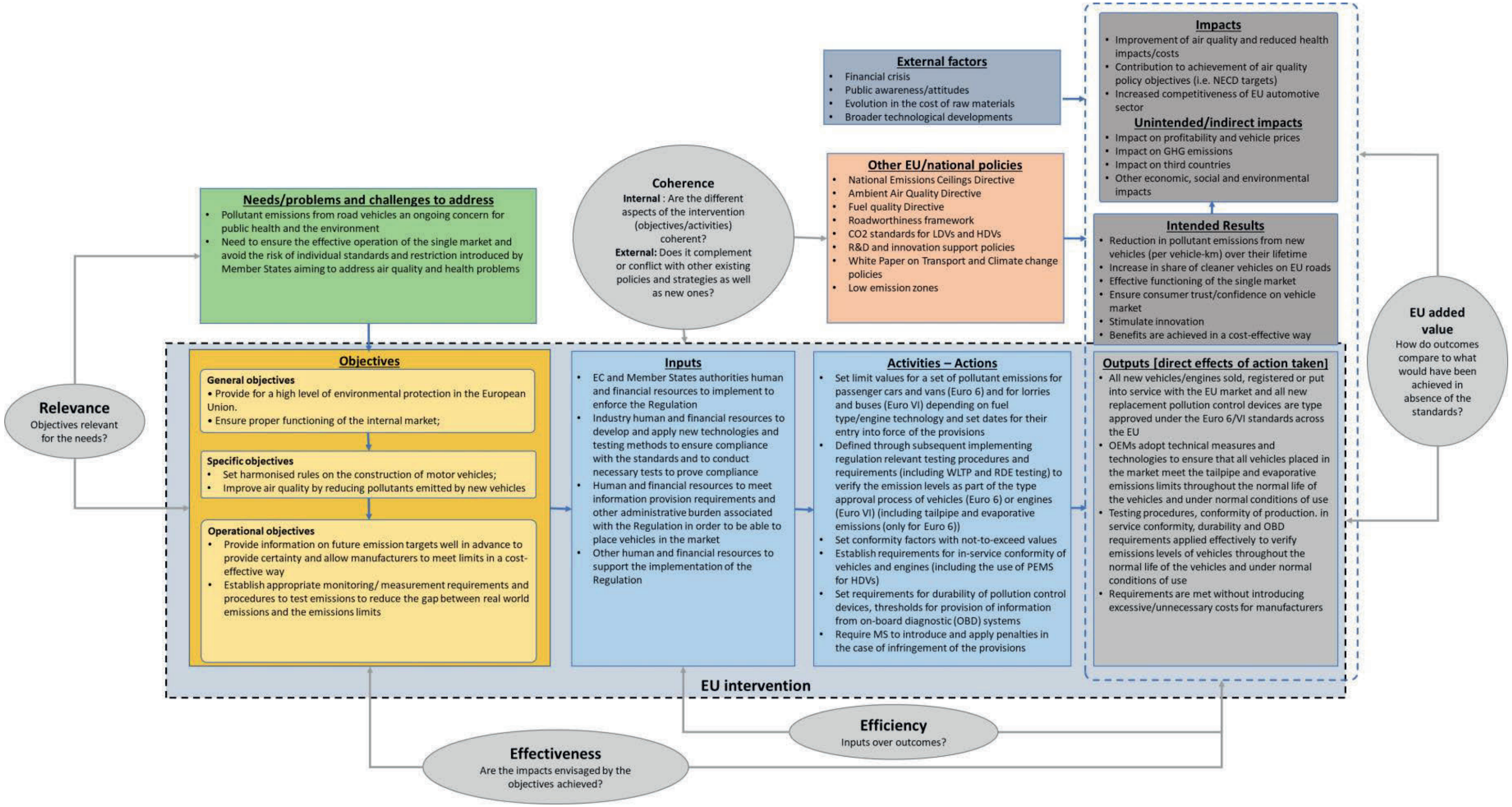
[32] OECD. Passenger car registrations Total, Percentage change, https://data.oecd.org/chart/6bbH

what the policy measure should be expected to achieve in terms of outputs, results and impacts in order to meet the objectives.

The diagram also identifies how wider policy aims and other external factors are linked to the actions undertaken and their outcomes. These include relevant policies that had a direct or indirect role (including the Roadworthiness framework, the National Emissions Ceiling Directive and Ambient Air Quality Directives, the Fuel Quality Directive and the CO_2 emissions performance Regulations for LDV and HDV).

It also identifies the relevant policies and developments indicated earlier that can play a role in the implementation or influence the outcomes of the standards.

Figure 2-2: Intervention logic for the Euro 6/VI and the relevant implementing legislation



2.6. Baseline definition and point of comparison

As in all evaluation studies, it is important to establish the baseline against which the intervention will be assessed, in terms of its effectiveness and efficiency and, where relevant, the other evaluation criteria. The proposed baseline scenario represents the counterfactual scenario, namely what would have happened in the absence of the intervention.

In the case of the Euro 6/VI standards, the adoption of the Euro 6/VI is a continuation of previous standards that were already in place, Euro 5 for LDVs and Euro V for HDVs. As such, the assessment of the performance of the Euro 6/VI, both in terms of outcomes as well as in terms of costs, should aim to establish the additional (marginal) impact of the intervention against a scenario where the respective Euro 5/V standards would continue to be in place, together with other possible interventions. More specifically:

- In the case of LDVs, the baseline scenario assumes that the Euro 5 standards would remain in place and that, in the absence of the Euro 6 intervention, there would have been no further changes to pollutant emissions limits for new vehicles and no further changes to the relevant testing procedures. It essentially assumes that all new vehicles entering the market since 2014 would continue to be type approved under the Euro 5 standards and would have to comply with the relevant requirements.
- The changes from the NEDC to the WLTP cycle are also considered as being part of the baseline on the basis that the introduction of the WLTP was motivated by the need to better capture the performance of vehicles in relation to CO_2 emissions and fuel efficiency.
- It is also important to reflect on the specific implications of the stepwise process of the Euro 6 implementation and, in particular, the significant changes to the testing procedures introduced with the adoption of the RDE procedures. As such, in our analysis we have also considered a second baseline that reflects the evolution of the legal framework up to the point of the introduction of the RDE test procedure. Namely, we consider a pre-RDE baseline that corresponds to the Euro 6b/c standards and assumes that the RDE test procedure would not have been introduced. In this case, the analysis examines the impacts associated only with the introduction of the Euro 6d-Temp and Euro 6d standards (post-RDE period).
- In the case of HDV, the baseline scenario assumes a continuation of the Euro V standard. As such, the assumption is that there would be no further changes to the emission limits and test requirements as those already in place and that all new HDVs entering the market would be Euro V vehicles. In this case, any changes to the testing procedures (including for example the OCE testing) is considered as part of the Euro VI.

From a practical perspective, the baseline scenario of no change to the requirements has been used to estimate:

- The level of change to the pollutant emissions per vehicle, the impact on total pollutant emissions and the resulting savings in damage costs associated with the standards as a result of the Euro 6 (total and Euro post-RDE) and Euro VI. For the purposes of the analysis we have used the SIBYL model that allows to make such comparison on the basis of alternative baseline scenarios. (see details in Annexes 2 and 3).
- The costs associated with Euro 6 by assessing the additional costs for ensuring compliance with the Euro 6/VI standards in comparison to Euro 5/V (including the

comparison between Euro 6 post-RDE and pre-RDE). Together with the analysis of the impacts, this will allow to assess cost-effectiveness in terms of abatement costs per tonne of pollutant emissions avoided and in comparison to the resulting damage cost savings[33].

In terms of the definition of the baseline, we also note that it is important to reflect on whether relevant developments would have been expected to happen even in the absence of the Euro 6/VI. This includes other legislation or measures that may have had a possible indirect impact but also events that may have played a role.

In our case, the relevant developments include:

- **CO_2 Regulations for passenger cars and vans** (respectively Regulation (EC) No 433/2009 and (EU) No 510/2011, both since 1 January 2020 repealed and replaced by Regulation (EU) 2019/631) that introduced requirements that led to the adoption of new technologies to achieve fuel efficiency and greenhouse gas (GHG) emissions reduction. Combined with Member States' policies, this had a possible impact on the share of CI vehicles in new registrations and the fleet that has been reflected in the SIBYL model.
- The **"dieselgate" scandal** that identified the use by some manufacturers of "defeat devices" during tests. Some manufacturers were forced to recall vehicles that had installed software controlling the vehicles' exhaust systems and were required to update the relevant software. There were also procedures introduced to be able to identify any such devices in the future (European Court of Auditors , 2019). Such developments have been considered independent of the adoption of the Euro 6 standard (i.e. it is assumed that they would have happened also under Euro 5 standards). We have reflected the impact of the software update in our analysis and updated the SIBYL model so that any changes made in relation to this are included as part of the baseline scenario (see more details in Annex 4).
- Other external factors discussed in Section 2.4, that have implications in terms of the direct and indirect impacts of the standards.
- Having said that, a key assumption made in our analysis is that, in the absence of Euro 6/VI, vehicle manufacturers would not have introduced technologies leading to reduced levels of pollutant emissions beyond what is required in the Euro 5/V standards. We do not expect that any of the external developments or trends would have led manufacturers to voluntarily fit additional technologies and incur additional costs to improve the air pollutant emissions performance of vehicles over and above those mandated by the Euro 5/V standards. In contrast to the CO_2 emissions standards where fuel efficiency represents a possible purchase criterion for consumers, differences in the pollutant emissions levels are not a driver of consumer choice. Furthermore, other instruments (such as low emission zones) are based on the available Euro standard. In the absence of Euro 6/VI, low emission zones would have been based on the most recent standard, namely Euro 5/V.

[33] Abatement costs incorporate manufacturer costs via ex-post estimates of the additional costs required to reduce air pollutant emissions. Damage costs (or savings) of pollution are estimated via standard cost factors.

3. Implementation /state of play

3.1. Introduction

In this section we present briefly the main elements of the legal framework and the changes that came as a result of the adoption of Euro 6/VI and implementing legislation. We also examine the implementation of the legislation and present the relevant market trends including the evolution of the sales of vehicles by type and the technologies used to meet the legislation.

3.2. Changes to the legal framework for Light Duty Vehicles as a result of Euro 6

The adoption of the Euro 6 standards and the implementing legislation brought changes to a number of aspects of the applicable legal framework. These included:

- Stricter tailpipe emission limits for certain pollutants;
- Introduction of new testing procedures;
- Changes concerning evaporative emissions; and
- New on-board diagnostics (OBD) requirements.

There were not changes in relation to the durability requirements or the roles and responsibilities of authorities, OEMs as part of the type approval procedures for pollutant emissions[34].

3.2.1. Changes to the limits for certain categories of pollutants and depending on vehicle technology (introduced by Regulation (EC) No 715/2007).

In the case of CI vehicles, the main difference was the reduction in the NOx emissions limit from 180mg/km under Euro 5 to 80 mg/km under Euro 6 (by 56%) (see Table 3-1). Minor changes were also made to the emissions limits for total hydrocarbons (THC) + NOx emissions, which saw a reduction of between 26% and 28% depending on the vehicle category, and PM, which saw a reduction of 10%. Emission limits remained the same for CO. In addition, a new limit was introduced for particulate number (PN) emissions at a level of $6x10^{11}$ particles per km (#/km).

[34] Regulation (EU) 2018/858, mandatory as of 1 September 2020, introduces more systematic market surveillance of vehicles already on the market. The role of Market Surveillance Authorities (MaSA), which may be independent from TAAs, is to assess continued conformity with emission limits met during type approval, using all emission type tests. This must be performed for a minimum of 1 in every 40,000 new vehicle sales. Approved third parties may carry out these tests on behalf of the MaSAs. However, as these requirements were not in force at the time of the evaluation they have been outside the scope of the analysis.

Table 3-1: Euro 5 and Euro 6 Emission limits for Compression Ignition (CI)[35]

Emission limits	N_1 Class I		N_1 Class II		N_1 Class III		M		N_2	
	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6
CO (mg/km)	500	500	630	630	740	740	500	500	740	740
NO_x (mg/km)	180	**80**	235	**105**	280	**125**	180	**80**	280	**125**
Total HC + NOxNOx (mg/km)	230	**170**	295	**195**	350	**215**	230	**170**	350	**215**
PM (mg/km)	5	**4.5**	5	**4.5**	5	**4.5**	5	**4.5**	5	**4.5**
PN (#/km)	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**	-	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**	**$6x10^{11}$**

Source: Regulation 715/2007

In the case of Positive ignition (PI) vehicles, the switch to Euro 5 from Euro 4 had already resulted in a significant reduction to the emission limits (see Table 3-2). In this case, Euro 6 NOx standards remained the same as those for Euro 5. Euro 5 had also introduced particle mass (PM) limits equal to those for CI engines for PI GDI vehicles, since it was shown that they also could emit significant quantities of particles. Euro 6 saw the introduction of PN emission limits for GDI engines at the same limit as those for CI engines. These limits were phased in over the first three years of Euro 6 implementation, starting with the less stringent temporary standard of 6.0 $x10^{12}$ particles per km (#/km) and reducing to 6.0 $x10^{11}$ #/km.

[35] Regulation 715/2007 (and updates)

Table 3-2: Euro 5 and Euro 6 Emission limits for Positive Ignition Vehicles.[36]

Emission limits (g/km)	**N_1 Class I**		**N_1 Class II**		**N_1 Class III**		**Category M**		**Category N_2**	
	Euro 5	**Euro 6**	**Euro 5**	**Euro 6**	**Euro 5**	**Euro 6**	**Euro 5**	**Euro 6**	**Euro 5**	**Euro 6**
CO	1000	1000	1810	1810	2270	2270	1000	1000	2270	2270
THC	100	100	130	130	160	160	100	100	160	160
NO_x	60	60	75	75	82	82	60	60	82	82
NMHC	68	68	90	90	108	108	68	68	108	108
PM [a]	5	**4.5**	5	**4.5**	5	**4.5**	5	5	5	5
PN (#/km)	-	**$6x10^{11}$**	-	**$6x10^{11}$**	-	**$6x10^{11}$**	-		-	

Source: Regulation 715/2007 ; [a] Limit applicable only to GDI engines.

3.2.2. Changes to the testing procedures to be followed in order to gain type approval

Requirements related to the testing evolved during the period since the introduction of Euro 6 as new legislation was introduced to further refine the implementation and to adapt to technical advances. More specifically, Commission Regulation (EU) No 2017/1151 introduced the WLTP to replace the NEDC testing procedure, which in combination with the introduction of Commission Regulation (EU) No 2016/427 (RDE 1), provided testing procedures which better reflect real-world driving emissions of vehicles.

At the time of the adoption of the Euro 6 standards, testing was conducted in a controlled lab environment using a chassis dynamometer following a predefined drive cycle, called the NEDC. The NEDC was split into two sections:

- The ECE 15 cycle which represents urban driving; and
- AA higher speed test to simulate highway driving.

Regulation 715/2007 stated that the European Commission should "*keep under review the need to revise the New European Drive Cycle*" in view of the already identified misrepresentation of real-world driving conditions.

With the adoption of Regulation (EU) No 2017/1151, the WLTP and WLTC were introduced. Thus, from Euro 6c onwards all vehicles have been type approved on the basis of the new test cycle. The WLTC is a much more dynamic cycle and includes higher maximum velocity and less idling time during testing and was designed using real-world drives as a basis. The WLTP was refined with the introduction of Commission Regulation (EU) No 2018/1832 (RDE 4 and WLTP 2). The implementation schedule for WLTP/WLTC is outlined in Table 3-3.

[36] Regulation 715/2007 and A technical summary of Euro 6/VI vehicle emission standards ICCT (2016)

Table 3-3: Implementation Schedule for WLTP/WLTC

Date	Requirements
September 2017	WLTP type approval testing introduced for all new car types. However, cars approved using the old NEDC test could still be sold.
September 2018	All new vehicles should be certified according to the WLTP test procedure.
January 2019 (WLTP 2)	All new cars at dealerships should have WLTP-CO_2 values (with some exceptions for a limited number of vehicles in stock).

Source: EC Regulations 2017/1151 and 2018/1832

Further to the changes to the test cycle, implementing regulations have introduced **requirements for testing of vehicle emissions on the road under real-driving conditions** (RDE testing). The RDE testing requirements mean that in addition to laboratory testing, all vehicle emissions must also be tested on the road under real-driving conditions. The objective of their introduction was to complement the WLTP by measuring emissions from vehicles during real-driving conditions as a response to the realisation that laboratory conditions do not accurately reflect emissions during real-driving conditions.

The RDE programme has been implemented via several regulatory iterations and has been applied to new Euro 6 type approvals since September 2017. Since September 2019 all new vehicles need to be tested according to the RDE.

According to Regulation (EU) 2016/427, the RDE test should be used to measure NOx and CO emissions for all passenger and light commercial vehicles while PN emissions should be measured for all Euro 6 CI and PI GDI vehicles for which limits are set. The data formulated by PEMS was initially required to be processed using the CO_2 moving average window (EMROAD) and the power binning (CLEAR) normalisation methods[37]. Since the introduction RDE Package 4 (Regulation (EU) 2018/1832) a direct unweighted calculation of emissions is reported, although the moving average window method is retained as a verification check of trip dynamics by CO_2.

The RDE test is performed during on road vehicle operation using PEMS and testing must last between 90 and 120 minutes. The route taken includes three segments: 1) urban driving at <60 km/h; 2) rural driving at 60-90 km/h; 3) highway driving at >90 km/h. The share of the driving time must be equally split into thirds and each driving segment must cover a distance of at least 16km. Other defined boundary conditions include ambient conditions, stop times, maximum speed, and altitude. The RDE 2 standard (Regulation (EU) 2016/646)

[37] EMROAD software is a tool developed for calculations of RDE emissions data using the moving average window method (MAW). The MAW method divides the RDE test trip into sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance. The “normality” of the windows is assessed by comparing their CO_2 distance-specific emissions with a reference curve and the RDE test is only complete when the test includes a sufficient number of normal windows, covering different speed areas (urban, rural, motorway). CLEAR software is used for the power binning method of calculating RDE emissions data. The power binning method uses the instantaneous emissions of the pollutants, mgas, i (g/s). The mgas, i values are classified in accordance with the corresponding power at the wheels and the classified average emissions per power class are weighted to obtain the emission values for a test with a normal power distribution according to the following points.

also introduced a set of additional dynamic boundary conditions which aim to limit the cumulative positive elevation gain over a trip to 1200 m/100 km and exclude driving that could be regarded as too smooth or too aggressive, based on indicators such as speed and acceleration.

An important element of the RDE test procedures was **the introduction of a conformity factor**[38] to take into account the increased uncertainties in measuring with PEMS on a longer trip with varying ambient conditions that can affect the performance of the PEMS, when compared to a laboratory testing (WLTP) which is of shorter duration and is done in repeatable conditions. In Regulation (EU) No 2016/646 a temporary conformity factor for NOx was set at 2.1, which was applicable for all new vehicle models as of September 2017 and for all new vehicles as of September 2019 (to reflect both the statistical uncertainty of the test procedure and of the measuring equipment) was established during a transition period. Euro 6d-Temp vehicles were type approved according to this conformity factor. At the same time, a final conformity factor of 1.5 for NOx was introduced to reflect just the uncertainty of the PEMS equipment. The conformity factor was revised by Regulation (EU) No 2018/1832 and reduced to 1.43 and is applicable since January 2020 for new vehicle models and from January 2021 for all new vehicles (Euro 6d) for cars and one year later for vans.. In addition, Regulation (EU) No 2017/1154 (RDE 3) introduced a conformity factor of 1.5 for PN, which is applicable from September 2017 for new models and September 2018 for all new vehicles.

Regulation (EU) 2017/1151 also reduced the number of tests required by defining a “PEMS test family” defined as all vehicles with the same powertrain and engine block-type, or number and disposition of cylinders. Engine size can differ within a PEMS test family with allowances of up to 32% for engines <1500cc and up to 22% for engines >1500cc. All vehicles within a PEMS test family must have the same emission control system.

Table 3-4 below summarises the progress in the RDE implementation and the main changes introduced in each stage.

Table 3-4: RDE Testing Implementation

RDE stage	Regulation	Action/change
1	2016/427	Definition of the RDE test procedure;
2	2016/646	Definition of NOx conformity factors to 2.1 Set introduction dates
3	2017/1154	Introduced PN conformity factor (1.5) which applies to the urban section and the entire RDE trip; Inclusion of cold start emissions (gaseous and PN) in EMROAD and CLEAR analysis
4	2018/1832	Introduced in-service conformity RDE testing. Lowered the error margin for NOx margin from 0.5 to 0.43

[38] This is measured as 1 (the Euro 6 emission limit) x margin (measurement error, e.g. 0.5).

3.2.3. Changes concerning evaporative emissions

Besides tailpipe emission limits, the Regulation also set limit values for evaporative emissions for PI vehicles, of 2g hydrocarbons per test under Regulation (EC) No. 715/2007. While there were no changes to the limit values, implementing

Regulation (EU) 2017/1221 introduced changes to the testing procedure which was set to 48 hours, up from 24 hours previously.

The new evaporative emissions test procedure developed by the United Nations Economic Commission for Europe (UNECE) took into account technological progress in the control of evaporative emissions from PI vehicles and brought the procedure in line with the WLTP test procedure and introduced new provisions for sealed tanks. In-service conformity testing requires the testing of evaporative emissions from properly maintained in use vehicles between 30,000 km/ 12 months (whichever occurs later) and 100,000 km/5 years (whichever occurs sooner).

However, we note that the current provisions only test for evaporative emissions while the vehicle is parked and not under driving conditions (i.e. running losses). They also do not control evaporative emissions during refuelling which are currently controlled in the EU by means of the so-called stage II vapor recovery system applicable to gas stations under Directive 2009/126/EC.

3.2.4. Changes concerning On-board diagnostics (OBD) requirements

Commission Regulation (EU) No 2017/1151 also set new thresholds for OBD from the introduction of Euro 6 that are intended to monitor the functioning of powertrain systems and components used to reduce exhaust gas emissions and identify possible areas of malfunction. The thresholds are around 70-75% lower for NOx and PM, and 10% lower for CO and non-methane hydrocarbons (NMHC) than under Euro 5 (see Table 3-5 and Table 3-6). This has meant that the new OBD systems need to be more sensitive to minor malfunctions/ irregularities in the emission control system, with the aim of earlier detection and correction of identified issues.[39]

Table 3-5: OBD Emission Limits for CI Engines[40,41]

		Mass of CO (mg/km)		Mass of NMHC (mg/km))		Mass of NOx (mg/km)		Particle Mass (mg/km)	
Category	Class	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6
M		1900	**1750**	320	**290**	540	**140**	50	**12**
N_1	I	2400	**2200**	360	**320**	705	**180**	50	**12**

[39] ICCT (2015) Accelerating progress from Euro 4/IV to Euro 6/VI vehicle emissions standards. Available at: https://theicct.org/sites/default/files/publications/ICCT_EuroVI_briefing_20150304.pdf

[40] Euro 5 OBD limits – Commission Regulation (EU) No 692/2008

[41] Euro 6 OBD limits – Commission Regulation (EU) No 2017/1151

		Mass of CO (mg/km)		Mass of NMHC (mg/km))		Mass of NOx (mg/km)		Particle Mass (mg/km)	
Category	Class	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6
	II	2800	**2500**	400	**350**	840	**220**	50	**12**
	III	2800	**2500**	400	**350**	840	**220**	50	**12**
N_2		1900	**1750**	320	**290**	540	**140**	50	**12**

Table 3-6: OBD Emission Limits Positive Ignition Engines (Gasoline)

		Mass of CO (mg/km)		Mass of NMHC (mg/km))		Mass of NOx (mg/km)		Particle Mass (mg/km)	
Category	Class	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6	Euro 5	Euro 6
M		1900	**1900**	250	**170**	300	**90**	50	**12**
N_1	I	3400	**3400**	330	**225**	375	**110**	50	**12**
	II	4300	**4300**	400	**270**	410	**120**	50	**12**
	III	4300	**4300**	400	**270**	410	**120**	50	**12**
N_2		1900	**1900**	250	**170**	300	**90**	50	**12**

3.3. Changes to the legal framework for Heavy Duty Vehicles

The adoption of the Euro VI standards (Regulation 595/2009) and the implementing legislation (Regulation 582/2011) brought changes to a number of aspects of the applicable legal framework. These included:

- Stricter tailpipe emission limits for certain pollutants;
- Introduction of new testing procedures;
- Changes concerning evaporative emissions; and
- New on-board diagnostics (OBD) requirements.

There were no changes in relation to the durability requirements or the roles and responsibilities of authorities, OEMs as part of the type approval procedures for pollutant emissions[42].

Table 3-7: Summary of Regulatory Requirements for HDVs[43,44]

Legislation	Summary of requirements
Regulation (EC) No 595/2009	• Emission limits covering CO, NOx, THC, NMHC, PM and PN for CI and CO, NOx, NMHC, PM and PN for PI vehicles; • in-service conformity of vehicles and engines; • durability of pollution-control devices; • OBD systems; • accessibility of vehicle OBD and vehicle repair and maintenance information; • measurement of fuel consumption and CO_2 emissions.
Commission Regulation (EU) No 582/2011) – Step A to C	• Specific technical requirements for type approval with regard to emissions; • Procedures for the measurement of in-service conformity requirements; • Ammonia measurement procedure; • CO_2 emissions and fuel consumption; • introduction of requirements with respect to the off-cycle in-use emissions testing procedure;
Commission Regulation (EU) No 2016/1718 (PEMS) – Step D	• Refines requirement for in-service conformity testing of engines using PEMS; • trip requirements;
COMMISSION REGULATION (EU) 2019/1939 – Step E	• Use of portable emissions measurement systems (PEMS) to measure particle numbers, and introducing the CF for PN ISC and the method for calculating the final CF considering the cold-and warm operation and introduction of stricter AES provisions

[42] Regulation (EU) 2018/858, mandatory as of 1 September 2020, introduces more systematic market surveillance of vehicles already on the market. The role of Market Surveillance Authorities (MaSA), which may be independent from TAAs, is to assess continued conformity with emission limits met during type approval, using all emission type tests. This must be performed for a minimum of 1 in every 40,000 new vehicle sales. Approved third parties may carry out these tests on behalf of the MaSAs. However, as these requirements were not in force at the time of the evaluation they have been outside the scope of the analysis.

[43] Commission Regulation (EU) No 2017/2400 and Commission Regulation (EU) No 2019/318 (VTP) pertain to the requirements for CO_2 emissions and are outside of the scope of this evaluation.

[44] Commission Regulation (EU) No 2019/1939 outlines the methodology for assessing AES (Auxiliary emission strategies) to bring in line with Regulation 2017/1151, in order to avoid another "dieselgate"; introduces maximum conformity factor for PN and cold start requirements for in-service conformity testing. This Regulation has been deemed outside the scope of this evaluation.

3.3.1. Changes to emission limits for HDVs

Euro VI vehicle emission standards set limits for a range of pollutant emissions, including CO, HC, methane (CH_4), NOx, PM, PN and ammonia (NH_3).

As with the LDVs, Euro VI brought a significant reduction in NOx emission limits compared with Euro V (see Table 3-8), from 2.0 g/kWh to 0.4 g/kWh for steady-state testing (80% reduction), and 2.0 g/kWh to 0.46 g/kWh for transient testing (77% reduction).

Due to the tighter emission limit set for NOx, which required the use of a Selective Catalytic Reduction (SCR) system, Euro VI has also introduced emission limits for ammonia for CI vehicles. This was in order to control the expected release of ammonia as a by-product of the use of SCR technology (AdBlue) employed to reduce NOx emissions from CI vehicles. PI vehicles which use natural gas or liquified petroleum gas (LPG) engines are also subject to CH_4 emission limits, which do not apply to CI vehicles.

Particle mass limits have also been significantly reduced between Euro V and Euro VI (see Table 3-8), from 0.02 g/kWh to 0.01 g/kWh for steady-state testing (50% reduction), and 0.03 g/kWh to 0.01 g/kWh for transient testing (66% reduction). As in Euro 6, Euro VI has introduced a PN limit, although this differs depending on the test method followed: 8 x 10^{11} #/kWh (WHSC) and 6 x 10^{11} #/kWh (WHTC). It should be noted, as discussed below, that the certification test cycle for Euro VI is different from that for Euro V and so comparisons are approximate (ICCT, 2016a).

Table 3-8: Emission limits for Euro V and Euro VI standards for CI and PI engines (bold indicate changes from Euro V to Euro VI)[45]

	CI engines		CI engines		PI engines	
	Euro V	Euro VI	Euro V	Euro VI	Euro V	Euro VI
Emission limit (g/kWh)	Steady-state testing (ESC and ELR)	Steady State testing (WHSC)	Transient testing (ETC)	Transient testing (WHTC)	Transient testing (ETC)	Transient testing (WHTC)
CO **(mg/kWh)**	1,500	1,500	4,000	4,000	4,000	4,000
THC **(mg/kWh)**	460	**130**	-	**160**	-	-
NMHC **(mg/kWh)**	-	-	550	-	550	**160**
CH_4[a] **(mg/kWh)**	-	-	-	-	1,100	**500**

45 Annex 1 Regulation 595/2009 and Annex XV of Commission regulation (EU) No 582/2011 and A technical summary of Euro 6/VI vehicle emission standards (ICCT, 2016a)

	CI engines		CI engines		PI engines	
	Euro V	Euro VI	Euro V	Euro VI	Euro V	Euro VI
Emission limit (g/kWh)	Steady-state testing (ESC and ELR)	Steady State testing (WHSC)	Transient testing (ETC)	Transient testing (WHTC)	Transient testing (ETC)	Transient testing (WHTC)
NOx **(mg/kWh)**	2,000	**400**	2,000	**460**	2,000	**460**
NH_3 **(ppm)**	-	**10**	-	**10**	-	**10**
PM **(mg/kWh)**	20	**10**	30	**10**	30	**10**
PN (#/kWh)	-	**8.0 x10^{11}**	-	**6.0 x10^{11}**	-	**6.0 x10^{11b}**
Smoke (m^{-1})	0.5	**-**	-	-	-	-

Note: PI = positive ignition; CI = compression ignition; [a] for Euro VI NG and LPG. [B] PN limit for PI engines applies from Euro VI-B and later.

3.3.2. Changes to the testing procedures and requirements

Euro VI introduced two new test methods that replaced the ESC/ELR and ETC[46] cycles used as part of Euro V. The WHSC which is carried out on an engine test bed is based on quantifying emissions over 13 modes, with a combination of engine speed (55%) and load (50%). The WHSC is based on real-world drives from the EU, United States, Japan and Australia. It involves a hot cycle start following preconditioning. The WHTC is a transient engine test that lasts 1,800 seconds and includes several motoring segments. It is based on real-world driving conditions for HDVs across the EU, United States, Japan and Australia. The WHTC was originally developed under the UNECE Working Party on Pollution and Energy (ICCT, 2016a). A comparison of the type approval tests for Euro V and Euro VI is provided in Table 3-9.

[46] Under the Euro V standards, diesel engines were tested using the combined European Steady-state Cycle (ESC), which calculated the weighted sum of emissions over 13 modes or combinations of engine load and engine speed; and the European Load Response Cycle (ELR), which measured smoke emissions, test. Positive ignition engines were tested on the European Transient Cycle (ETC) which is based on real-world drives. The ETC included of three sections: 1) urban – many stops and starts with an average engine speed of ~50 km/h; 2) rural – average speed of 72 km/h; 3) motorway – average speed of 88 km/h.[46]

Table 3-9: Evolution of HDV type approval tests from Euro V and Euro VI (bold indicate areas where changes were introduced)

	Euro V	Euro VI
Test procedure	ESC, ETC	WHSC (hot-start test only), WHTC (hot and cold-start testing)
Test type	Engine dynamometer	Engine dynamometer
Idling time	6% of total ETC	17% of total WHTC
Average engine load	55% ESC, 31% ETC	25% WHSC, 17% WHTC
Meeting emissions limit	Two separate test cycles which both must meet the emissions limit	Two separate test cycles which both must meet the emissions limit
Cold-start test	No	Yes, 14% weighting of test and only included in WHTC
Off-cycle test	No	World Harmonised OCE test – 0.6g/kWh NOx limit[47]

Source: (ICCT, 2016a) *NOx emissions from heavy duty and light duty CI vehicles in the EU: comparison of real-world performance and current type-approval requirements*

Implementing Regulation (EU) No 582/2011 introduced the use of PEMS for the type approval of HDVs. The objective was to simplify the approval process and to avoid the expense and time required to demount the engine during an ISC (in the past HDV engines could only be tested using a test bench). It set trip requirements for the ISC and introduced the use of moving average window method for calculating emissions.

Commission Regulation (EU) No 582/2011 also extended the use of off-cycle emission testing which tests engine-speed versus torque/load combinations which fall outside the test cycle but within a specified range, using the engine dynamometer emissions suite to quantify the engine's emissions. This Not To Exceed (NTE) test aims to ensure that the emission control systems have not been calibrated to only meet emission limits during the WHSC test cycle.

The subsequently adopted Commission Regulation (EU) No 2016/1718 elaborated further the trip requirements for testing in-service conformity using PEMS, introducing reduced power threshold requirements for calculating emissions. More recently, Regulation (EU) No 2019/1939 amended Regulation (EU) No 582/2011 as regards measurement of emissions during cold engine start periods and use of portable emissions measurement systems (PEMS) to measure particle numbers. These changes will apply to new vehicle types or engine types from 1 January 2021, and to new PI, type-A dual fuel and type-B dual fuel engines from 2023. Table 3-7: provides a summary of the requirements of Regulation (EC) No 595/2009 and its implementing Regulations.

3.3.3. Engine test cycles and procedures

Cold-start emissions testing was more recently introduced by Regulation (EU) No 2019/1939 with a conformity factor of 1.5 applied to CO, NOx, THC, NMHC (PI engines), CH_4 (PI engines). As of 2021, ISC testing of new vehicles will include PN emissions at the proposed conformity factor of 1.63. Table 3-10**:** outlines the Euro VI stages and their corresponding requirements.

Table 3-10: Euro VI Phase-In Requirements

Euro VI Stage	Regulation	Type approval Application date		OCE/ISC Requirements				
		New vehicles	All vehicles	PEMS power threshold (minimum engine power as a % of maximum engine power)	Cold start included for PEMS testing	OCE NTE (g/kWh)	PEMS conformity factor NOx, CO, HC, NMHC, CH_4	PEMS conformity factor PN
A	Commission Regulation (EU) No 582/2011	01/2013	01/ 2014	20%	No	NOx 0.6 THC 0.22 CO 2.0 PM 0.016	1.5	-
B (CI)	Commission Regulation (EU) No 582/2011	01/2013	01/ 2014					
B (PI)	Commission Regulation (EU) No 582/2011	9/ 2014	9/2015					
C	Commission Regulation (EU) No 582/2011	01/ 2016	01/2017					
D	Commission Regulation (EU) No 2016/1718	09/2018	09/ 2019	10%				
E	Regulation (EU) No 2019/1939	09/ 2020	09/ 2021		Yes			1.63

3.3.4. Changes to on-board diagnostic requirements

On-board diagnostic requirements for HDVs were refined and strengthened in Regulation (EC) No. 582/2011 as they became increasingly important due to the increased sophistication of in-cylinder controls and aftertreatment systems. The OBD thresholds for NOx and PM have been lowered by 75% and 82% respectively based on the WHTC. New requirements under Euro VI also introduced the monitoring, using OBD, of the diesel particulate filter (DPF) substrate and system, the SCR system including the reagent used, the Lean NOx Trap (LNT) system capability and the reagent, the EGR flow and performance, the oxidation catalyst hydrocarbon conversion efficiency, fuel injection and turbocharging systems, all of which are employed to aid reduction in emissions. OBD systems are also required to issue warnings for unexpected levels of urea consumption and impose more severe inducements if the urea level of quality is insufficient for proper SCR performance.

Table 3-11: OBD threshold limits for Euro V and Euro VI

		CI engines		PI engines	
	g/kWh	**Euro V[48]**	**Euro VI[49]**	**Euro V**	**Euro VI**
Phase in period for Euro VI (January 2013 – January 2016)	NOx	-	1.5	-	1.5
	PM mass	-	0.025	-	-
	CO	-	-	-	7.5
General requirements	NOx	7.0	1.2	-	1.2
	PM mass	0.1	0.025	-	-
	CO	-	-	-	7.5

3.4. Implementation of the legislation - Type approval activity

The evolution of emission type approval activity was identified as a relevant monitoring indicator in the impact assessment studies that supported the adoption of Euro 6 and Euro VI Regulations. However, as there is no obligation for reporting on the number of type approvals by the relevant authorities such information is not reported. As a result, there is no systematic dataset at the EU level on the number of type approvals with regards to pollutant emissions (reflected in the form of emission certificates) that could reflect the implementation of the standards.

In the context of the study we asked both TAAs and manufacturers to report on the number of type approvals granted/obtained in the period since the introduction of the standards. We

[48] Directive 2005/55/EC

[49] Commission Regulation (EU) No 582/2011

received nine responses providing data on the number of emission type approvals for light duty and heavy duty vehicles. The dataset is not complete as it misses data from some TAAs with significant level of type approval activity (NL, UK, IT), but the analysis of data on WVTA activity from the Netherlands suggests that the nine MS represent around two thirds of the total activity[50].

Table 3-12 summarises the number of emission type approval per authority for the period since the adoption of the Euro 6 and Euro VI standards. It points to the relative concentration of activity in a relatively small number of Member States. This is particularly the case for HDVs where the type approval activity in Germany, France and Spain represents 82% of the total. In the case of LDVs, emission type approvals were more broadly spread. While the same three Member States represent a total of 62%, there is also sizeable activity in Ireland, Luxembourg, Sweden and the Czech Republic.

Table 3-12: Total number of emission type approvals for passenger cars and vans granted by Type approval authorities (selected MS)

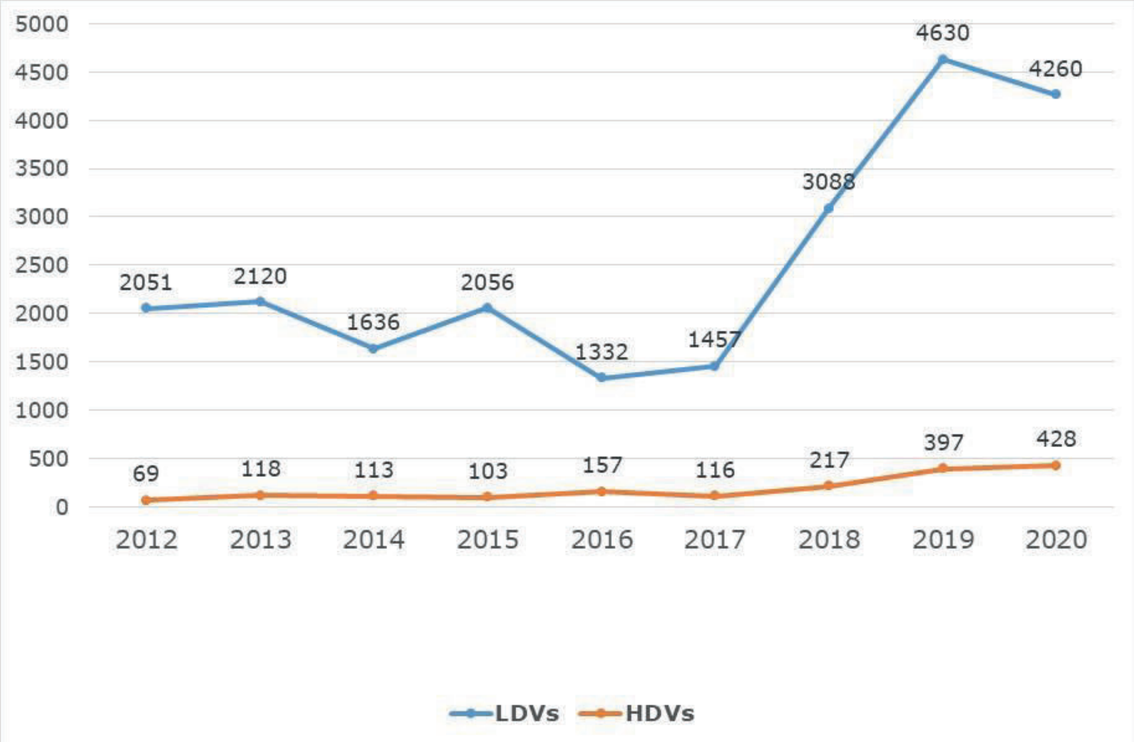
Member State	LDVs		HDVs	
	2014-2019	% of total	2013-2019	% of total
FR	4182	25%	422	29%
DE	3905	24%	535	37%
ES	2125	13%	227	16%
IE	1920	12%	44	3%
LU	816	5%	6	0%
SE	563	3%	56	4%
CZ	478	3%	92	6%
BE	210	1%	50	3%
RO	6	0%	0	0%
Total	**16,531**		**1,432**	

Source: Data provided by type approval authorities in the context of the study

The data provided by the nine authorities point to a significant increase in the number of Euro 6 emission type approvals granted since the introduction of the WLTP (i.e. after 2017) (see Figure 3-1). From a total of 1,457 type approvals in 2017, the number more than doubled in 2018 (3,088) and increased further in 2019 (4,630) with a similar trend observed in 2020 (number of approvals by June 2020 was 2,332). A similar increase in the number of type approvals is also observed for HDVs after 2017 in these 9 Member States, reaching 397 in 2019 from 116 in 2017.

[50] Analysis of data from the Netherlands on the number of Whole Vehicle Type Approvals (WVTA) suggests that the nine MS that have provided data represent around 67% of the total WVTA activity for the period 2011-2019. NL, UK and IT represented an additional 31%. It is reasonable to assume that a similar distribution would apply to emission type approvals.

Figure 3-1: Evolution of the number of emission type approvals for Euro 6 and Euro VI (period 2012-2020*) for nine type approval authorities (dates refer to the first day where standard was applicable for new types)



*Source: Data provided by nine type approval authorities (DE, FR, IE, ES, LU, SE, RO, BE, CZ); * Data for 2020 do not include FR. Remaining are based on projections for the whole year.*

There are a number of reasons that have led to the increase in the number of Type Approvals granted, some of them more directly related to the Euro 6 than others. Feedback provided by two OEMs suggests that this increase in emission type approval activity is linked with the changes to specific aspects of the testing procedures (i.e. ISC, Evaporative Emissions Control System (EVAP), European On-Board Diagnostics (EOBD) test and the OBFCM) and the various testing combinations over a short period[51]. This meant that OEMs had to recertify existing models on the basis of the new testing procedures and requirements. However, TAAs and Technical services also pointed out that the introduction of CO_2 related monitoring and reporting obligations based on WLTP has also led to an increase to the number of re-certifications that are not linked to the Euro 6 standards. As such, the increase in the number of emission type approvals reported is partly linked to the Euro 6 requirements and partly driven by the CO_2 and reporting obligations.

In the case of HDV, the explanation provided by two technical services suggested that the increase was solely the result of necessary CO_2 related certification[52] while one major TAA commented that they did not observe an increase in emissions type approvals but only those related to CO_2 certification.

There are also diverging views as to whether this increase in the number of type approvals should be expected to continue. While one TAA indicated that this should be expected to

[51] E.g. Euro-6d-TEMP, Euro-6d-EVAP, Euro-6d-EVAP-ISC, Euro-6d-EVAP-ISC-OBFCM

[52] Verification testing procedure as specified in Regulation (EU) 2017/2400 that includes an on-road test to verify the CO2 emissions of new vehicles after production

stop in the absence of any further changes to the legislation, another TAA suggested that the increased number of type approvals granted should be expected to continue. The explanation on the reason for the increase in the first place (related to WLTP and CO_2 monitoring) would suggest that the main driver is not emission related requirements. Thus, for the purposes of the study and the cost estimates made, in the absence of any further changes to the requirements, the level of type approval activity (and the associated certification) has been assumed to return to the previous levels (as before 2018).

3.5. Market trends

3.5.1. Evolution of sales of Euro 6/VI vehicles over time

Unfortunately, at the EU level there are no publicly available data on the number of new vehicle registrations classified by their pollutant emissions performance. Relevant datasets are available by private providers[53] at significant costs that were not included in the budget of this study. At national level, we are only aware of publicly available data by the German authorities (KBA). Additional relevant data on vehicle registration shares were made available to the study team for the Netherlands, Sweden and Austria. While not covering the broad geographical scope of the EU, we note that these MS represent advanced economies with GDP per capita above the EU average, their respective rate of renewal of passenger cars is close to the EU average[54].

Table 3-13 below summarises the evolution in the share of passenger car vehicle registrations per Euro standard for the period 2013-2020 on the basis of the data collected. Similar data on vans are not available. The key conclusion is that Euro 6 RDE vehicles (Euro 6d-Temp) appeared in 2018 and that by 2019 more than 90% of new PI cars and around 80% of CI cars were Euro 6d/temp or Euro 6d.

Table 3-13: Evolution in the share of Euro 5 and Euro 6 passenger cars new registrations in selected countries (AT, DE, NL, SE)

		2013	2014	2015	2016	2017	2018	2019
PI passenger cars								
DE	Euro 5	88%	71%	24%	0%	0%	0%	0%
	Euro 6 a/b/c	12%	29%	76%	100%	100%	85%	8%
	Euro 6d-Temp	0%	0%	0%	0%	0%	15%	90%
	Euro 6d	0%	0%	0%	0%	0%	0%	2%
NL	Euro 5				0%	0%	0%	0%
	Euro 6 a/b/c				100%	100%	85%	8%
	Euro 6d-Temp				0%	0%	15%	89%
	Euro 6d				0%	0%	0%	3%

[53] Such as IHS Markit (www.ihsmarkit.com)

[54] Based on data on renewal rates (i.e. new registrations as share of total vehicle fleet) for the period 2009- 2018 from Eurostat (road_eqr_carmot) and (road_eqs_carmot). With a 5.3% renewal rate for the period 2014-2019, Netherlands has been below the EU average of 5.8%. In comparison, the renewal rates for Germany, Austria and Sweden have been higher than the EU average (7.1%, 6.8% and 7.7%) (see also : https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Table_5_Renewal_rate_of_passenger_cars,_by_country_update_2020.png)

AT	Euro 5	95%	75%	25%	0%	0%	0%	0%
	Euro 6 a/b/c	5%	25%	75%	100%	100%	90%	23%
	Euro 6d-Temp	0%	0%	0%	0%	0%	10%	75%
	Euro 6d	0%	0%	0%	0%	0%	0%	2%
SE	Euro 5	89%	67%	13%	0%	0%	0%	0%
	Euro 6 a/b/c	11%	33%	87%	100%	100%	62%	5%
	Euro 6d-Temp	0%	0%	0%	0%	0%	38%	92%
	Euro 6d	0%	0%	0%	0%	0%	0%	2%
CI passenger cars								
DE	Euro 5	94%	76%	29%	0%	0%	0%	0%
	Euro 6 a/b/c	6%	24%	71%	100%	100%	85%	17%
	Euro 6d-Temp	0%	0%	0%	0%	0%	15%	79%
	Euro 6d	0%	0%	0%	0%	0%	0%	4%
NL	Euro 5				0%	1%	0%	0%
	Euro 6 a/b/c				100%	99%	85%	16%
	Euro 6d-Temp				0%	0%	15%	81%
	Euro 6d				0%	0%	0%	2%
AT	Euro 5	95%	75%	25%	0%	0%	0%	0%
	Euro 6 a/b/c	5%	25%	75%	100%	100%	90%	23%
	Euro 6d-Temp	0%	0%	0%	0%	0%	10%	75%
	Euro 6d	0%	0%	0%	0%	0%	0%	2%
SE	Euro 5	95%	74%	20%	0%	0%	0%	0%
	Euro 6 a/b/c	5%	26%	80%	100%	100%	53%	7%
	Euro 6d-Temp	0%	0%	0%	0%	0%	47%	91%
	Euro 6d	0%	0%	0%	0%	0%	0%	2%

Source: KBA (DE) [55] *and non-public data made available to the CLOVE consortium (AT, SE, NL)*

At the same time, it is important to note that, as a share of the total fleet, Euro 6 RDE vehicles represent only a small proportion. The available data from Germany (KBA) point to an increasing but still small share of Euro 6 vehicles in the total vehicle fleet and the fact that the RDE vehicles were still a small share at the beginning of 2020 (7.1%). While there may be variations across the EU in the penetration of Euro 6 RDE vehicles, RDE Euro 6 vehicles represent only a small share of vehicles on the EU roads.

Table 3-14: Evolution of total passenger car fleet by fuel and emission standard in Germany (numbers in 000s)- Data refer to the beginning of the year indicated

	1/2014	1/2015	1/2016	1/2017	1/2018	1/2019	1/2020
CI							

[55] Data extracted from multiple tables provided in vehicle statistics dataset https://www.kba.de/DE/Statistik/Fahrzeuge/fahrzeuge_node.html Themensammlungen (FZ 13) and Themensammlungen (FZ 14)

	1/2014	1/2015	1/2016	1/2017	1/2018	1/2019	1/2020
Euro 6 b/c	121	435	1,394	2,674	3,797	4,696	5,536
Euro 6d-Temp	-	-	-	-	-	245	1,060
Euro 6d						0.039	39
PI							
Euro 6 b/c	182	580	1,700	3,384	5,358	7,415	9,395
Euro 6d-Temp						529	2,240
Euro 6d						0.085	41.7
Total							
Euro 6 pre-RDE	304	1,025	3,129	6,138	9,317	12,397	14,931
Euro 6d-Temp	-	-	-	-	-	774	3,300
Euro 6d						0.124	80.7
Total PC fleet	**43,334**	**43,872**	**44,520**	**45,228**	**45,870**	**46,466**	**47,045**
% of Euro 6	1%	2%	7%	14%	20%	27%	33%
% of Euro 6 RDE						**1.7%**	**7.1%**

Source: Own analysis based on KBA data[56]

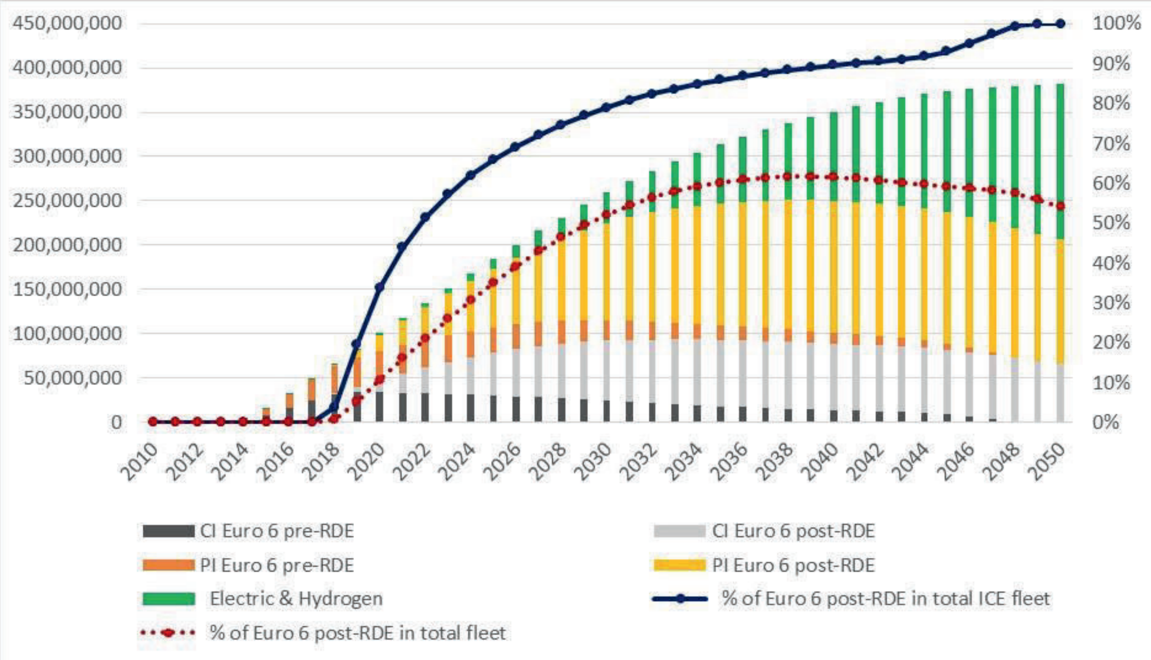
All in all, the available data point to the fact that the introduction of Euro 6 vehicles in the fleet – and particularly the Euro 6 post-RDE – is still at its initial stages. Post-RDE Euro 6 vehicles still represent a small share of vehicles on the EU roads.

For the purposes of the analysis of the impacts on emissions across the EU, we have used data available in the SIBYL model. The model includes projections for the evolution of registration and of the fleet up to 2050. Data on the evolution of the fleet (Figure 3-2) indicate an expected 50% share of all post-RDE Euro 6 LDVs to the total ICE LDVs by 2022. This includes all CI and PI vehicles, including also all hybrid vehicles with an ICE engine (i.e. also plug-in hybrid vehicles)[57]. In the long run, non-ICE vehicles are expected to represent a significant share of the fleet. However, even up to 2050, vehicles with an ICE engine are still expected to be the main post-RDE vehicles, representing more than 50% of the total fleet.

[56] ibid.

[57] According to SYBIL model data, PHEVs (CI and PI) represented 0.44% of the fleet. They are expected to reach 8.9% of the total fleet by 2030 and 21.3% by 2050.

Figure 3-2: Projected evolution of Euro 6 vehicle fleet (pre and post RDE) for light duty vehicles (cars and vans) (EU total) – Data from SIBYL model

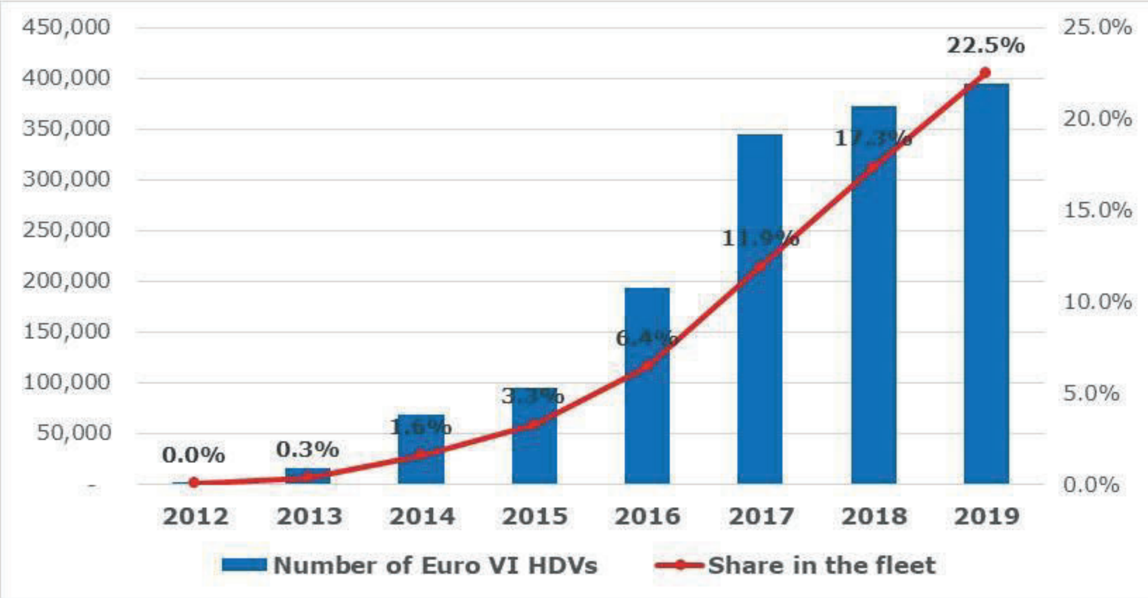


Source: Own analysis based on data from SIBYL model

In the case of **HDVs,** available data from Germany (KBA) on vehicle registrations and stock of vehicles for the period 2013-2019 suggest a gradual increase in the number of Euro VI registration and an increasing share of the newer Euro VI in the total fleet reaching 22.5% at the end of 2019 (see Figure 3-3)[58]. Furthermore, data made available to the study team for Sweden and Austria, indicate that the share of Euro VI new registrations reached 100% by 2015 (see Table 3-15).

[58] The data from KBA suggest a high share of Euro V registrations even after 2013. In principle, this is not possible under the Euro VI standards (all new registrations should meet Euro VI requirements after 31.12.2013). Asked for clarification, KBA informed us that there has been a mistake in the data for Euro V for a number of years. As such, we have not included them in the analysis.

Figure 3-3: Evolution of Euro VI registrations and share in total fleet of heavy duty vehicles (lorries and buses) in Germany (data on fleet share refer to the first day of the following year)



Source: Own analysis based on KBA data[59]

Table 3-15: Evolution of share of new registrations of heavy duty vehicles (lorries and buses) by Euro standard in Austria and Sweden

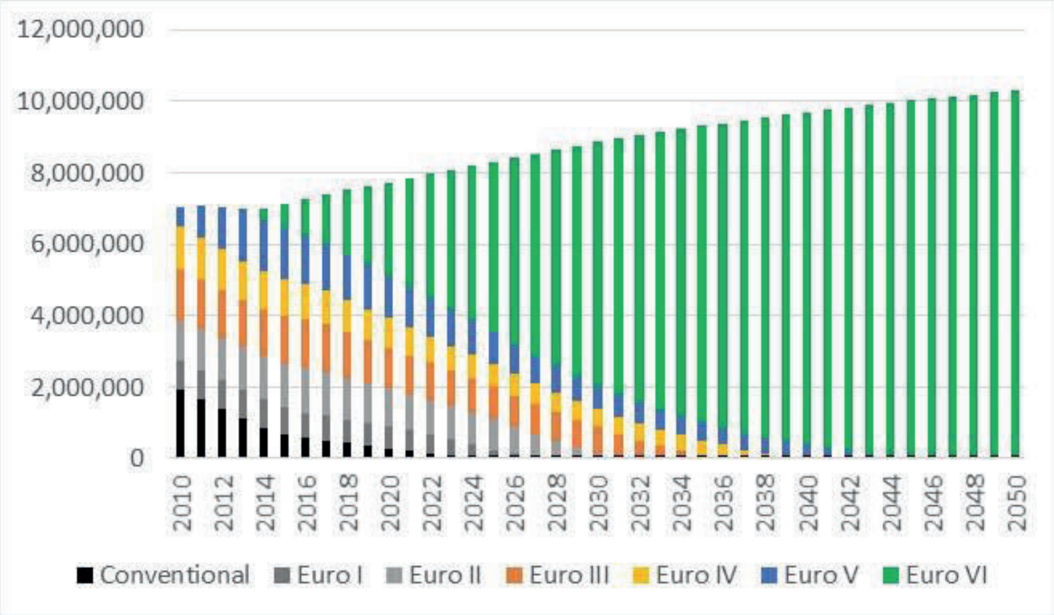
MS	Standard	2011	2012	2013	2014	2015	2016	2017	2018	2019
SE	Euro V	100%	99%	90%	29%	1%	0%	0%	0%	0%
	Euro VI	0%	1%	10%	71%	99%	100%	100%	100%	100%
AT	Euro V	100%	98%	83%	5%	0%	0%	0%	0%	0%
	Euro VI	0%	2%	17%	95%	100%	100%	100%	100%	100%

Source: Non-public data made available to the CLOVE consortium (AT, SE)

The data from the SIBYL model suggest that by 2018 the share of Euro VI in the total fleet across the EU was 24% and by the end of 2020 it is expected to reach 34%. As shown in Figure 3-4 it is projected that the fleet will include only Euro VI vehicles by 2040.

[59] Data extracted from multiple tables provided in vehicle statistics dataset https://www.kba.de/DE/Statistik/Fahrzeuge/fahrzeuge_node.html Themensammlungen (FZ 13) and Themensammlungen (FZ 14)

Figure 3-4: Projected evolution of fleet by Euro VI emission standard for heavy duty vehicles - (EU total) – Data from SIBYL model



Source: Own analysis based on data from SIBYL model

3.5.2. Technologies used to ensure compliance with the Euro 6/VI standards

In order to meet the new pollutant emission limits and the changes to the testing procedures, manufacturers of vehicles have had to introduce or upgrade relevant technologies in two main areas:

- In-cylinder control technologies including fuel/air mixing technologies and engine design to improve combustion and reduce engine out emissions
- Exhaust emissions control technologies to reduce tailpipe emissions

In addition, in response to new OBD requirements, additional sensors were introduced while changes to the evaporative emissions requirements have also led to the introduction of additional technologies.

In this section we present an overview of the approach followed by OEMs to meet the requirements. The analysis focuses on the technological and other changes made in relation to the previous set of standards (Euro 5/V standards). It is based on a combination of sources, including studies that have analysed the technologies used by OEMs, input from the experts within the CLOVE consortium and direct input from the manufacturers in the context of the targeted stakeholder consultation.

The analysis does not intend to provide a comprehensive review of the technologies used by OEMs but only to provide the overall picture of the package of technologies and procedures adopted by the manufacturers to ensure compliance with the new requirements. It should be noted that OEMs have varied their approach and technologies depending on the vehicle type/engine size while also taking into consideration costs, reliability, fuel economy, consumer acceptance and their overall business strategy.

3.5.2.1 *LDVs*

In the case of the Euro 6 standards for LDVs, manufacturers had to introduce different technologies depending on vehicle technology (i.e. PI or CI) to meet the respective emission limits. Furthermore, the move to RDE testing with Euro 6d-Temp led to further changes to the technologies used to ensure that vehicles meet the limits under the new testing procedures.

3.5.2.1.1 CI (Compression ignition) vehicles

In the case of CI vehicles with the direct and controlled fuel injection with excess of air, PM and NOx emissions are the main concern and are those pollutants for which new and/or improved technologies had to be applied. HC and CO emissions are not usually a concern, as the lean operation of the engine reduces engine-out HC and CO emissions and enables high oxidation efficiency in simple oxidation catalysts.

In terms of in-cylinder control of NOx and PM in CI engines, the main systems/technologies used include fuel injection system improvements (e.g. high-pressure fuel injection with variable injection fuel timing and metering, as well as redesigned nozzle and piston bowl), air handling control (e.g. use of variable geometry turbochargers to provide the right amount of air under specific engine operational conditions) and further advances in exhaust gas recirculation (EGR) technologies (EGR over a wider operating map).

In terms of aftertreatment technologies, the most common technologies used include lean NOx traps (LNT) and/or selective catalytic reduction (SCR) with ammonia as the reductant (for NOx), together with diesel oxidation catalyst (DOC) and, in the case of PM, diesel particulate filters (DPF).

In the case of Euro 6, the changes to the NOx emission limits required a combination of NOx aftertreatment devices (LNT or SCR) and DPF in addition to, in some cases, in-cylinder measures. Furthermore, moving from pre-RDE (Euro 6b/c) to RDE (Euro 6d-Temp and Euro 6d) has led to a combination of changes and new technologies, including improvements to the EGR system (e.g. increasing the heat exchange performance of EGR cooler), variable swirl control system, together with the addition of a SCR with a soot filter (SDPF) and in some cases an Ammonia Slip Catalyst (ASC) to mitigate the emission of additional NOx emissions and ammonia emissions.

In addition, moving to Euro 6d-Temp and Euro 6d (RDE) typically led to introduction of NOx and temperature sensors.

Table 3-16: Typical emission control technologies used by OEMs in relation to Euro 5 and Euro 6 standards for CI vehicles (bold indicate new technologies introduced in each step)

	Euro 5	Euro 6b/c	Euro 6d-Temp	Euro 6d
In-cylinder control	Limited EGR	Limited EGR	EGR	EGR
Aftertreatment control				
For NOx	DOC	**SCR/LNT,** DOC	SCR, DOC	SCR, DOC **SDPF, ASC**
PM/PN	DPF	DPF	DPF	DPF

	Euro 5	Euro 6b/c	Euro 6d-Temp	Euro 6d
OBD sensors	Pressure sensors	Pressure sensors	Pressure sensors **NOx, temp sensors**	Pressure sensors NOx, temp sensors
Evaporative emissions		-	-	-

Source: (ICCT, 2012a) and information from consortium experts and direct input from OEMs as part of the targeted stakeholder consultation

3.5.2.1.2 Positive ignition (PI) vehicles

In the case of positive ignition (PI) engines (petrol), emission control technologies have focused on improving stoichiometric air-fuel control together with aftertreatment control including three-way catalytic converters (TWC) and system integration through electronic sensing and control.

Euro 6 standards did not bring changes to the emissions limits for NOx for PI vehicles. As such, there has been no need for changes to existing technologies already applied. However, changes in the costs of platinum group metals for catalytic converters often also required changes in TWC formulation on wash coat and PGM formulations. Sensing capabilities were also improved with the adoption of universal wide range oxygen sensors although these were not directly driven by the Euro 6 standards. Finally, the move to the Euro 6d standards led to the use of more advanced three-way catalytic converters systems.

The introduction of CO_2 emission targets led to an increased use of certain technologies improving fuel efficiency, including engine downsizing and an increased use of gasoline direct injection (GDI). As GDI tends to produce higher amounts of particles specific emission standards regulating particulate mass and particulate number were introduced in Euro 6 GDI vehicles. Thus, in order to meet the standards, especially Euro 6d, a combination of advanced fuel injection strategies and aftertreatment by wall-flow particulate filters have been used by OEMs in all GDI vehicles.

In relation to the evaporative emissions, changes to stricter test requirements, typically required the use of a larger canister, a more effective purge valve and relevant OBD sensors.

Table 3-17: Emission control technologies used by OEMs in relation to Euro 5 and Euro 6 standards for PI vehicles (bold indicate new technologies introduced)

	Euro 5	Euro 6b/c	Euro 6d-Temp	Euro 6d
In-cylinder control	Combustion optimisation	Combustion optimisation	Combustion optimisation	Combustion optimisation
Aftertreatment control				
NOx	TWC	TWC	TWC	**Advanced TWC**
PM/PN			***GPF (for GDI)***	***GPF (for GDI)***

	Euro 5	Euro 6b/c	Euro 6d-Temp	Euro 6d
OBD			**Pressure sensors**	Pressure sensors
Evaporative emissions			**larger canister, improved purge valve**	larger canister, improved purge valve

Source: (ICCT, 2012a), information from consortium experts and direct input from OEMs as part of the targeted stakeholder consultation

3.5.2.2 *HDVs*

In the case of HDVs, the tightening of NOx and PM limits as a result of the Euro VI together with the introduction of the WHTC and WHSC required the adoption of a combination of advanced in-cylinder controls, improvements in SCR systems and addition of DPFs.

This included the refinement of air and fuel management technologies, the introduction of more complex fuel injection timing and metering algorithms and fuel injector designs including the use high efficiency turbochargers. Improvements to the EGR systems were also made in some cases (including hot EGR and improved EGR separation systems). Two OEMs that responded to the targeted stakeholder consultation also reported changes (re-engineering/optimisation) to the combustion system.

In relation to aftertreatment technologies, manufacturers relied on SCR (as in the case of Euro V) but in most cases they also introduced Ammonia Slip Catalyst (ASC) systems. To meet the PM and PN limits, DPFs have also been introduced. Two manufacturers reported that they had to completely redesign the SCR and DPF system and one also reported the introduction of a new urea dispenser system. Euro VI also require significant improvements to the OBD systems, leading to the introduction of additional sensors including NOx and PM sensors.

Table 3-18: Emission control technologies used by OEMs in relation to Euro V and Euro VI standards for HDVs (bold indicate new technologies introduced)

	Euro V	Euro VI
In-cylinder control systems	EGR	EGR
Aftertreatment control		
NOx	open-loop SCR systems DOC (in some vehicles)	**closed-loop SCR systems** **ASC** DOC
PM/PN		**DPF**
OBD requirements	Additional urea level and quality monitoring	**NOx and PM sensors**

Source: ICCT (2016b), information from consortium experts and input from OEMs as part of the targeted stakeholder consultation

3.5.3. Testing equipment

Further to the technologies used in the vehicles, changes were needed to the testing facilities and equipment used to check compliance with the new requirements. These were either purchased by OEMs themselves or by the technical services. They included:

- New Portable Emission Monitoring Systems (PEMS) (for LDVs and HDVs);
- Changes to the chassis dynos to be certified for WLTP cycle as part of Euro 6 and to the test benches to ensure that it is certified based on new WHTC/WHSC cycles as part of Euro VI; and
- Addition to the test bench gaseous emission analysis capability to ensure that ammonia emissions can be certified for Euro VI.

4. Study methodology

The methodological framework and the tools used to evaluate the Regulations are presented in this chapter.

4.1. Methods and tools used

The methodological framework and the research tools used were defined in the evaluation matrix that was developed in the initial stages of the study. The evaluation matrix was used to define in detail for each evaluation question the approach that would be used to answer the questions. This included:

- A set of operational questions to be examined to help answer the evaluation questions;
- Relevant indicators to help answer the questions and the judgment criteria used to guide our analysis;
- The research tools and the sources of data used to collect the relevant information and data;
- The overall method of analysis used, combining the above to answer the questions.

The evaluation matrix is presented in Annex 1.

The following section presents in more detail the research tools used to support the collection of data that included desk and field research.

4.1.1. Data collection approach

A key element of the evaluation was the collection of data, including relevant literature and data sources and input from stakeholders on the basis of a targeted stakeholder consultation through an online questionnaire and follow up interviews. The selection of the specific tools was considered appropriate to reach the broad range of stakeholders that are directly affected (industry, authorities) or have a strong interest (NGOs, research organisations), while also allowing for more in depth discussions (through the use of selected interviews). Feedback received in public consultations (inception impact assessment (IIA), public consultation (PC) and AGVES position papers) has also been taken on board in the findings of this report. Stakeholders had the opportunity to provide feedback on the evaluation over the period January to November 2020.

Alternative tools were also considered at the time of the development of the methodology but were not selected:

- A case study approach focusing on specific Member States was not adopted as it was not expected to provide added value or more information/data beyond that arising from the targeted stakeholder consultation and the in-depth interviews with individual stakeholders. This was due to the international nature of the automotive sector with manufacturers using technical services and TAAs in different Member States and the fact that vehicles type approved by one TAA can be sold across the EU (i.e. the impacts per Euro 6/VI vehicle are expected to be the same irrespective of the Member State). Furthermore, a country focus was not expected to allow for the collection of more information from OEMs or TAA since the main reason/constraints was the unwillingness to share relevant information (where available).
- The use of external expert panels was also considered but it was felt this was not likely to help with the cost collection aspects due to the strong data confidentiality concerns. Nonetheless, we organised informal discussions within the CLOVE consortium intended to make the best use possible of existing experience and expertise to assist in the analysis.

4.1.1.1 *Desk research*

Desk research was the first source of evidence to support the analysis in this study. There is already an extensive pool of literature relating to the pollutant emissions from road vehicles, which provides relevant information on the performance of different aspects of the Regulations and can help answer a number of questions.

In particular, the literature review covered the following:

- Previous assessments of the Euro 5/V and Euro 6/VI Regulations;
- Reports and outputs from the Post Euro 6 Part A study prepared by the CLOVE consortium which included an analysis of the impacts of the Euro 6 standards;
- Academic articles, studies and reports related to the technologies used on vehicles and examining the impact of the standards on pollutant emissions; and
- Automotive market studies, reports and web-sources including data and/or analysis on aspects related to structure of the automotive sector, costs of technologies and vehicle prices, economic indicators and other relevant data.

Additionally, relevant data sources were used to support various parts of the analysis including:

- European Environmental Agency data from the National Emission Ceilings Directive database;
- Handbook on Emission Factors for Road Transport; and
- Data on vehicle registrations and stock by emission standard (including publicly available from KBA (DE) and data available to the consortium for the Netherlands.
- IHS Markit Database on light vehicle powertrain and Medium & Heavy Duty Vehicle Engine data
- Eurostat structural business statistics
- OECD patent data

Publicly available data were supplemented by data provided by the partners within the CLOVE consortium in their relevant areas of expertise. These mainly related to cost estimates associated with the implementation of the Regulations.

4.1.1.2 *Field research*

4.1.1.2.1 Targeted stakeholder consultation

Targeted stakeholder consultation based on the combination of an online questionnaire and follow up interviews was used to collect relevant evidence to supplement and/or cross-check the evidence gathered through the desk research. These methods allowed us to collect input from a broad range of stakeholders representing different viewpoints and interests.

The online questionnaire combining open and closed questions was used to collect input from a range of stakeholder groups in a systematic way:

- Automotive sector including car, van, truck and bus industry manufacturers, equipment suppliers and their representatives and representatives of the repair and maintenance sector[60];

1. Member States authorities, including type approval authorities;
2. Environmental NGOs;
3. Consumer organisations; and
4. Other relevant organisations including technical services and academic and research organisations active in the specific field.

Depending on the type of stakeholder and relevant experience, different stakeholder groups were asked a slightly different sub-set of the questions. The final version of the questionnaire can be viewed in Annex 8.

The questionnaire was distributed to a total of 174 members of the Advisory Group on Vehicle Emission Standards (AGVES). The use of the AGVES group as the target of the online questionnaire was considered appropriate as it brings together stakeholders from the full range of stakeholders while, at the same time, it was expected to contribute to a high response rate.

A total of 73 fully or partly complete responses were received during the 14-week period that the questionnaire remained available (4th March – 8th June 2020)[61]. They were subsequently analysed, and they are presented in the report. In the analysis presented in the following sections, the responses have been grouped in three main categories:

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[60] The study team did not examine separately the impact of the Euro 6/VI standards on SMEs. The vehicle manufacturers that are directly affected by the Euro 6/VI are in their great majority large multinational enterprises. Small enterprises are mainly suppliers of equipment that, in their majority, are only indirectly affected by the standards through the increased demand for improved emissions control and other equipment. In their majority they are not directly affected by the testing and other requirements of the Euro 6/VI. Developers of complete systems that may also require type approval are most often large Tier 1 suppliers. Small volume bus producers are also not directly affected since in most cases they purchase a chassis with an engine system developed and type approved by large manufacturers to which they fit the bus bodies. As such, it was not considered necessary to analyse separately the impact on SMEs. Nonetheless, industry sector representatives that contributed to the consultation also have SMEs as their members.

[61] There were also 32 responses that did not answer any evaluation question. These were disregarded in the analysis. Furthermore, one organisation provided three separate responses coming from three different departments.

- Industry (including associations and individual businesses)
- Authorities (ministries and type approval authorities) and technical services
- Civic society and research organisations (including NGOs, academic and consumer representatives).

In addition to the questionnaire, the study team conducted 26 follow up phone interviews with a selected number of stakeholders within each stakeholder group. These interviews were intended to build on the questionnaire responses, providing further details and clarifications to the relevant questions.

The consultation period was originally expected to last for 5 weeks. However, as a result of the COVID-19 pandemic, two extensions were requested, resulting in a ~14-week long consultation period to give all stakeholders groups the opportunity to respond to the questionnaire.

Finally, the study team took into consideration position papers submitted by two organisations as input to the consultation as well as those provided via the AGVES expert group. During the AGVES meeting on 27 October 2020, stakeholders were invited to provide further inputs in relation to cost data for the evaluation study. Additional comments were received from three industry stakeholders (ACEA, MAN Truck & Bus SE and Robert Bosch GmbH). These have been taken into account in the evaluation study as reflected in the subsequent sections of this report.

Table 4-1 summarises the profile of the respondents that contributed to the stakeholder engagement activities. A detailed of list of all stakeholder organisations that contributed to the study and identified themselves is presented in Annex 7.

In terms of the geographical scope, the input provided covers a total of 17 individual Member States[62] along with EU level organisations (industry representatives and civic society representatives) and a smaller number of non-EU respondents (including non-EU OEMs and industry associations). At national level, there was a broad distribution with the highest number coming from respondents based in Germany (12) and France (11) and all others will less than four. We should note that many of the respondents (including OEMs and suppliers) have EU wide or international operations which means that their input did not necessarily reflect a national perspective.

[62] MSs not covered include EL, HR, CY, MT, SK, SI, BG, LV, EE, PT.

Table 4-1: Summary of targeted stakeholder engagement

Type of stakeholder		No	Detail
Online questionnaire			
Car, van, lorry and bus industry	Vehicle manufacturers (OEMs)	18	Including 10 EU OEMs (DE (4), FR (2), SE (2), IT and NL) and 5 non-EU OEMs covering both LDVs (11) and HDVs (4) (3 anonymous)
	Equipment suppliers	12	Including 11 EU (BE (3), FR (3), PL (2), CZ, DE and LU) and 1 non-EU specialised supplier of emission control equipment, sensors, general automotive parts, powertrain technologies (2 anonymous)
	Industry associations	13	Includes 11 European and 2 international associations representing OEMs, component suppliers and emission control equipment suppliers (large and small), fuel industry, organisations involved in road inspections, transport sector users.
Member States including approval authorities	Public authorities	9	Authorities from DE, RO, BE (2), NL FI, DE (2), LT, SE
	Type approval authorities / technical services	11	TAA from DE, AT, NL, ES and Technical services from FR (3)[63], DE (2), RO, PL
Civil society and research organisations	NGOs	3	Including environmental, health and local authorities' representative
	Consumer organisations	2	1 EU and one national representative
	Academic/research organisations	3	Automotive sector and environmental policy R&D organisations (DE, FR and HU)
TOTAL		**73**	
Interviews			
Car, van, lorry and bus industry	Vehicle manufacturers	3	1 EU (DE) and 1 non-EU LDV OEM 1 EU (NL) HDV OEM
	Equipment suppliers	9	8 EU (BE (3), CZ, FR (2), DE, PL) and 1 non-EU
	Associations	8	6 EU and 2 non-EU covering fuel, vehicle testing, control equipment,
Member States including approval authorities	Ministries	1	FI
	Type approval authorities / technical services	2	FR, AT
Civil society and research organisations	Environmental NGOs	2	Covering environment and Health
	Consumer organisations	0	-

[63] Three responses were provided from one organisation (from different departments). In most cases answers provided covered different topics but there were also some overlaps.

Type of stakeholder		No	Detail
	Academic/research	2	Automotive R&D and environmental policy (DE and FR)
TOTAL		**26**	

Public consultation

A number of public consultation activities have also been carried out in relation to this study. An overview of the responses relevant to the evaluation are presented in Table 4-2. A more detailed presentation is provided in the stakeholder consultation report that has been submitted separately to this study (D3.1.2. Synopsis Report).

Table 4-2: Summary of public consultation responses

Consultation activity	Timeframe	Comments	Responses received by stakeholder group
Inception Impact Assessment	27 March – 3 June 2020	41 of the 68 responses received made reference to the evaluation of Euro 6/VI.	Automotive industry (26 EU from AT (2), BE (6), CZ, DE (8), ES (3) FI (2), FR (2) and IT (2) and 1 non EU). Citizen (2 EU (DE and PT) and 1 non EU) Consumer organisation (1) Environmental NGOs (3) EU27 and other authorities (including non-MS) (4 EU (BE and NL (3) and 2 non EU) Other (1 non EU)
Public Consultation	6 July – 9 November 2020	166 responses received, all responded to questions on the evaluation of Euro 6/VI.	Academic / research organisations (5 EU from DE, FR (2), HU and PL and 1 non EU). Automotive industry (AT (2), BE (12), CZ, DE (18), DK (2), ES (2), FI, FR (5), IT (8), NL (2), PT, RO, SE (4) and 10 non EU). Consumer organisations (5) Citizens (46 from AT, BE, CZ (5), DE (14), DK (2), EL (4), ES (2), FR (5), HU, IT (3), NL (5), PL, PT, RO and 9 non EU). Environmental NGOs (12) EU27 and other authorities (including non-MS) (25 EU (AT, BE (6), CZ, DE (4), DK, ES, FR, IT, NL, PL, RO, SE, SK and 3 non EU) Other (5 EU and 1 non EU)
Position papers received from AGVES members via CIRCABC	January – 9 November 2020	12 out of 24 responses received made reference to the evaluation of Euro 6/VI	Automotive industry (8 including international associations) Environmental NGOs (1 EU (BE)) EU27 and other authorities (including non-MS) (1 EU (BE)) Other (2)

4.1.2. Use of COPERT/SYBIL model

We have used the COPERT software[64] and SYBIL model[65] to support the quantification of the impacts of the Euro 6/VI and the assessment of their effectiveness and efficiency.

COPERT has been used to provide emission factors for different vehicle pollutants to calculate air pollutant and GHG emissions from different categories of vehicles. COPERT is coordinated by the European Environment Agency (EEA). The SIBYL model is a vehicle stock, activity and emissions projection tool that enables estimations and projections up to 2050. In combination with the COPERT data on emission factors, the SIBYL model was used to develop an estimate of the emissions reductions over the period which the Euro 6/VI have been implemented and to compare with the baseline scenario (see more in section 2.6).

In addition to this, the model was use to monetise the pollution benefits based on the estimated emissions savings and using the Handbook of external cost of transport (European Commission, 2019c)(more detail on this is provided in Annex 4).

4.2. Study limitations

There are a few limitations to the research methodology that need to be taken into account:

- An important challenge was that the study was conducted during the period of the global COVID-19 pandemic that had a worldwide impact on businesses, including the automotive sector. Many stakeholders were required to suspend business operations around the time that the targeted consultation for this study commenced. As a result, the response rate to the consultation was low and the duration of this process was subsequently extended on two separate occasions following requests from both vehicle manufacturers and Member States to the CLOVE consortium and directly to the Commission. This extension to stakeholder consultations was not a limitation exclusive to this study but was experienced widely across EC consultations.
- Another challenge was the very low response rate to questions related to the costs of compliance with the standards as part of the efficiency questions. Despite repeated requests during the period of the targeted consultation, only a very small number of vehicle manufacturers (2 in the case of Euro 6; 3 in the case of Euro VI) provided relevant data to support the assessment of the compliance costs. Concerns related to data confidentiality were raised as the main reason for not sharing relevant data[66]. The result was that it was not possible to cross check and validate the costs estimates provided in the attempt to estimate the total costs to the sector as part of the analysis. As a way to address the study team presented to the participants of the AGVES meeting on November 26th 2020, the main cost estimates

[64] https://copert.emisia.com/

[65] https://www.emisia.com/utilities/sibyl-baseline/

[66] The study team organised a call with ACEA (the EU association representing most OEMs) to clarify any questions and discuss any concerns in terms of the handling of data.

and assumptions made and asked for feedback and comments with the initial request to verify the conclusions[67].

- Another challenge was the collection of relevant monitoring and reporting data including in relation to the level of type approval activity for different vehicle categories as well as in terms of the costs of implementation. Such data are not collected at the EU-level (although these data are available to type approval authorities) as there is no such obligation in the legislation and no organised process for their collection at EU-level[68]. This is despite the fact that the number of type approvals was identified as the relevant indicator to monitor the implementation of the Euro 6/VI standards in the respective impact assessment studies.
- The study team has attempted to address these limitations through a combination of desk research and data collection, request from input from other stakeholders with relevant expertise[69] and from experts within the CLOVE consortium team with relevant experience. Further to that, the result of the bottom up cost estimates, developed on the basis of available data, were also compared against certain key indicators (e.g. turnover of the sector, level of R&D expenditure) as an additional way to assess the plausibility of the cost estimates developed. In relation to the monitoring data (i.e. number of type approvals), with the support of the Commission, a data request was sent to all Type Approval authorities which resulted in responses from nine of them indicating the number of emission type approvals granted over the period 2008-2020 for LDVs and HDVs and on the fees charged per type approval.
- Nonetheless, despite the systematic effort of the study team to address the data limitations, it was not possible to cover all information gaps or to triangulate the cost estimates. As such, there is a certain level of uncertainty in some of the cost estimates made where reasonable assumptions had to be made. This uncertainty is reflected in the wide range of the cost estimates provided in our analysis.

[67] Three organisations representing the automotive sector (on OEM, one supplier and one association) provided specific comments that were taken into account in the analysis.

[68] OEMs are obliged to publish data during RDE type approval tests according to Regulation 2017/1154 and (as amended) by Regulation 2018/1832. Such data are provided by some manufacturers via the EU association website (https://www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data). However, the data provided do not include all OEMs and are not provided in a consolidated manner (detailed data can only be downloaded for each model separately) that would allow for an analysis of the data in order to draw potentially relevant conclusions within the time constraints and project budget. We are also not aware of any study that has analysed such data.

[69] The study team organised a detailed discussion with the Dutch Type Approval Authority (TAA) and a French Technical Service (UTAC) asking for verification of assumptions made in relation to the costs for emission type approval and for further information to fill in certain gaps.

5. Analysis of the evaluation questions

In this section we present the answers to the evaluation questions. The questions are presented under the general evaluation headings of relevance, effectiveness, efficiency, coherence and EU-added value.

5.1. Effectiveness

5.1.1. Introduction

In our assessment, we are looking into Euro 6d (RDE approved vehicles) separately. We examine the available evidence of the impact of the standards in comparison to the baseline as described in Section 2.6. The available evidence is based on a combination of data analysis, input from secondary sources (e.g. relevant studies on the topic) and direct input from stakeholders as part of the surveys and interviews

5.1.2. EQ1 To what extent has Euro 6/VI made cleaner vehicles on EU roads a reality?

5.1.2.1 *Introduction*

In this section, we examine the extent to which the adoption and implementation of the Euro 6/VI standards and the implementing legislation was successful in meeting its core objective, namely to make light-duty and heavy-duty vehicles on the road cleaner.

In answering this question, we examine the following closely related aspects:

- Whether Euro 6/VI certified vehicles emit less pollutants than Euro 5/V;
- Whether changes in emission levels are reflected on EU roads;
- How the level of pollutant emissions from Euro 6 vehicles evolved over time as a result of the changes to the testing procedures introduced as part of the Euro 6 standards;

We use the analysis to assess the overall impact of Euro 6/VI vehicles on total emissions on EU roads.

In answering these questions, we rely on evidence from the literature on the level of real-world emissions of light and heavy-duty vehicles as this has been collected in the context of a number of studies conducted in the last years. We also use data on emissions factors from the COPERT model that allow to examine that the evolution of the average level of real-world emissions over time for most of the regulated pollutants (see Annex 3). We supplement these with input from stakeholders that were asked to comment on the effectiveness of the Euro 6/VI standards.

5.1.2.2 *Are Euro 6/VI vehicles cleaner (i.e. less polluting) in relation to Euro 5/V vehicles?*

In assessing the extent to which Euro 6/VI vehicles are cleaner, our main focus is on identifying the change in Euro 6/VI vehicles' emission factors in relation to the Euro 5/V vehicles for all regulated pollutants, as presented in Section 3. We analyse the role of the Euro 6 standards for LDVs and Euro VI for HDVs in turn.

5.1.2.2.1 The case of Euro 6 for LDVs

There is sufficient evidence in the literature indicating a reduction of real-world emissions levels of vehicles following the introduction of Euro 6, with Euro 6 vehicles becoming progressively cleaner over time as new stages were introduced. These studies have been based on various method, including PEMS based testing, modelling and remote sensing. The following paragraphs summarise the available evidence in relation to each of the regulated pollutants.

NOx

- A study that measured real world emissions using PEMS from 149 Euro 5 and 6 diesel, gasoline and hybrid passenger cars on urban and motorway driving cycles reported "significant improvement in NOx emissions between Euro 5 and Euro 6. NOx emissions reduced from 0.75 g/km for Euro 5 diesel vehicles to 0.35 g/km for Euro 6 diesel vehicles on urban roads, and from 0.75 to 0.25 on motorways (O'Driscoll , et al., 2018). The models sampled accounted for 56% of all passenger cars sold in Europe in 2016.

- Emission factors reported by the Handbook Emission Factors for Road Transport using the PHEM model and based on German traffic conditions[70] (TU Graz, 2019) also show an average reduction in NOx emission factors from 800 mg/km to 44mg/km from Euro 5 to Euro 6d-TEMP CI passenger cars.
- Building on the CONOX dataset of 700,000 records of remote sensing measurements across Europe, the TRUE initiative compared emissions between Euro 5 and Euro 6 vehicles. They found that Euro 6 CI vehicles emitted half the amount of NOx compared to their Euro 5 counterparts with Euro 6 CI vehicles emitting on average (expressed in g/km). According to their data, the 50% lowest emitting Euro 6 vehicles are emitting between 0.5 and 0.1 g/km of NOx, while the 50% lowest emitting Euro 6 vehicles are emitting between 1.0 and 0.5 g/km (Bernard, et al., 2018). For PI vehicles, they identified a slight reduction in NOx emission factors. though the 95% lowest emitting Euro 6 vehicles emitting <0.1g/km less than the lowest Euro 5 vehicles.
- Although these results are provided through remote sensing of fleets in Spain, France, the United Kingdom, Switzerland and Sweden, they are similar to those obtained during PEMS measurement conducted by government authorities in France, Germany, the Netherlands, and the U.K. and by Environmental Action Germany (Deutsche Umwelthilfe) on 541 Euro 5 and Euro 6 CI passenger vehicles (Bernard, et al., 2018).
- Based on a sample of 100,000 remote sensing measurements around the UK, Ricardo's identified sizeable reductions in NOx emissions of up to 55% for Euro 6b/cCI passenger cars in comparison to Euro 5 counterparts, and 68% for CI vans (Ricardo, 2017).

PN

- The literature reports high PN levels in the early stages of Euro 6 for PI vehicles, enabled by an initial derogation to the limit allowing for ten times higher levels ($6x10^{12}$#/km). The removal of this derogation to align PI with CI vehicles' requirements reportedly led to large reductions in PN, by rendering the use of Gasoline Particulate Filters (GPF) unavoidable (Giechaskiel, et al., 2019; AECC, Concawe, Ricardo, 2017).
- In that respect, work by AECC indicated typical reductions in PN of 70-80% when retrofitting a Euro 6 GDI with a GPF and testing it on an RDE-compliant route (AECC, Concawe, Ricardo, 2017).
- PN emission factors reported by the Handbook Emission Factors for Road Transport also suggest a reduction in CI passenger cars' emissions of more than 80% between Euro 5 to Euro 6d. This is consistent with data from the COPERT model. For PI passenger cars, emission factors are extremely low and below the limit, although the slightly increased moving from Euro 6b to Euro 6d. However, we note that this finding is based on only one Euro 6d-Temp vehicle measurement (TU Graz, 2019).

PM

- The NEMO emission model (Rexeis & Hausberger, 2009) shows a slight increase in PM emission factors for CI passenger cars from Euro 5 to Euro 6. However, their assessment is solely based on the modelled impacts of reduction in emission limits, and does not consider the impact of changes in testing procedure.
- After surveying the available literature on particle emissions of gasoline vehicles Giechaskiel, et al. (2019) highlight that stringent PM limits and the introduction of particle number limits for GDI vehicles in the European Union (EU) resulted in significant PM reductions.
- AECC indicated that GPF provides a small reduction in PM (0-30%), though PM cannot be considered much more than semi-quantitative due to volatile artefacts (AECC, Concawe, Ricardo, 2017).

CO

- We are not aware of relevant studies assessing LDVs performance in terms of CO emissions. However, according to the emission factors from COPERT, CO emissions from LDVs decreased by 70% between Euro 5 and Euro 6d vehicles, from 939.3 mg/km to 281.1 mg/km.

[70] The model calculates engine power and engine speed and on engine emission maps, which provide the corresponding emission levels. It takes into account vehicle technology, and traffic situations. The average vehicle data is weighted according to new registration share and corrects for deterioration effects. The driving conditions are simulated based on a mix of traffic situations in Germany (TU Graz, 2019)

THC and NHMC

- We are not aware of relevant studies assessing LDVs performance in terms of THC and NMHC emissions. According to the COPERT model, overall THC emissions from LDVs decreased by 38% between Euro 5 and Euro 6d vehicles (from 88.5 to 54.5 mg/km); and by 33% for NHMC (from 69.7 to 46.9 mg/km).

Table 5-1 below summarises the evolution of emissions factors for vans and cars on the basis of available information from the COPERT model for 2020. The available data differentiate between Euro 6 pre-RDE (i.e. Euro 6 b/c) and Euro 6 RDE (Euro 6d-temp and Euro 6d).

The values provides include the most recent update of COPERT (version 5.4)[71] that also takes into account aspects such as the effect of cold-start phase, the operation under hot (engine and after-treatment system) conditions, degradation of emission control systems due to high mileage/age, as well as the impact of tampering and malfunctions not detected by OBD. Such impacts were not covered in the studies reported above. As such there are variations between the data presented in the table and the analysis above.

More detailed information is presented in Annex 3 including graphs of the emission factors' evolution for all pollutants. The COPERT model does not include data on PN emission factors.

As can be seen, in line with the literature sources presented earlier, there was significant reduction in the level of emissions between Euro 5 and Euro 6 a/b/c for most pollutant emissions, particularly NOx and exhaust particles and slightly less for other pollutants (CO, THC and NHMC). Euro 6d and Euro 6d-temp brough the emissions per vehicle down further to values closer to the actual limits (taking also into account the margin provided by the conformity factors).

Table 5-1: Summary table of emission factors' evolution for LDVs (cars and vans) in EU-28 in 2020[72]

	Emission factors (mg/km)				% change from Euro 5 vehicles		
	Euro 5	Euro 6 a/b/c	Euro 6 d-temp	Euro 6 d	Euro 6 a/b/c	Euro 6 d-temp	Euro 6 d
	CI passenger cars						
NOx	1,069.0	492.7	119.1	119.1	-54%	-89%	-89%
particles-total[73]	23.2	19.4	18.8	18.8	-17%	-19%	-19%
particles - exhaust	4.9	1.0	0.4	0.4	*-79%*	*-91%*	*-91%*
CO	74.1	51.6	51.5	51.5	-30%	-30%	-30%
THC	20.7	13.4	13.4	13.4	-35%	-35%	-35%
NHMC	2.6	1.8	1.8	1.8	-31%	-31%	-31%
	PI passenger cars						
NOx	57.8	43.5	20.6	20.5	-25%	-64%	-65%
particles - total	20.7	19.8	18.7	18.7	-5%	-10%	-10%
particles - exhaust	2.4	1.4	0.3	0.3	*-42%*	*-86%*	*-86%*
CO	2,902.2	1478.3	495.9	492.0	-49%	-83%	-83%
THC	244.3	212.4	96.4	92.3	-13%	-61%	-62%
NHMC	224.3	193.3	92.6	88.4	-14%	-59%	-61%
	CI vans						
NOx	1,541.9	1065.7	169.1	141.7	-31%	-89%	-91%
particles - total	36.3	33.0	31.9	31.9	-9%	-12%	-12%
particles - exhaust	4.9	1.6	0.4	0.4	*-68%*	*-91%*	*-91%*
CO	101.9	71.3	69.9	59.8	-30%	-31%	-41%
THC	20.7	13.4	13.4	13.4	-35%	-35%	-35%
NHMC	2.6	1.8	1.8	1.8	-31%	-32%	-31%
	PI vans						
NOx	62.6	36.0	22.2	21.0	-43%	-64%	-66%
particles - total	33.7	33.1	31.8	31.8	-2%	-6%	-6%
particles - exhaust	2.2	1.7	0.3	0.3	*-23%*	*-84%*	*-84%*

[71] https://www.emisia.com/wp-content/uploads/files/docs/COPERT_v5.4_Report.pdf

[72] Emission factors are expected to evolve over time. Detailed tables with the ranges are presented in Annex 3.

[73] particles emission factors reported include both exhaust and non-exhaust emissions.

	Emission factors (mg/km)				% change from Euro 5 vehicles		
	Euro 5	Euro 6 a/b/c	Euro 6 d-temp	Euro 6 d	Euro 6 a/b/c	Euro 6 d-temp	Euro 6 d
CO	3,549.5	1,133.0	634.2	520.5	-68%	-82%	-85%
THC	208.8	176.9	85.9	91.2	-15%	-59%	-56%
NHMC	179.4	159.5	81.9	87.5	-11%	-54%	-51%

Source: own analysis based on COPERT model (EMISIA, 2021)

The evidence suggests an overall reduction in pollutant emission is supported by stakeholders from all categories that responded to the targeted stakeholder consultation. 40 out of 61 respondents strongly agreed and 20 more partly agreed that that Euro 6 standards have led to the introduction of cleaner vehicles on the market (see Annex 9, Figure 10-1). Only 1 stakeholder from a research institution, strongly disagreed with Euro 6 leading to the introduction of cleaner vehicles in the market. Their criticism was mainly linked to the negative impact of the use of defeat devices in Euro 6 vehicles by some manufacturers. However, as indicated, the installation of RDE made it harder for a defeat strategy to be installed.

5.1.2.2.2 Euro VI for HDVs

The introduction of Euro VI standards brought changes not only to the NOx emission limits for all HDVs, but also introduced new stricter limits for THC, NHMC, CH_4 and NH_3. The available evidence on the evolution of the level of emissions between Euro V and Euro VI vehicles for each of the regulated pollutants is presented in the following sections.

NOx

A number of studies point to significant levels of improvement in terms of the level of NOx emissions from HDVs between Euro V and Euro VI vehicles.

- Laboratory testing with chassis dynamometers on eleven HDVs conducted by ICCT found a 95% decrease in real world NOx emissions per vehicle, from 4.5 g/km to 0.2 g/km (ICCT, 2016c).
- Grigoratos et al. tested five Euro VI vehicles considered typical of the European fleet in their respective categories (three tractors, a lorry and one long-distance bus). Vehicles were tested under standard operating conditions and were fitted with PEMS equipment. The cycle route and vehicles tested are intended to represent the typical fleet of Euro VI diesel HDVs and driving conditions in Europe. This study found lower NOx emission levels for all types of tested HDVs in comparison to what the literature reports for Euro V counterparts, and thus concludes that NOx emissions have decreased. However, they highlight that different aftertreatment strategies may lead to different levels of emissions reduction amongst the fleet (Grigoratos, et al., 2019).
- Emissions of refuse collection vehicles (one Euro V and seven Euro VI) were measured over actual operation cycle in Italy, through PEMS and chassis dynamometer tests. The results suggest a reduction in NOx emissions from 32.3 g/km on Euro V vehicles down to up to 10.2 g/km on Euro VI vehicles (Giechaskiel, et al., 2019)
- Ricardo's remote sensing study across the UK also identified a 58% reduction in NOx emission factors for HDVs in the weight category 3.5 to 7.5 tonnes, and a 88% reduction for the largest HDVs (>12 tonnes) (Ricardo, 2017).
- A study by HBEFA points to a reduction in NOx emissions from Euro V to Euro VI of at least the same level as the reduction in type approval limit (i.e. 80% for CI HDVs and 77% for PI HDVs). Like Grigoratos et al., the study highlights differences between EGR and SCR technologies (TU Graz, 2019).

NH3

Suarez-Bertoa et al. measured Euro VI vehicle NH3 emissions through PEMS, on a route that contains a larger percentage of urban operations compared to the rural and motorway shares (as opposed to the route prescribed in the regulation). They found that NH3 emissions were up to seven times lower than those measured in a previous study on a Euro V trucks (Mendoza-Villafuerte, et al., 2017; Suarez-Bertoa, et al., 2016).

However, according to the emission factors in COPERT, Euro VI vehicles emit 70% (buses) to 75% (trucks) more NH3 than Euro V (from 16.9 mg/km to 28.7 for buses and 11.4 to 20.2 mg/km for trucks).

PM

TNO performed PEMS measurements on a bus operating in urban conditions in Utrecht (Netherlands) and on two city routes that are representative of its typical use. They found that the PM emissions of Euro VI bus were approximately 85% lower than the Euro V EEV city bus in use with NOx emissions also 38% lower (TNO, 2014).

PN

There are no available study comparing the performance of Euro V and Euro VI vehicles in terms of PN. Qualitatively, in their test of five Euro VI buses, Grigoratos et al. (2019) concluded that PN emissions are not a concern and remain well below the emission standard's limit.

CO

Similar to PN, CO emissions were reported to be at low levels and below the emission standard's limit (Grigoratos, et al., 2019) although there were no specific data available. Available emission factors from COPERT model indicate a significant drop in HDV's CO emissions, from 2712.2 to 390.1 mg/km (86% reduction).[74]

THC

Similar to PN and CO, THC emissions are generally at low levels and below the emission standard's limit (Grigoratos, et al., 2019). Emission factors from COPERT model indicate a reduction in HDV's THC emissions of 30%, from 60.1 to 42.0 mg/km.

NMHC

We have not identified any relevant information in the literature concerning NHMC emissions. Emission factors from COPERT model indicate a reduction in HDV's NMHC emissions of 30%, from 59.0 to 41.2 mg/km.

CH4

There was no evidence identified in the literature in the case of methane (CH_4). CH4 emissions are generally not expected from CI engines, which make up almost the entirety of the HDV fleet. However, according to the emission factors in COPERT HDV's CH4 emissions decreased by 27% from Euro V to Euro VI from 1.1 to 0.8 mg/km.[75]

In Table 5-2 we present the evolution of emission factors for Euro V and Euro Vi vehicles for 2020 based on data from the COPERT model (v.5.4). The emission factors presented in the table cover aspects not covered in studies presented above, as in the case of Euro 6 for LDVs.

Detailed graphs of the emission factors' evolution for all pollutants are provided in Annex 3.

It points to important reductions in the HDVs' emission factors on all pollutants (trucks and buses) except NH3 whether the available data suggest an increase of emissions.

Table 5-2: Summary table of emission factors' evolution for HDVs (buses and trucks) in EU-28 in 2020

	Emission factors (mg/km)		% change from Euro V vehicles
	Euro V	Euro VI	
	Diesel buses		
NOx	16188.2	4602.8	*-72%*
particles total[76]	161.8	136.8	*-15%*
particles exhaust	101.9	76.9	*-25%*
NH3	16.9	28.7	*+70%*
CO	4538.7	630.5	*-86%*
THC	95.7	67.0	*-30%*
NMHC	94.0	65.6	*-30%*
CH4	1.7	1.4	*-21%*
PN[77]	n.d.	n.d.	
	Diesel trucks		
NOx	7894.4	2282.0	*-71%*
particles - total	116.1	103.7	*-11%*
particles - exhaust	58.8	42.4	*-28%*

[74] Although CO limits have not changed, reductions in CO emissions can be explained by the introduction of Diesel Particulate Filters (DPF).

[75] This slight increase is caused by CNG EEV buses.

[76] particles total emission factors reported include both exhaust and non-exhaust emissions.

[77] COPERT model does not include data on emission factors for PN.

	Emission factors (mg/km)		% change from Euro V vehicles
	Euro V	Euro VI	
NH3	11.5	20.2	*75%*
CO	2451.3	363.6	*-85%*
THC	55.0	39.2	*-29%*
NMHC	54.0	38.5	*-29%*
CH4	1.0	0.8	*-26%*
PN	n.d.	n.d.	

Source: own analysis based on COPERT model (EMISIA, 2020)

Similar to LDVs, the large majority of respondents to the targeted stakeholder consultation agreed or strongly agreed that Euro VI standards have led to the introduction of cleaner vehicles on the market (see Annex 9, Figure 10-2). 30 out of 47 respondents strongly agreed that Euro VI led to cleaner HDVs on the market and 16 out of 47 partly agreed.

Amongst the stakeholders that partly agree, most (such as an EU environmental NGO and a type-approval authority) point to outstandingly high emissions in some driving conditions that are not accounted for in the tests, as well as the exclusion of some key pollutants from the regulation.

5.1.2.3 *Are vehicles on the EU roads cleaner?*

The extent to which cleaner vehicles on EU roads has (or is expected to) become a reality is a function of (1) the individual performance of newly registered Euro 6/VI vehicles but also (2) the rate at which the cleaner Euro 6d vehicles enter the market (i.e. rate of renewal as new registrations as share of total vehicle fleet).

The analysis of market trends presented in Section 3.5 points to increasing registration but still limited market shares for Euro 6/VI vehicles:

- In the Netherlands, the first Euro 6 RDE vehicles entered the fleet in 2017 with a significant increase to the total share by 2019 (over 80% of new cars registrations)
- In Germany, a total of 3,044,338 Euro 6d-Temp passenger cars and 92,560 Euro 6d new passenger cars were registered by 2019 (86% of total registrations of that period)
- In the case of HDVs**,** data from Germany on vehicle registrations and stock of vehicles for the period 2013-2018 shows a fast increase in the share of newer Euro VI vehicles since 2017, reaching 17.3% at the end of 2018.
- However, new registrations are not translating into a renewal of the vehicle fleet. For instance, the evolution of passenger car fleet by fuel and emission standard in Germany indicates that only 1.7% of the passenger car fleet was Euro 6-RDE in 2019, and 27% was Euro 6.

Hence, while Euro 6/VI standards have succeeded in progressively making type-approved vehicles cleaner, its actual contribution to making "cleaner vehicles on EU roads a reality" has not yet been realised. The newly registered vehicles do not yet represent the majority of the fleet in use. Other factors potentially contributing to the introduction of cleaner vehicles are discussed in Sections 5.1.4.2 and 5.1.4.3.

Text box 5-1: Discussions over the representativeness of the available evidence for the EU-27

The evidence provided in Sections 5.1.2.2 and 5.1.2.3 needs careful consideration in light of the differences in Member State's fleet.

The evidence provided above is mainly based on vehicles representative of Western European fleet, and do not account for differences in driving conditions across EU Member States. Where studies were representative of the average European fleet, this has been clearly identified in line with the evidence.

We note that, based on data on renewal rates for the period 2009- 2018 from Eurostat (road_eqr_carmot) and (road_eqs_carmot), Germany and the Netherland's respective rate of fleet renewal is close to the EU average. With 5.3% renewal rates for the period 2012-2019, Netherlands has been below the EU average of 5.8%. Germany's renewal rate has been higher than the EU average (7.1% for the 2012-2019)

Significant delays in the replacement of older more polluting vehicles are reported in Eastern and Central Europe[78] particularly due to the importance of second-hand market:

- ACEA 2018 report on vehicle use in Europe (ACEA, 2018) also indicates that vehicles in Eastern and Central Europe are older than in other EU countries (median age of PC in Eastern European countries was 14.4 years in 2018, in comparison to 9.3 years in non-Eastern European countries, based on the average

[78] Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic and Slovenia.

vehicle age in years per country)[79]. In 2018, 95% of passenger cars in Eastern EU countries were registered before 2015, against 82% in all other EU countries; and 69% were registered pre-2007, against 42% in all other EU countries (*ibid*). Roughly the same proportions were calculated for HDVs.

- In 2018, only 6% of the total passenger cars fleet in Eastern and Central Europe[80] was less that 2 years old, in comparison to 13% in other countries. 6% was between 2 and 5 years old in comparison to 17% in other countries. In contrast, 29% of the passenger cars fleet in Easter and Central Europe was above 20 years old, while these older vehicles only represent 6% of other countries' passenger cars fleet (Eurostat (2020) *ROAD_EQS_CARAGE Passenger cars, by age*).
- According to the input from one EU NGO, the share of older HDVs in the fleet in these Member States is higher than in other European regions.

Hence, at the level of individual Member States, it is expected that the share of cleaner Euro 6d/VI vehicles will remain smaller for some time, and so the reduction in total emissions on EU road will be delayed in some regions.

5.1.2.4 *What was the impact of Euro 6/VI on the total level of emissions?*

The overall impact on the level of total pollutant emissions from Euro 6/VI is a combination of the evolution in the performance of vehicles and their share in the market, two aspects analysed above.

We have analysed the available data with the use of the COPERT and SIBYL models to quantify the expected level of the total emissions from vehicles over time and the emissions savings achieved. The model accounts for improvement in vehicles' performance as well as fleet composition. The main results are presented in Table 5-3 (total for all LDVs) and Table 5-4 (separately for CI and PI vehicles) for all regulated pollutants compared to the baseline. Furthermore, the comparison of total savings from Euro 6 (incl. RDE) to Euro 5 and of Euro 6 RDE to pre-Euro 6 RDE enables to identify the share of savings achieved by introducing RDE testing. Detailed presentation including graphs presenting the emissions and emission savings per pollutant up to 2050 are available in Annex 3.

As can be seen, in the absence of Euro 6 (Euro 5 baseline), an additional 0.45 Mt of NOx would have been emitted in 2020 only (i.e. saving of 36.7%), and 1.68 Mt in total between 2014 and 2020. This is higher than the 24% reduction in overall NOx emissions in 2020 expected by the IA study supporting the adoption of the Euro 5 and 6 standards as a result of Euro 6 (European Commission, 2005a). However, we note that the support study examined a scenario with a lower limit of 75 mg/km in comparison to the 80 g/km eventually adopted. Furthermore, the results in Table 5-4 points out that most of the savings achieved in terms of NOx are due to reduction of emission from CI vehicles.

Table 5-3: Summary table of expected net impact of Euro 6 on total emissions from LDV's (cars and vans) in EU-28 in Mt in comparison to the baseline - Comparison to IA support study estimates for 2020

	Euro 6 RDE to Euro 6 pre-RDE			Euro 6 (total) to Euro 5			IA support study estimate (expected change in 2020)
	2014-2020	In 2020	2021-2050	2014-2020	In 2020	2021-2050	
NOx (absolute)	0.12	0.08	17.94	1.68	0.45	44.19	
% change	1.8%	7.8%	56.1%	21.8%	36.7%	78.1%	*24%*
particles total (absolute)[81]	0.00	0.00	0.05	0.01	0.00	0.25	
% change	0.1%	0.4%	2.3%	6.4%	10.0%	17.0%	*0%*
particles exhaust	0.00	0.00	0.05	0.01	0.00	0.25	*n.a.*
% change	1.4%	6.5%	46.4%	28.0%	45.1%	81.3%	
CO (absolute)	0.27	0.15	14.70	2.78	0.82	60.81	
% change	0.0%	0.0%	12.1%	11.5%	17.7%	14.3%	*n.a.*
THC (absolute)	0.03	0.02	2.46	0.06	0.03	2.58	
% change	0.0%	0.0%	15.6%	13.3%	20.5%	13.9%	*n.a.*
NHMC	0.03	0.02	1.94	0.04	0.02	2.06	
% change	0.0%	0.0%	12.8%	11.9%	18.2%	14.3%	*n.a.*

[79] Data provided for all EU countries except Bulgaria and excluding the United Kingdom.

[80] Data provided for all EU countries except Slovakia, Bulgaria and Greece and excluding the United Kingdom.

[81] "particles total" includes exhaust and non-exhaust emissions. "Exhaust emissions" are "particles emitted as a result of incomplete fuel combustion and lubricant volatilization during the combustion procedure". "Non-exhaust emissions" are "either generated from non-exhaust traffic related sources such as brake, tyre, clutch and road surface wear or already exist in the environment as deposited material and become resuspended due to traffic induced turbulence." (GRIGORATOS & MARTINI , 2014)

Source: own analysis based on COPERT/SIBLY model (EMISIA, 2021)

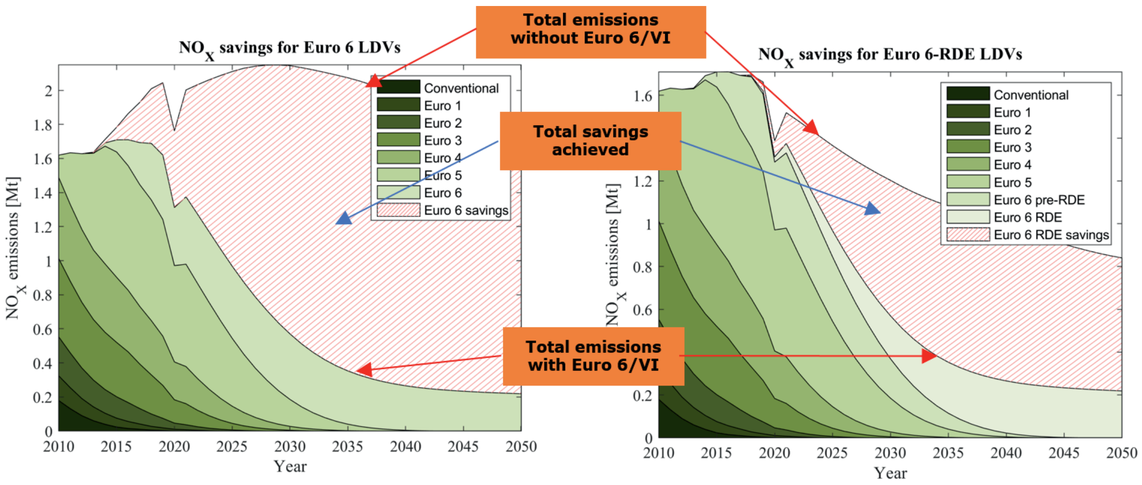
Table 5-4: Summary table Euro 6 net impact on emissions from CI and PI light duty vehicles' (cars and vans)

	Euro 6 RDE to Euro 6 pre-RDE			Euro 6 (total) to Euro 5		
	2014-2020	In 2020	2021-2050	2014-2020	In 2020	2021-2050
	CI LDVs					
NOx (absolute)	0.12	0.07	17.50	1.65	0.44	43.30
% change	1.7%	7.6%	57.4%	19.6%	33.4%	76.9%
particles total	0.00	0.00	0.03	0.01	0.00	0.20
% change	0.1%	0.4%	2.2%	5.6%	8.8%	15.0%
particles exhaust	0.00	0.00	0.03	0.01	0.00	0.20
% change	0.7%	3.4%	37.9%	29.5%	46.6%	82.8%
THC	0.00	0.00	0.16	0.02	0.00	0.14
% change	0.0%	0.0%	15.2%	13.2%	20.4%	13.7%
CO	0.00	0.00	0.43	0.07	0.02	0.54
% change	0.0%	0.0%	11.5%	11.3%	17.6%	14.1%
	PI LDVs					
NOx (absolute)	0.0	0.0	0.4	0.0	0.0	0.9
% change	3.4%	11.6%	37.0%	14.1%	26.6%	54.6%
particles total	0.0	0.0	0.0	0.0	0.0	0.1
% change	0.40%	1.28%	4.15%	2.54%	4.47%	8.14%
particles exhaust	0.00	0.00	0.02	0.00	0.00	0.05
% change	4.20%	15.26%	60.47%	22.38%	39.42%	75.81%
THC	0.0	0.0	2.3	0.0	0.0	2.4
% change	4.4%	13.5%	37.2%	5.0%	14.3%	38.6%
CO	0.3	0.2	14.3	2.7	0.8	60.3
% change	3.2%	11.9%	39.2%	24.8%	41.9%	73.1%
NMHC	0.0	0.0	1.9	0.0	0.0	2.0
% change	4.20%	12.87%	34.41%	4.73%	13.54%	35.74%

Source: own analysis based on COPERT model (EMISIA, 2021) and (European Commission, 2005a)

As foreseen in the IA support study, emission reductions will continue to increase as more polluting vehicles are removed from the vehicle fleet and the share of Euro 6 vehicles increases (European Commission, 2005a). Figure 5-2 illustrates this trend, pointing to a total cumulative reduction in NOx emissions 44.19 Mt of NOx by 2050, a total level of reduction of 78.1%. As shown when comparing these two charts, most of the NOx savings of Euro 6 are accrued by RDE.

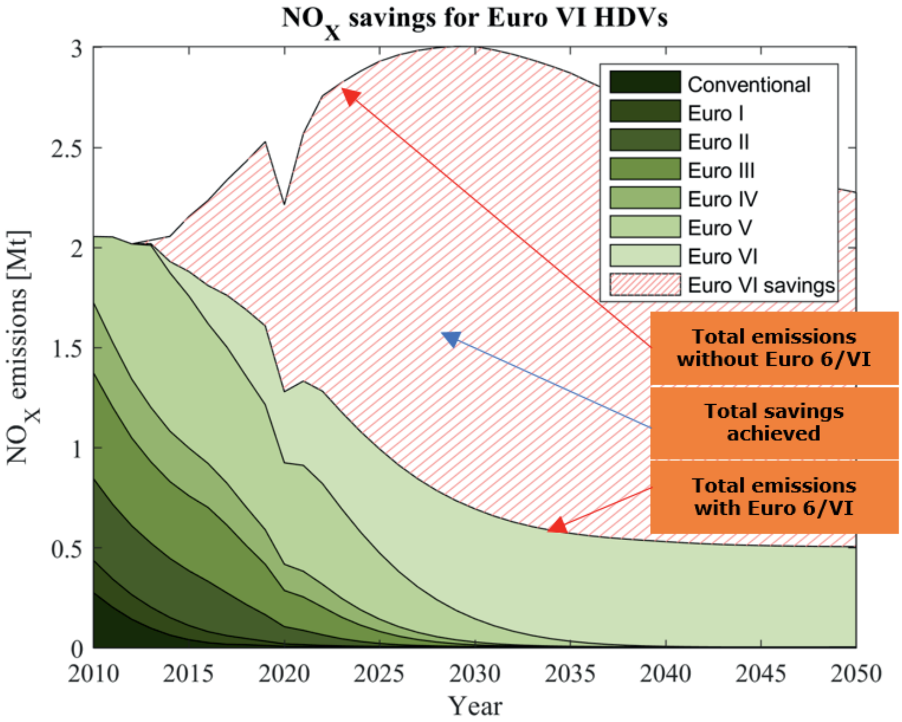
Figure 5-2: NOx savings in EU-28 for Euro 6 LDVs (cars and vans)



Source: Own analysis based on COPERT model (EMISIA, 2021)

For HDVs, the analysis indicates 60.6 Mt of expected savings in NOx emissions for the whole period up to 2050, as illustrated in Figure 5-3 below. In 2020, expected savings are estimated at around 0.9Mt of NOx. This represents a 52% change from the baseline, higher that the level estimated in the Euro VI IA support study for 2020 (European Commission, 2007). In the case of total particles emissions, the level of change achieved in 2020 (11.8%) is lower than the level expected in the IA (22%).

Figure 5-3: NOx savings in EU-28 for Euro VI HDVs (lorries and buses)



Source: Own analysis based on COPERT model (EMISIA, 2021)

Table 5-5: Summary table of Euro VI net impact on total level of emissions from HDV's (lorries and buses) in EU-28 in Mt - Comparison to the IA support study estimates

	Euro VI to Euro V			IA support study estimate (expected change in 2020)
	2013- 2020	2020	2021-2050	
NOx (in MT)	4.0	0.9	60.5	
% change	35.7%	52.0%	76.4%	37%
particles total (in MT)	0.0	0.0	0.3	
% change	7.0%	11.8%	27.7%	22%
particles exhaust (in MT)	0.0	0.0	0.3	
% change	13.5%	22.6%	52.5%	
CO (absolute)	1.5	0.3	21.7	
% change	43.1%	61.9%	90.0%	n.a.
NH3 (absolute)	0.0	0.0	-0.1	
% change	-30.4%	-45.7%	-81.4%	n.a.
THC (absolute)	0.0	0.0	0.3	
% change	14.0%	23.4%	50.5%	n.a.
CH4	0.0	0.0	0.0	
% change	12.4%	20.5%	47.1%	n.a.

Source: own analysis based on COPERT model (EMISIA, 2021) and (European Commission, 2007)

Overall, the savings from Euro 6/VI indicated above amount to 5.68 Mt of NOx saved between 2014 and 2020, for which HDVs contributed to 70%.

The above conclusions are also supported by the responses provided by stakeholders in the context of the public consultation. The large majority of respondents from all stakeholder groups (128 out of 168) indicated that, based on their experience, air pollution originating from new cars and vans has decreased. 76 of them considered that these reductions were "significant". Similarly, 121 out of 195 indicated that, based on their experience, air pollution from *new* lorries and buses has decreased. 79 of the considered that these reductions were "significant".

5.1.2.5 *Conclusion*

In identifying the "extent to which Euro 6/VI has made cleaner vehicles on the road a reality", we have analysed the difference in regulated pollutants emissions between Euro 5/V certified and Euro 6/VI certified cars, vans, trucks and buses. We then discussed the composition of the fleet and rate of replacements and conclude on Euro 6/VI effectiveness to curb road emissions overall in EU-28.

Euro 6/VI has had a positive impact towards making vehicles cleaner by reducing the levels of pollutants emitted per vehicle (including cars, vans, buses and trucks) for a number of regulated pollutants. This was shown through relevant on-road tests and is reflected in the emission factors. More specifically, in the case of light-duty vehicles, the most recent Euro 6d CI vehicles achieve a level of reduction in NOx emissions of around 89% in comparison to Euro 5, and 19% for PM. Earlier Euro 6 vehicles (Euro 6b/c) had already achieved a sizeable reduction of NOx emissions of 54% according to the emissions factors data from COPERT although the emissions were still significantly higher than the limits. In the case of Euro 6d PI LDVs, the level of reduction achieved are smaller for NOx (65%) and PM (10%). For HDVs, the available emission factors suggest a level of reduction in NOx emissions of around 72% in comparison to the Euro V vehicles. In the case of PM, 12% reduction was achieved.

However, while the analysis points to significant reductions to the level of emissions per vehicle, the benefits of cleaner vehicles are not yet felt on EU roads, as less than half of the fleet is currently Euro 6 or Euro VI-E type-approved (20% for LDVs and 34% for HDVs). An even smaller share of the fleet represents the significantly cleaner Euro 6 RDE vehicles.

Our analysis suggests that, given the emissions reductions per vehicle and the fleet composition, the implementation of Euro 6 has contributed to net savings of NOx emissions for LDVs of around 0.45 Mt in 2020 (36.7% reduction in comparison to the baseline) and smaller savings of PM (10% reduction in comparison to the baseline). Euro VI is expected to have contributed to net savings of NOx emissions from HDVs by 0.9 Mt (52% reduction in comparison to the baseline) and 0.01 Mt of PM (11.8% reduction in comparison to the baseline).

In terms of other regulated pollutants, the available data for LDVs point to a net reduction of both CO and THC, 17.7% less for CO and 20.5% less THC in 2020 than would have been if Euro 6 had not come into force. For PI LDVs, 13.5% less NHMC was emitted. For HDVs, CO has reduced by 61.9%, , CH4 by 20.5% and THC by 23.4%. However, NH3 increased by 45.7%. Similar data are not available in relation to PN emissions but the literature reports large reductions in PN for LDVs since the tightening of the standards and the introduction of GPFs in PI vehicles.

The above conclusion focuses on the analysis of the standards' effectiveness within their operative boundaries (i.e. it is limited to the regulated pollutants, the mandated approved type-approval procedure and testing cycles). The following sections discuss the effectiveness of the regulation beyond these boundaries, including the effectiveness of the testing procedures themselves and unintended positive or negative impacts of the standard, as well as the emission levels of non-regulated pollutants (such as NH3, discussed in Section 5.1.6.2.3).

5.1.3. EQ2 How effective are the existing testing procedures to verify the emission standards?

5.1.3.1 *Introduction*

The analysis in EQ1 (Section 5.1.2) has already pointed to the important changes to the level of real-world emissions observed over time that was triggered by the changes to the testing procedures. In the case of LDVs this included the move to the WLTP laboratory test procedure and, more importantly, the introduction of RDE procedure. For HDV this included a shift from ESC & ELR (European Stationary Cycle to European Load Response) to WHTC/WHSC (World Harmonized Transient Cycle/World Harmonized Stationary Cycle) test cycles with in-service conformity testing.

In this section, we assess the effectiveness of the testing procedures in verifying the emission standards. More specifically, we examine the effectiveness of the new test procedures in terms of:

- Reducing the gap between real-world emissions and type-approval emissions.
- Increasing reliability of testing procedures in the measurements of the vehicle's emissions, and in the verification of the level of emissions in comparison to the emissions limits.

5.1.3.2 *What has been the impact of the changes to the testing procedures in terms of reducing the gap between real emissions and type approval emissions?*

5.1.3.2.1 Changes to the testing procedures for LDVs (cars and vans)

In the case of LDVs, there was a significant level of deviation between real-world and type-approval emission prior to the changes to the testing procedures. This was clearly documented in a number of studies that measured real world emissions for the Euro 6 vehicle type-approved before the introduction of RDE-testing process:

- On the basis of dynamometer tests, a study of 73 Euro 6 CI cars with various NOx treatment systems found that emission levels measured exceeded the emission limit by roughly five times (Hooftmman, et al., 2018).
- JRC tested 15 vehicles (including 13 Euro 6b) on a chassis dynamometer. To ensure a fair coverage, the vehicles were selected based on sales numbers, manufacturers, powertrain technologies and vehicle segments (JRC, 2018). The analysis showed that:
- In the case of NOx emissions, Euro 6b CI vehicles (8 vehicles tested, excluding LCVs) emit on average up to 297% higher than the emission standard limit, while Euro 6b PI vehicles with GDI (3 vehicles tested) emit up to 30% more[82].
- In the case of CO, Euro 6b diesel vehicles (8 vehicles tested, excluding LCVs) are within their emission standard's limit (80mg/km) on average, while Euro 6b PI vehicles without GDI (2 vehicles tested) emit up to 40% more than their respective limit (60mg/km).
- A separate study using PEMS measured NO_x emissions on n 149 Euro 5 and 6 diesel, gasoline and hybrid passenger cars. Results for the 39 diesel Euro 6 vehicles tested show that their NO_x emissions in urban areas are up to 450% higher than the emission limits (O'Driscoll , et al., 2018)
- As part of the TRUE Initiative, remote sensing emissions data for each Euro-vehicle family were collected in France, Spain, Sweden, Switzerland and the UK between 2011 to 2017 through the CONOX project (700,000 records). The analysis of the data concluded that for Euro 6 PI vehicles, the worst performing manufacturers were within 1.5 times the Euro 6 type-approval limit. In the case of CI vehicles, the best performing manufacturer emitted more than twice the type approval limit, with all other groups emitting 4 to 12 times more depending of the manufacturer (Bernard, et al., 2018).

No evidence was identified of significant deviation between real-world and type-approval emission of THC and NMHC.

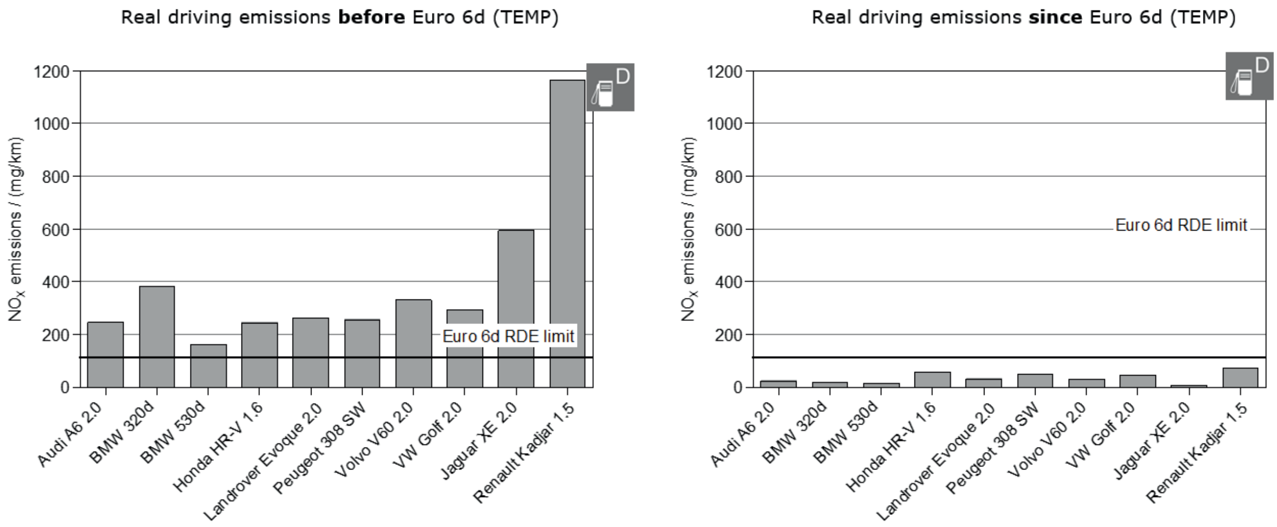
In comparison to Euro 6 vehicle type-approved before the introduction of RDE-testing, available evidence also suggests a clear reduction in the level of deviation from the type-approval emission limits in the case of Euro 6c vehicles (using the WLTP) but much more with the introduction of Euro 6d-Temp. The JRC tested 20 vehicles in 2018, including four Euro 6d-Temp, two Euro 6c and 13 Euro 6b (JRC, 2019a). For comparability, they use the same methodology as in the JRC study mentioned above. Their results are summarised below:

- For NOx: Euro 6d-Temp diesel vehicles (3 vehicles tested) and gasoline (1) were below the emission standard limit of 80mg/km and 60mg/km on the full RDE compliant test. Another test covering a wider range of conditions (altitude and temperature ranges outside RDE boundaries) revealed that three vehicles had a maximum emission value above the emission limit, but emission factors remained within 25% of the recommended threshold. The Euro 6c diesel vehicle tested was also below the limit, though with 3mg/km more emitted than the Euro 6d-Temp gasoline vehicle.
- For CO: Euro 6d-Temp diesel vehicles (3 vehicles tested) were also well below the emission standard limit, emitting up to 98% less that the maximum amount allowed. Similar to NOx, the Euro 6c diesel vehicle tested was also below the limit, though with 3mg/km more emitted. No Euro 6c nor d-TEMP gasoline vehicles' emissions were measured as being above the limit.

The results collected through the CLOVE consortium effectiveness study (Part A) comparing real-driving emission of vehicles (based on PEMS measurement data) before and after the introduction of RDE also confirm the findings of the studies mentioned earlier and point to significant changes to the level of NOx (Figure 5-4) and PN (Figure 5-5) across a range of model from different manufacturers (CLOVE , 2020).

[82] The diesel limit (80mg/km) is higher than the gasoline NOX limit (60 mg/km)

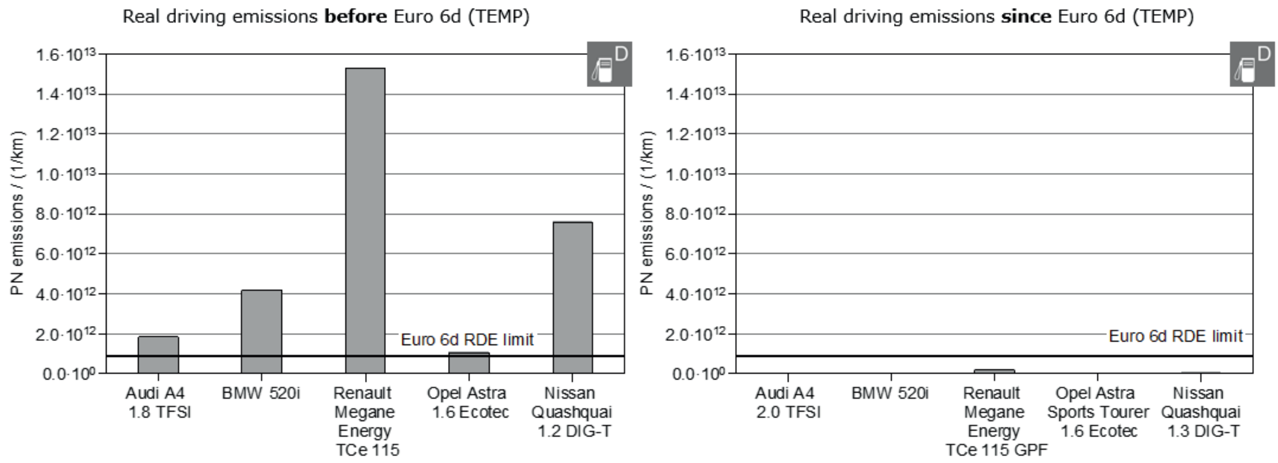
Figure 5-4: NOx emissions on a sample of vehicles before and after Euro 6d-Temp



Source: Bundesministerium für Verkehr und digitale Infrastruktur, 2016. Bericht der Untersuchungskommission „Volkswagen“
and https://www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data, https://group.renault.com/en/rde-2/, https://erwin.audi.com/erwin/performRdeSearch.do

Source: CLOVE (2020)

Figure 5-5: PN emissions on a sample of vehicles before and after Euro 6d-



Source : http://www.duh.de/uploads/media/Hintergrundpapier_GDI-Pressegespraech.pdf
and https://www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data, https://group.renault.com/en/rde-2/, https://erwin.audi.com/erwin/performRdeSearch.do,
https://www.nissanrde.eu//,

Source: CLOVE (2020)

The above quantitative analysis is also supported by the majority of stakeholders that responded to the targeted stakeholder consultation. Overall, 50 out of 61 respondents strongly agreed that the introduction of RDE test procedures reduced the gap between type-approval and real-world pollutant emissions. Only one stakeholder from the academia and research sector strongly disagreed but they still recognised that that RDE “made a positive impact on finding out if defeat strategy in relation to NOx is in use”. Among those that only partly agreed, the representative of an EU local transport NGO highlighted that RDE tests are an improvement but that they still do not consider the full extent of urban driving reality while an EU health NGO considered that the introduction of conformity factors has limited the effectiveness of RDE. Both statements were also supported by a technical service organisation and a testing equipment supplier.

There was more scepticism among stakeholders concerning the role of WLTP, even though the majority (42 out of 61) still agreed that it has been effective in reducing the gap between type-approval and real-world pollutant emissions. However, 13 out of 61 respondents partly or strongly disagreed. In their comments, representatives from OEMs, civil society, authorities and civil society mainly pointed to WLTP’s positive role in measuring CO_2 emissions. An EU environmental NGO provided further explanation, highlighting that WLTP only tests vehicles on a limited range of engine conditions and that opportunities to use “auxiliary emission strategies” remain. Among other NGOs, an EU environmental NGO and an international transport research organisation stated that, if implemented alone without RDE testing, WLTP would have likely only led to limited improvements in emissions performance as the manufacturer’s target improvements at the load/speed region of the test while retaining poor emissions performance outside of these regions.

Evaporative emissions testing

The adoption of Regulation 2017/1151 as amended by 2017/1221 brought changes to the testing procedures used to measure evaporative emissions with a combination of the one-hour hot soak test at constant temperature, followed by a 48-hour diurnal test at a specified temperature profile (20–35°C). As these were only recently adopted, there is no evidence available of the level of impact, although they are expected to have a positive impact considering the expected introduction of (1) larger canisters, a more effective purge valve and (2) relevant OBD sensors by OEMs to meet the new limits.

However, a number of reports (ICCT, 2019c) (CLOVE, 2020) and input from industry stakeholders (including one EU equipment association, one supplier and ICCT) suggest that the EU requirements are less demanding both in terms of the limit values and the duration of the test when compared against those adopted in the US and China[83]. As a result, according a report by MECA (MECA, 2020), canisters in Euro 6d vehicles have capacity of up to 46% less than those in the US. Furthermore, due to the more demanding 72-hour diurnal test and the use of onboard refuelling vapor recovery systems to meet refuelling requirements (not applicable in Europe) purge rates on US and China vehicles are 50-65% higher than Euro 6d vehicles. According to one supplier, there are significant differences in the level of evaporative control technology used for the same models in the US and European market which are a result of the much less stringent requirements. This is a clear example of the fact that the industry will only implement better technologies only if required by the Regulation.

All in all, while the changes to the evaporative emissions standards can be expected to lead to reduction the evaporative emissions from PI engines, it is also the case that they have been less demanding that those adopted in other markets. As such, it can be expected that the level of emission reductions achieved is lower that what would have been possible.

5.1.3.2.2 Changes to the testing procedures for HDVs (lorries and buses)

In the case of HDVs, the move from ESC/ELR testing to WHTC/WHSC was simultaneous to the introduction of new Euro VI emission limits. Before then, gaps were identified between Euro V real-world vehicle emissions and their emission standard limit, though not in all conditions:

- In the Netherlands, TNO tested 12 HDVs on different trips (urban, rural and motorway) using PEMS. Results show some Euro V lorries emit above their respective NOx emission limit of 2 g/km: up 100 times more at lowest speed (10km/h) and twice more at 50km/h. Emissions at higher vehicle speed (above 50km/h) are below emissions limit for the most part, unless vehicles have a higher payloads (TNO, 2010).
- Through chassis dynamometer testing, the ICCT reports data from a test centre in Finland on 38 HDVs, including 25 Euro V vehicles. Euro V vehicles were reported to emit up to five times their NOx emission limit, with the majority emitting between 2 and 4 times more (ICCT, 2015a).
- Both tests were performed over several cycles, including urban driving, truck delivery cycles, truck motorways and highway cycles. This broad array of cycles suggests that these findings are applicable across other Member States where similar driving conditions exist. No evidence was identified for significant deviation between real world and type approval emission of THC and NMHC.

Only a limited set of HDVs emission data under real-world road condition is publicly available that would allow to compare gaps in emission between Euro V and Euro VI. This is a known gap in the literature, highlighted by Grigoratos et al. (2019) who point to limited data published after the introduction of Euro VI regarding HDV's real-world emissions. Findings from the literature are summarised below:

- A Ricardo analysis of HDV measured over "real-world cycles" (either measured on the road through PEMS, or on a chassis dynamometer) showed that Euro VI HDV's regulated pollutants emissions are broadly under the limit, except under very congested driving conditions, when the technology used (SCR aftertreatment) was not able to maintain an effective temperature for NOx conversion (Ricardo, 2018).
- Grigoratos et al. (2019) highlight that one out of five Euro VI HDV tested on-road through PEMS exceeds NOx emission limit by a factor of 1.7. However, when the same vehicle is tested under higher speed conditions, emission levels fall within the limit. All other pollutants' measurements show compliance with Euro VI emission limits.
- Similar findings were reported on a study of 25 Euro-VI vehicles of different categories under different driving conditions in the Netherlands conducted by TNO. The study highlighted that NOx emission under low-speed conditions such as during urban driving and heavy traffic are not yet well accounted for and may lead to more emissions (TNO, 2016).
- TNO also analysed PEMS based data from a sample of busses representing 64% of the Euro VI engine types used in public transports in the Netherlands. For three out of seven situations tested, the average NOx emissions were above the Euro VI limit,

[83] The US Tier 3 limit includes a high temperature (32C-38C) hot-soak and 72 hours diurnal test with a maximum limit of 0.3g/test and 0.6 g/test for low and high altitude. It has also running losses and refuelling emissions limits. The China 6 standard has 0.7 g/test for 48 hours and mandates higher conditioning temperature (38C) prior to the test (ICCT, 2019c).

pointing to ongoing difference between real-word and type-approval emissions (TNO, 2018).

The studies mentioned above identified outstanding gaps in NOx emissions in low-speed driving conditions and for idle vehicles with low loads, which was already highlighted in Euro V vehicles. TNO (2016) and Grigoratos (2019) considered that improvements in the in-service conformity testing requirements could resolve this gap. In particular, lowering the power threshold is suggested, so that stricter control is performed on emissions under urban driving conditions.

This has also been echoed by stakeholders during the targeted stakeholder consultation, who highlight the particular impact of this gap on air pollution in cities, as buses used in urban areas are mainly driven at low loads, low speed and with large idle time (ICCT, 2020, TNO, 2020). In response, since 2018 PEMS data analysis for In-Service Conformity tests has been modified, including a lowering of the minimum power threshold from 20 to 10% to better account for low load and urban operation (European Commission, 2016).

Aside from this point, stakeholders broadly agree on the effectiveness on new testing procedures on HDVs since the introduction of Euro VI. 44 out of 45 agreed that the introduction of on-road testing procedures (i.e. in-service conformity testing) has reduced the gap between type-approval and real-world pollutant emissions. Among the 23 stakeholders who only partly agreed, an EU local transport NGO, an international transport research organisation, an EU environmental NGO, a type-approval authority and an EU automotive parts suppliers' association also refer to outstanding driving conditions that are not captured although they are common in urban areas (such as idle, load operations and lower speeds and cold-start). Other stakeholders, such as an automotive parts supplier and an EU vehicle testing suppliers' association, highlight insufficient effort against tampering and defeat practices, with outstanding tampering behaviours not addressed by on-road testing with PEMS such as the manipulation of AdBlue systems.

As in the case of LDVs, the picture is a bit more mixed concerning the effectiveness of laboratory test cycles such as WHTC and WHSC. Although 38 out of 44 respondents agree that the introduction of those tests have reduced the gap between type-approval and real-world emissions, 6 stakeholders do not share this opinion. Their opinion can be summarised by an international transport research organisation's claim, according to which a change in laboratory testing procedure such as this one was necessary but was not sufficient to ensure full coverage of the engine and aftertreatment calibration in a wide range of conditions.

5.1.3.3 *Have the testing procedures increased reliability in terms of the measurement of the vehicles' emissions and verification of the level of emissions in comparison to the emissions limits?*

In this section we assess the contribution of the testing procedures[84] towards increased reliability considering three criteria:

- The degree that they represent actual real-world driving *cycles;*
- The degree that they represent actual real-world vehicle driving *conditions* throughout a vehicle's entire lifetime on EU roads and in all conditions of use*;*
- The level of margin that manufacturers have to optimise their vehicles and software specifically during the test to improve results.

These criteria have been identified in the literature as the main explanations for differences in the emission levels (Weller, et al., 2019). For each criterion, we identify the improvements of a given testing cycle in comparison to the previous one.

5.1.3.3.1 Testing procedures for LDVs (cars and vans)

With the approval of the last RDE regulation package, the reliability of testing procedures for LDVs has significantly improved in relation to a number of criteria as summarised below:

- Driving cycle – NEDC only covered a limited portion of all possible real-world cycles, using a single 11km driving cycle only. WTLP (tested through the WLTC driving cycle) extended the test to a 23 km route, but still only covered a limited subset of all possible route conditions that could be encountered in real-life. This was improved through the introduction of RDE, requiring urban, rural and motorway driving (Bodisco & Zare, 2019) (Tsiakmakis, et al., 2017) (CLOVE, 2020) (ICCT, 2017b)
- Driving conditions – NEDC testing was limited to low dynamic driving conditions, including high shares in idling time, short high-speed phases and low acceleration. This was significantly improved through WTLP, which included 43.8% acceleration, 39.9 % deceleration and only 3.7% constant driving, (as opposed to 40.3% constant driving during NEDC). Further parameters were then included in the RDE regulation in

[84] Detailed description of the different features of each testing procedures have been presented in Section 3.2.

the form of "boundary conditions" that account for differences in ambient temperature, altitude difference. In its latest package (RDE 4th package), the regulation further expands the representativeness of driving conditions tested by including surveillance of the in-use vehicle fleet by type approval authorities and other accredited independent laboratories (CLOVE, 2020) (ICCT, 2017a) (ICCT, 2017b).

- Robustness against optimisation/defeat strategies – Both the NEDC and the WLTP tests included a fixed set of testing conditions, making the testing cycle repeatable and reproducible and hence allowing manufacturers to optimise vehicles' engine prior to testing. The WLTC cycle still follows a pre-defined vehicle speed profile which allows OEMs to design systems specifically for these test conditions and specifically trained vehicle control strategies. In its latest package, RDE testing is extended to ISC requirements and, with Regulation (EU) 2018/858, also includes market surveillance. The available choice of software options has also been reduced to one software that needs to be reported to the TAAs, and TAAs are now responsible for in-service conformity checks instead of relying on technical reporting by manufacturers (ICCT, 2018a) (ICCT, 2017a) (ICCT, 2017b) (CLOVE, 2020).

Table 5-6 below summarises the conclusions of the analysis pointing to great improvements to the robustness of the procedures against optimisation/defeat strategies, and slight improvements in the representativeness of driving cycle and driving conditions during the test.

Table 5-6: Summary table of the evolution of the reliability of testing procedures for LDVs against relevant criteria

	Lab based only - NEDC	Lab based only - WLTP	RDE + WLTP
Driving cycle	✗✗	✗	✓
Vehicle driving conditions	✗✗	✓	✓✓
Robustness against optimisation/defeat strategies	✗✗	✗	✓✓✓
✓✓✓ : A complete or close to complete coverage of driving cycle and driving conditions / a very low to null margin for optimisation ✓✓ : A good coverage of driving cycle and driving conditions / a low margin for optimisation ✓ : An average coverage of driving cycle and driving conditions, but with significant room for improvement / an outstanding margin for optimisation, but with low impact		✗✗✗: A totally incomplete coverage of driving cycle and driving conditions / a very high margin for optimisation with large impacts on emission levels ✗✗: An incomplete coverage of driving cycle and driving conditions / a high margin for optimisation with impacts on emission levels ✗: A diverse but insufficient coverage of driving cycle and driving conditions / an outstanding margin with impacts on emission levels	

Sources: Own elaboration based on (ICCT 2018) (ICCT, 2017) (ICCT, 2017) (CLOVE, 2020) (Bodisco & Zare, 2019) (Tsiakmakis, et al., 2017)

While the introduction of RDE has significantly improved Euro 6 testing procedure, the following outstanding limitations are identified in the literature and echo some of the stakeholders' responses:

- **Driving conditions not covered under boundary conditions:** RDE boundary conditions do not include certain driving operations (such as short trips) but where important part of the overall emissions from vehicles' operation is accumulated (CLOVE , 2020). Other driving conditions are not covered either under RDE relevant boundary conditions or vehicle selection criteria (for ISC testing). Those include: high mileage (vehicles in use for longer than 5 years or 100000 km since this is the period prescribed by the Regulation for ISC) and high altitude and severe cold/hot ambient conditions (CLOVE , 2020) (Weller, et al., 2019).

- In their answer to the stakeholder survey, an EU environmental NGO identified the same limitations. They suggest that these may be remedied by (1) extending the boundary conditions (altitude and temperature) to reflect the measurement capability of the best in class PEMS equipment, (2) removing any limits on maximum altitude gain, minimum/maximum driving dynamics and maximum motorway speed and (3) applying all emission limits during DPF regeneration. They also suggest that emission limits should also apply on all sections of the RDE test (as is already the case for the urban phase of the test), and that the urban phase in itself should be subject to a not to exceed limit for shorter urban trips.

- Other omitted real world driving conditions include auxiliary systems' use such as air conditioning, trailers, etc, which impact vehicle loading, driving resistances and power demand and hence, the level of emissions (CLOVE , 2020) (Weller, et al., 2019). The Commission has generated guidance for those specific driving conditions to be met during the test, which are not legally binding and guide the use of vehicle auxiliary systems (e.g. air-conditioning, electrical auxiliaries like rear window and mirror heating). External (non-vehicle) devices like a telephone charger or mini-fridge are not permitted to be powered. It also notes that the use of a trailer (to carry the PEMS) is permitted.

- **Potential to calibrate engine to specific RDE testing conditions** - If restricted by boundaries such as VxApos and maximum speed, and averaging to compensate possible excursions, RDE can also be defeated. According to ICCT, some manufacturers (for instance, MAZDA 6 tests done by Baden Württemberg environment agency) identify the area where all possible test conditions are included and calibrate the engine very closely to those conditions (ICCT, 2019d). In the stakeholder survey, an EU environmental NGO suggested that there should be no prescribed trip order to reduce the risk of test recognition and emissions cheating.

Other outstanding limits to RDE testing mentioned in the literature do not pertain to the reliability of the tests themselves but broader aspects of the Regulations. They include:

- An incomplete coverage of regulated pollutants (CLOVE , 2020).
- Alleged ties between some type-approval authorities and manufacturers (ICCT, 2018a) in some cases linked to the overall type approval framework. Initial propositions suggested the creation of an EU-wide type-approval authority, or the removal of financial ties between manufacturers and testing services, but these have not been included in the Regulation (EU) 2018/858. Nonetheless, the additional provisions for independent testing should be expected to help mitigate this.
- The minimum compulsory annual ISC checks. Through RDE's 4th package, the minimum compulsory annual ISC checks by the authorities are set at 5% of PEMS families or at least two families per manufacturer, and the number of vehicles to decide whether an ISC check is passed is between 3 and 10 per vehicle family. As a result, a vehicle family for which only 50% of the vehicles are in good condition has a 50% probability that all its vehicles pass the ISC check (ICCT, 2018a).
- The existence of "conformity factors", meaning that the current legal emission limits don't actually have to be met under all RDE testing conditions. This may discourage the uptake of technology to manage emissions in more extreme driving conditions (Hooftman, et al. 2018). Studies show that technology for strict compliance already exists in normal driving conditions (Triantafyllopoulos, et al. 2018).
- Data gathered by T&E in March 2019 from the RDE databases on the ACEA and JAMA website's shows that while 87% of 6d-temp/6d diesel cars on the database already met the NOx emission limits without the need for a conformity factor (including during urban driving), 37 vehicles did not meet this limit. These vehicles only passed the test because of the use of the conformity factor. Among them, 3 manufacturers were responsible for most of the high emissions, although their vehicles were capable of emitting less than 20mg/km (including during urban driving). This indicates that conformity factors allow some manufacturers to give preference to cheaper rather than "cleaner" technologies despite having the technical ability to fully comply with the limits (Transport & Environment, 2019).
- Notwithstanding the above limitations, 81 out of 124 respondents to the public consultation agreed that RDE testing ensures that cars and vans are compliant with the pollutant limits in all driving conditions. This was mainly supported by industry (47 out of 59 respondents) and less so by Member States and civil society representatives. At the same time, only 42 out of 121 respondents from all stakeholder groups consider that the shortcomings of the existing on-road tests contributes to an increase in pollutant emissions to a great or "very great" extent. These are mostly represented by civil society representatives (11 out of 17) and least by industry representatives (10 out of 55), 45 considered that it does not at all, or only very little.
- This reflects the conclusion that outstanding limits to RDE testing do not pertain to the reliability of the tests themselves but to broader aspects of the Regulations. Most respondents have highlighted concerns that tampering, cost of vehicle maintenance, vehicle ageing, and inadequate periodic technical inspections and roadside inspections may contribute to an increase in air pollutant emissions.

5.1.3.3.2 Testing procedures for HDVs (lorries and buses)

The use of PEMS in the context of in-service conformity tests for HDVs has brought significant improvements to the reliability of Euro VI testing. Before then, the testing cycle mostly improved from the earlier cycles by including cold-start emissions but was still only constituted of an engine test bed, which underrepresents low-engine-load or low-exhaust-temperature condition (ICCT, 2016c). Improvements in the reliability of HDV's certification tests to measure emissions are summarised below and in Table 5-7.

- *Driving cycle* – Both ESC/ELR and WHTC/WHSC tests are performed on tests beds. These do not require manufacturers to demonstrate compliance with emission limits outside of a test bed on any specific driving cycle, either at the time of type approval or after vehicles have been put into use. Since the introduction of ISC requirement, vehicles must operate over "typical routes" that must include urban (speeds under 50 km/h), rural (speeds of 50–75 km/h) and motorway (speeds of over 75 km/h) operation (ICCT, 2012b) (CLOVE, 2020) increasing the coverage of the real world driving.

- *Driving conditions* – While the ESC/ELR did not represent all engine conditions nor temperatures, WHTC/WHSC included a greater range of driving conditions allowing to capture engine response to changing parameters. It notably introduced a cold start test and a new cycle with lower engine load and increased idling time. Overall, new testing parameters cover a wide range of load and speed operation, which results in real world emissions similar to test bed results (Weller, et al., 2019) (CLOVE, 2020) (ICCT, 2012b) (ICCT, 2016c)(Ricardo, 2018)
- *Robustness against optimisation/defeat strategies* – As for LDVs, predictable test cycles both under ESC/ELR and WHTC/WHSC allowed manufacturers to define pre-test engine conditioning, such as starting the test with a warmed-up engine to ensure low exhaust temperature performance were not accounted for. WHTC/WHSC added an additional "off-cycle test" testing additional randomly selected points on the engine map to ensure that the emissions-control system is not narrowly calibrated to meet emissions limits. ISC requirements through PEMS further ensure that an even broader range of engine load and ambient condition is included at all times, so that prior-calibrating is not possible for manufacturers (CLOVE, 2020) (Weller, et al., 2019) (ICCT, 2012b) (ICCT, 2016c).

Table 5-7: Summary table of the evolution of the reliability of testing procedures for HDVs against relevant criteria

	ESC/ELR	WHTC/WHSC	Additional ISC requirements
Driving cycle	✗✗	✗	✔✔
Vehicle-driving conditions	✗✗	✔	✔
Robustness against optimisation/defeat strategies	✗✗	✗	✔
✔✔✔: A complete or close to complete coverage of driving cycle and driving conditions / a very low to null margin for optimisation ✔✔: A good coverage of driving cycle and driving conditions / a low margin for optimisation ✔: An average coverage of driving cycle and driving conditions, but with significant room for improvement / an outstanding margin for optimisation, but with low impact		✗✗✗: A totally incomplete coverage of driving cycle and driving conditions / a very high margin for optimisation with large impacts on emission levels ✗✗: An incomplete coverage of driving cycle and driving conditions / a high margin for optimisation with impacts on emission levels ✗: A diverse but insufficient coverage of driving cycle and driving conditions / an outstanding margin for with impacts on emission levels	

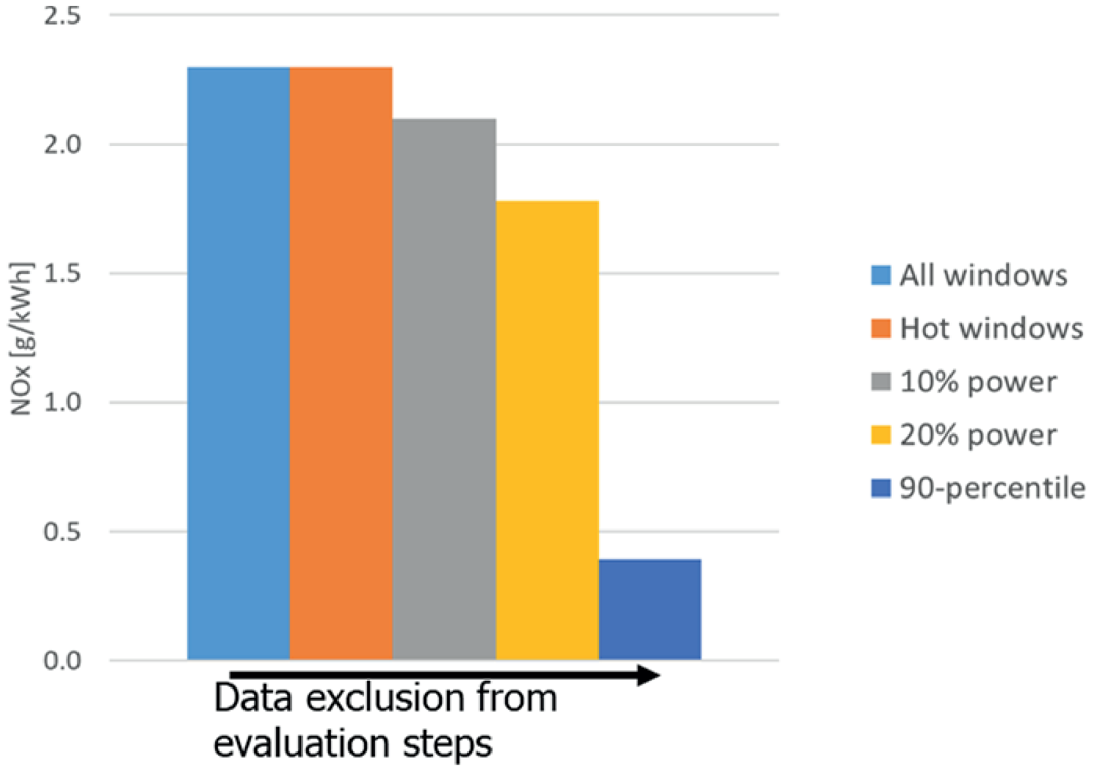
Sources: Own elaboration based on (CLOVE, 2020) (Weller, et al., 2019) (ICCT, 2012b) (ICCT, 2016c) (Ricardo, 2018)

Stakeholders responding to the public consultation largely agree that PEMS testing ensures that lorries and buses are compliant with the pollutant limits in all driving conditions (73 out of 116). Only 34 indicated disagreement, mostly from Member States (6 out of 11) and civil society representatives (8 out of 15).

While the introduction of WHTC/WHSC and, most importantly, of ISC testing requirements through PEMS have improved Euro VI testing procedure, the following outstanding limitations are reported:

- PEMS improvements are still limited to the use of the MAW method (moving average window), that allow for smoothening of emissions across the driving cycle by eliminating windows below 10% power from the analysis. According to findings from the Part A study, this results in ignoring a lot of windows with rather high NOx (although not necessarily highest ones) (CLOVE , 2020). Figure 5-6 illustrates the proportion of emissions that are excluded as a result.

Figure 5-6: Example for the effects from the MAW evaluation method[85]



Source: CLOVE (2020)

Other outstanding limits to HDV emissions' testing mentioned in the literature and by stakeholders do not pertain to the reliability of the test cycle themselves, but broader aspects of the Regulations:

- An important level of tampering is still reported under Euro VI by a large number of respondents to the targeted stakeholder consultation, from all stakeholder groups. Unlike LDV, no third-party verification is included in the legislation and ISC for HDV is undertaken by manufacturers. These factors indicate that a margin for optimisation remains.
- An EU environmental NGO also reported the wide availability of emulators and other technologies to disable SCR system on trucks (Can Bus Emulator, 2020). This issue per se is not indicative of the use of a defeat device, but of tampering by the owner of the vehicle, however, it indicates that the manufacturers do not pay appropriate attention to the security of their systems and allow for tampering and hacking to occur.
- A previous remote sensing measurement in Denmark measured a total of 874 HDV's emissions, including 425 foreign vehicles and 503 Euro VI vehicles against 303 Euro V vehicles. The results identify that less than 25% of HDVs fitted with SCR catalysts are cheating (Ellerman, et al., June 2018).
- A recent ICCT report provided further context on the role of the regulatory provisions in allowing for the use of these devices (ICCT, 2019d). On the one hand, the solution required to ensure the functioning of SCR systems need to be refilled periodically. Turning off the SCR system, as in the tampering examples made earlier, extends the tank refill interval or eliminates the need to refill, making the vehicle cheaper to its user. On the other hand, according to the ICCT (ICCT, 2019c), the regulation provisions related to the use of Auxiliary Emission Strategies (AES)– that allow turning off the emission control system to protect the engine or aftertreatment system from damage – give room for the use of such strategies even if this not justified. Furthermore, they point out that it can be quite challenging for TAA to review and approve these strategies in the context of the type approval process. Authorities did not confirm this point although a few of them confirmed that review and approval of AES can be challenging. More generally, tampering is a concern shared by most of the stakeholders answering the public consultation. 95 out of 124 respondents from all categories indicated that they agree to a great or a "very great" extent that tampering may possibly contribute to increasing air pollutant emissions. Only one citizen out of all respondents indicated no concern at all.

[85] The emission data was collected in normal use. For example, some trucks were operating in supermarket goods distribution. Therefore, the trips were not typical ISC-PEMS trips, with their limitations in time and order. In normal use, low engine power windows, with higher emissions, are much more common. The large reduction (90-percentile) is due to the fact that more high emission data is retained in the initial MAW, than the few urban windows that are retained in the representative, yet limited and biased, ISC-PEMS trip

5.1.3.4 *Conclusion*

To assess the effectiveness of the testing procedures in verifying compliance with the emission standards, we examined the success of the new test procedures in reducing the gap between real-world emissions and type-approval emissions, and critically analysed the reliability of testing procedures in measuring vehicles' emissions and in representing the level of real-world emissions in comparison to the emissions limits.

- We find that the existing testing procedures are mostly effective in verifying emission standards, thanks to the introduction of PEMS testing, and in any case more effective than the under Euro 5 and Euro 6 a/b. However, some opportunity for using auxiliary emission control devices remain for the OEM and tampering is still possible for the vehicle operator, so a gap between real-world emissions and type-approved emission may still remain.
- For LDVs, the gap between LDVs' real-emissions and type approval emissions was reduced, primarily as a result of the introduction of RDE testing. This is noticeable from the significant reduction in emission factors that occurred between Euro 6 a/b and Euro 6d vehicles rather than between Euro 5 and Euro 6 a/b. However, there is still possibility for OEMs to calibrate the engine very close to the wide, but not all-inclusive test boundary conditions, based on ambient temperature, engine temperature at start-up, and timers.
- In relation to evaporative emissions, it is still too early to assess the impacts of the changes to the testing requirements. They are generally expected to bring improvement and reduction of evaporative emission but, when compared against the more demanding requirements in other regions (e.g. US, China), they should not be expected to achieve the same level of effectiveness.
- WHTC and WHSC had positive but limited results in reducing the gap between HDVs real-world emissions and type approval emissions. The engine cycle coverage remains insufficient and a margin for optimisation of vehicle's engine to the test remains. In particular, emulators and other technologies are available to vehicles operators to disable SCR system on trucks, and no third-party verification is required, while the regulation allows for the deactivation of emissions control under some conditions to protect the engine or aftertreatment system from damage. As a result, still important levels of tampering by manufacturers and/or consumers can be observed.
- Moreover, an important amount of emissions produced throughout the entire lifetime of vehicles on EU roads and in all conditions of use remains unaccounted for in the new testing procedures:
- For LDVs, tests' boundaries exclude certain driving operations (e.g. short trips, high mileage and high-altitude circuits, and severe temperature conditions) with high level of emissions, well above the limits. While not part of the normal driving conditions they are not that uncommon and can contribute to a high level of emissions. Furthermore, RDE tests also omit further real-world conditions, such as very high or low speeds, vehicle loading, driving resistances and power demand and hence miss certain part of the emissions from vehicles.
- For HDVs, tests' boundaries exclude emissions measured at low loads, low speed and idle time that buses are mostly subject to (hence underestimating emission levels in urban areas). Although the power threshold was recently reduced from 20 to 10%, an important amount of emission remains accounted for.

5.1.4. EQ3 What are the factors that have influenced positively and negatively the achievements observed? In particular, which obstacles to cleaner vehicles on EU roads still remain?

5.1.4.1 *Introduction*

The following section draws on the conclusions from the analysis in the previous sections 5.1.2 (EQ1) and 5.1.3 (EQ2) to assess the level of influence that each factor had in reducing overall emissions. We examine the role that the emission standards themselves have played in comparison to the testing procedures, to specific components of the testing procedures, to other components of the legislation and to other external factors that had a positive and/or negative impact. To do so, we examine:

- To what extent have specific provisions/aspects of the legal framework played a role in terms of achieving the objective of reducing pollutant emissions?
- To what extent have other external parameters/factors played a role in terms of achieving cleaner vehicles on EU roads?
- To answer these questions, we rely primarily on the analysis of evidence from the literature and input from stakeholders.

5.1.4.2 *To what extent have specific provisions/aspects of the legal framework played a role in terms of achieving the objective of reducing pollutant emissions*

In this section we examine the parameters of the legislation which appear to have played a role (positive or negative) in making vehicles cleaner.

5.1.4.2.1 For LDVs (cars and vans)

The analysis presented in Section 5.1.2 (EQ1) pointed to significant improvements following the introduction of emission limits, but the greater share of improvements was brought with the revision of the testing procedures and the introduction of RDE. The analysis in Section 5.1.3 (EQ2) provided evidence of the positive influence of testing procedures, without which gaps between real-world emissions and emission limits would remain large. Stakeholders' input also pointed to the same overall picture.

- In terms of the **emission limits**, most stakeholders that responded to the targeted consultation considered that they had a positive or somewhat positive impact, both in case of cars (57 out of 59) and vans (43 out of 46). Only two, from the industry and authorities/technical services stakeholder groups, indicated that they had no impact on cars' emissions. Similarly, among the respondents to the public consultation 143 out of 161 also agree that the Euro standards for cars and vans were appropriate for reducing pollutant emissions from road transport, suggesting that they played a positive role. Furthermore, the majority of stakeholders from industry (59 out of 79) and citizens (32 out of 54) also agreed that the limits for air pollutant emissions for new vehicles are strict enough. However, 9 out of 13 Member States' representatives and 10 out of 18 civil society representatives consider that the limits are not strict enough.
- On the positive side, specific mention was made to the introduction of PN limits, as highlighted by a representative from an EU vehicle manufacturer, an automotive parts supplier, a representative from a technical service and an international transport research organisation. It was seen as an important step to better regulate fine particulates
- On the negative side, a few critical views focused on the presence of different limits for vans. One type approval authority considered that limits were "somewhat successful" in "reducing actual pollutant emissions from cars", but "somewhat detrimental" in "reducing actual pollutant emissions from vans" as the higher "not-to-exceed" (NTE) limit in vans allowed for higher levels of emissions even if vans are already more polluting than cars (as they are mostly used in urban areas where emissions are higher). An EU environmental NGO also supported this answer by highlighting that, as a result of differences in the emission standards for certain categories (N1-3), cheaper and less effective aftertreatment systems are fitted on vans. (see further discussion on presence of different requirements for cars and vans in section the same section below).
- In terms of the **testing procedures**, 52 out of 59 respondents in the case of cars and 38 out of 45 in the case of vans considered that RDE had very positive impacts. Only one respondent from the industry sector identified no impact of RDE on cars' emission. In contrast, only 17 considered that WLTC was highly successful in the case of cars and 12 in the case of vans. Instead, 6 and 11 respondents from all stakeholders' categories reported no impact of WLTC on cars' and vans' emissions respectively. An EU automotive parts suppliers' association (AECC) stated that adding RDE to the regulation had the biggest positive impact on ensuring that emissions are controlled over a wide range of driving conditions. An automotive parts supplier and an automotive component supplier also considered that all other measures had a minor impact in comparison to the introduction of RDE testing.

Within the context of the new testing procedures, different parameters allowed for the achievements of Euro 6/VI objectives (including OBD requirements/provisions, ISC requirements and the possibility of independent testers to perform such tests, etc).

The available evidence indicates that **ISC requirements** (4^{th} RDE package) has had a positive role:

- While the first RDE packages (without ISC) still had limitations in accounting for all driving conditions (such as temperature, altitude and mileage), ISC requirements with independent testers would reportedly enable a greater array of conditions to be accounted for. Supporting this view, an EU environmental NGO highlighted that the stringency of emission limits was only helpful in combination with the introduction of RDE and in-service conformity testing. A representative from a type approval authority also stated that, when it includes ISC, RDE is the main driver to improve vehicle technology for clean vehicles.
- Further positive impacts are expected from the ISC, which would serve to ensure the robustness of RDE testing as shown in a study from Degraeuwe and Weiss (Degraeuwe & Weiss, 2017). Comparing emission from petrol and diesel LDVs type-

approved vehicles under NEDC and RDE cycles, the authors highlight that a large part of elevated NOx emissions cannot be explained by the insufficient dynamics of the test cycle, nor by the narrow temperature-range used, but rather by the use of "defeat devices". Hence, they conclude that RDE may only be robust if backed by in-use conformity testing and market surveillance.

- During the EMIS committee[86] hearings, the JRC emphasised that the best designed type-approval tests would not be able to ensure the effective prevention of defeat devices, and in-service conformity testing and market surveillance would ensure better compliance and hence, emissions reduction (JRC, 2016).
- Stakeholders were rather positive in their assessment of the impact of ISC's testing from third parties. 16 out of 41 and 8 out of 25 consider that it had a highly successful impact for cars and vans respectively and 13 out of 41 and 6 out of 25 considered it had a somewhat successful impact. A small share of respondents (11 out of 41 and 8 out of 25) indicated no impact at all, and 1 and 3 indicated a somewhat negative impact. These were mainly representatives from vehicle manufacturers, but also one EU national authority. Several NGOs considered that the introduction of third party ISC testing is too recent to measure its impact but that it is expected to have significant positive impact.

Another parameter linked to the testing procedures that is seen as having had a significant positive impact on the achievements is the **inclusion of cold-start emissions** in the measured data as part of the 3RD RDE package. Studies show than this allows the tests to capture an important part of pollutants' emissions previously not accounted for in the certification process:

- When adding cold-start to PEMS data, diesel cars can contribute up to 38% more of the total NOx emissions, and cold-starts also contribute up to 86% of the PN emissions of GDI vehicles without a particulate filter. Prior to the approval of the 3rd RDE package, these cold-start emission would not be accounted for, as the first five minutes of registration were excluded from the data (Hooftman, et al., 2018).
- Some pollutants' emissions are mainly due to cold-start phases (CO on diesel vehicles and PN). Hence, excluding them from the final data would have led to a decrease in the amount of these pollutants' emissions measured, although real-world emissions are not actually reducing (Marotta, et al., 2015).
- Stakeholders also identified other factors that may have positively contributed to the achievements observed for LDVs. The responses suggest a moderately positive role for the OBD provisions and in-use performance monitoring, as explained below:

OBD thresholds – There was no strong support of the role of OBD provisions. 19 out of 41 respondents to the targeted consultation considered that OBD thresholds were successful in achieving emission reductions from vans, and 27 out of 52 for cars. However, the remaining respondents indicated that it had no impact.

- According to an EU local transport NGO (EU non-governmental organisation) and a regional authority, OBD provisions are not robust and clear enough and can be manipulated. An international vehicle testing association and an EU environmental NGO also highlighted that the thresholds are too high, so that not all faults are being detected. The EU environmental NGO considered that stricter emissions limits are needed to prevent disabling aftertreatment systems by the user. This implies that OBD requirements are not sufficient in preventing this. As argued, even though decreasing the OBD thresholds has increased the chance that broken aftertreatment components are identified and fixed, it is still unlikely that the OBD thresholds are set sufficiently low to ensure that all faults are detected. For example, PM OBD 6.1 and 6.2 thresholds are deemed unlikely to identify cracked or missing DPFs and GPFs, which in some cases significantly increase the amount of PN emitted.
- This results in a lack of monitoring of missing particle filters, increasing the risk that DPFs and GPF's are illegally removed for cost saving by its user, as this fault is unlikely to be identified through OBD PM monitoring. This is particularly a risk for vans, as many vans in the EU are part of commercial fleets and the cost saving incentive is much larger for a fleet operator compared to individual consumers due to the multiplier effect.
- The majority of respondents to the public consultation agreed that "OBD ensures that new vehicles are compliant with the pollutant limits over their entire lifetime" (69 out of 125). However, this majority is driven by industry representatives (40 out of 59 of them agree). In contrast, most Member State representatives disagree that OBD ensure compliance over the entire vehicle's lifetime (7 out of 11). Out of all respondents, 49 out of 125 have disagreed. Furthermore, 98 out of 120 respondents to the public

[86] European Parliament's enquiry committee into the emissions scandal

consultation also suggested that the limited effect of OBD may contribute to an increase in air pollutant emissions, out of which 42 out of 120 indicated that it may contribute to a "great" or "very great" extent.

In-use performance monitoring - 14 out of 38 respondents to the targeted stakeholder consultation indicated that In-Use performance ratio (IUPR) for passenger cars was successful towards the achievements observed, however only 8 believe it was highly successful. For vans, this corresponds to 16 out of 32, including 6 who report a "highly successful" contribution and only 1 manufacturer reporting a "somewhat detrimental" contribution but without further elaboration. An EU environmental NGO, indicated the "the increase in in-use performance ratios since Euro 5 has made it more likely that emission critical faults are identified."

- At the same time though, the lack of monitoring of missing particle filters for PI vehicles increases the risk for illegal removal of GPFs, as this fault is unlikely to be identified through OBD PM monitoring. According to the EU environmental NGO, if monitoring of this fault was mandatory through IUPR, missing GPF's could be identified through the use of pre- and post-GPF pressure sensors and the monitoring of the delta pressure, as it the case for many diesel vehicles.

Finally, there were other aspects of the requirements that are generally considered to have played a less positive role. This included both specific provisions of the standards (e.g. the conformity factors, durability requirements) as well as broader aspects of its implementation (i.e. the different regulatory framework for cars and vans, the gradual phase in of the standards and the overall complexity of the legal framework). These are discussed in the following paragraphs:

- **Conformity factors - The introduction of conformity factors** could be considered as having had a negative influence on the achievement of the objective. They have been introduced to account for PEMS equipment uncertainties, but some stakeholders (e.g. NGOs) have argued they allow more flexibility than is necessary. According to the JRC, the typical measurement uncertainty using PEMS is 20-30% (JRC, 2016) with the 43% margin provided in Euro 6d based on the worst-case step drift of 5 ppm and a large 3L diesel engine, which is not necessarily applicable to all cases (Giechaskiel, et al., 2018). Furthermore, according to some expert views, a conformity factor of 1.25 would already be feasible given that some vehicles on the market are already compliant (*i.e.* have CF of 1) (Emissions Analytics, 2016). Thus, the evidence above suggests that the conformity factor has probably been too large and allowed for additional emissions that are not clearly justified on the basis of the PEMS measurement uncertainties.

- Having said that, any conclusion concerning the role of the conformity factors in the reduction of emissions should also be seen in relation to the need to provide sufficient lead time to industry to adapt to the new requirements. In this context, despite the high conformity factors, Euro 6d-Temp vehicles (with a CF of 2.1) already represented a significant improvement in comparison to Euro 6c vehicles, as presented in section 5.1.2.4, and providing the time for further improvement to the more demanding Euro 6d (CF 1.43) and potential further reduction of CF in the coming period.

- **Durability requirements** - Technical measures taken by the manufacturer must be such as to ensure that tailpipe and evaporative pollutant emissions are effectively limited, throughout the normal life of the vehicles and under normal conditions of use. The standards set requirements for manufacturers to check the in-service conformity (ISC) and durability of their vehicles (up to five years or 100,000 km for LDVs, 160,000 km or 5 years for small buses and pick-up trucks).

  The current durability requirements do not properly reflect the actual normal lifetime of a vehicle. According to data from ACEA (ACEA, 2020b), the average age of a passenger car in the EU is 10.8 years and the average age of a van is 10.9 years with a trend towards extending the lifetime of vehicles in the last years. In 2016, the average age of a passenger cars was 10.6 years indicating a small increase in two years by 2%. Furthermore, regarding mileage, according to a recent LCA study in the transport sector (Ricardo , 2020), the average lifetime mileage in the EU is around 225,000 km for a passenger car and 200,000 km for a light commercial vehicle.

- As such, the durability requirements appear to be significantly lower (up to 50%) than the average fleet age and lifetime mileage for LDVs. As also indicated by the ICCT (ICCT, 2019), the durability requirements set by current European regulations appear too limited and not representative of the average useful life of EU's LDV fleet. As a result, they are potentially not effective in ensuring that LDVs continue to perform as expected over important part of their useful lifetime.

  Indeed, respondents to the public consultation support the conclusions above, as 72 out of 124 respondents agree with the statement "real-world emissions are not adequately monitored [and not adequately limited] over the entire lifetime of a vehicle". Only respondents from the industry stakeholder group indicated disagreement in relatively large numbers, as 19 out of 58 "completely disagreed" that real-world emissions were not adequately monitored throughout the entire lifetime. However, though 24 industry representatives still agreed.

- **Separate regulatory frameworks for cars/vans –** Some authorities reported that having different implementation dates and more relaxed emission limits for vans have a negative impact on the technology used for these vehicles, even though they are more polluting. Other organisations from the civil society and a technical services provider also raised questions about the appropriateness of these differences between cars and vans.
- In particular, data from a recent study by TNO shows that there is no technical justification for N1 CL3 or CL2 vehicles to have higher emission limits N1 CL1 vehicles, as the technology already exists for all classes of vans to respect the present N1 CL1 80 mg/km limit at present (TNO, 2017). An EU environmental NGO also claimed that as a result of different implementation dates, many LCV vans on sale today still do not comply with the emission limits on the road, as RDE testing is still not mandatory for all LCV's until 2022.
- On the other hand, having separate regulatory frameworks for cars/vans and lorries/buses is considered not at all complex by 56 out of 126 stakeholders responding to the public consultation. Among the 56 respondents from all categories, 39 are industry representatives.
- **Gradual phase in of requirements –** Stakeholders appeared also sceptical of the role that gradually phasing in Euro 6 standard played in achieving the objectives. In total, 24 out of 49 considered that it highly or somewhat successful while 17 considered that it was somewhat or highly detrimental. Industry representatives were the most critical (10 out 24 expressed a negative view). While some industry representatives recognised that is was a necessary measure to ensure that the regulatory development follow the development of technology, they also indicated that the way it was undertaken was detrimental as it did not allow for sufficient lead time to comply. They highlight the importance of defining every upcoming step in the legislation when the first step is adopted. This assessment was also shared by a representative from a national authority, highlighting that the late implementation of RDE led to difficulties in interpreting what "normal use driving" is, hence causing higher levels of emissions. Research organisation and NGO representatives also shared these conclusions about the negative impact of gradual phasing-in on the level of emissions.
- **Overall complexity of tests and legislation –** An important number of stakeholders consider that the standards are complex. Among the respondents to the public consultation, 98 out of 126 respondents from all stakeholder groups considered that the standards are complex or very complex. The procedure of emission tests is the feature considered "very complex" or "complex" by most of the respondents (86 out of 124 respondents from all categories), followed by the number of emission tests (79 out of 123 consider), and by the differences in emission limits based on fuel and technology (54 out of 128 respondents). The responses provided were largely similar across all stakeholder groups (industry, Member States, civil society and citizens) with only small differences. The one exception was the high share of civil society representatives (seven out of 18) that considered that that number of emissions tests did not contribute to the complexity of standards.
- Besides the impacts on the costs of compliance (discussed later in EQ10), this complexity of the legal framework is also seen as having a negative impact on the achievements of the objectives of Euro 6. 30 out of 53 respondents considered that it has played a negative role in the case of cars and 23 out of 41 in the case of vans. The responses are largely consistent across all groups. Among respondents to the public consultation, a sizeable minority of stakeholders (63 out of 123) agreed that the complexity of the standards increases the risk of non-compliance, especially respondents from civil society (15 out of 37) and citizens (22 out 37). In comparison, 21 out of 80 representatives from the industry disagreed that the complexity of the standards increases the risk of non-compliance.
- Elaborating on their response to the targeted consultation, TA authorities considered that it may have led to errors in performing tests and calculations and increased the capacity needed by manufacturers to comply with the legislation. According to a stakeholder from a technical services provider, the latter negative consequence may lead to an increase in prices to the consumer, hence slowing down the rate of fleet turnover and, ultimately, the reduction in overall emission. Another industry representative (a vehicle testing supplier) considered that the complexity of the regulation has slowed down the development of technical solutions. From their side, NGO and research organisation stakeholders agreed that there is a need for simpler tests and monitoring, making the legal framework less complex.
- **Technology and fuel neutrality:** Finally, the fact that the standards are not technology and fuel-neutral (i.e. that limits are different depending on the vehicle technology) is also seen as problematic. According to Suarez-Bertoa et al (Suarez-

Bertoa, et al., 2019), different emission standards based on fuel and technology may have hindered further progress on the achievements observed. After investigating emissions from a representative sample of European market Euro 6b to Euro 6d-Temp vehicles through PEMS, the authors find that under certain conditions, gasoline vehicles can exhibit important emissions of CO, that high PN emissions were also recorded for PFI vehicles on three models, although high emissions from PFI vehicles were not considered relevant when developing Euro 6 regulation. In their response to the targeted stakeholder consultation, on national authority also expressed support for a more technology neutral regulation.

- Similarly, the majority of respondents to the public consultation consider that "developing fuel-neutral and technology neutral limits" would be important or very important to improve the effects of the emissions limits (87 out of 124 respondents). This includes 33 out of 58 respondents from the industry, 10 out of 12 Member States' representatives, 15 out of 18 civil society representatives and 29 out of 36 citizens).

Overall, for all stakeholders consulted and across the literature, the introduction of RDE testing stands out as the parameter with the most positive impact on the emission reduction achieved. Notwithstanding, there continues to be some debate regarding the appropriateness of the measurement error. In turn, OBD and IUPR are considered beneficial but insufficient at this stage, as they do yet detect tampering or removal of emission control technologies. However, Recital 26 of Regulation No (EU) 2017/1154, notes that: "The Commission should keep under annual review the appropriateness of the final conformity factors". The gradual phase-in of standards, the presence of separate regulatory frameworks for cars and vans and the overall complexity of the legislation were all reported as having possibly played a negative role in the achieving the objectives.

5.1.4.2.2 For HDVs (lorries and buses)

In relation to Euro VI, the analysis of EQ1 (Section 5.1.2) presented earlier already pointed improvements following the introduction of emission limits. In turn, the analysis in EQ2 (Section 5.1.3) provided evidence of the positive but still limited influence of testing procedures.

Stakeholders' input also pointed to the same overall conclusions concerning the role of the key aspects of the legislation:

- **Role of emission limits:** All stakeholders considered that level of stringency of the Euro VI emission limits had a successful or highly successful impact on the achievement observed on Lorries, and 39 out 39 thought the same for buses. An EU environmental NGO and an international transport research organisation commented that the introduction of a PN limit on HDVs was effective to ensure that diesel trucks are fitted with particulate filters, which could not be achieved under Euro V PM limit alone. However, ICCT argued that their own analysis suggests there is still room to lower limits from 23 nm to 10 nm for solid particles without large investment costs nor significant modifications to existing measurement systems.
- **Role of testing procedures:** Most stakeholders also agreed that the new testing cycles *(WHSC/WHTC)* were successful in achieving lower emissions (on buses: 25 out of 36 for WHSC and 34 out of 36 for WHTC; on lorries: 25 out 30 and 36 out 37). However, an important number suggested no impact (10 for buses and 12 for lorries) and one stakeholder from an engineering services provider indicated a somewhat detrimental impact, suggesting that only "in-use requirements are highly effective". Environmental NGOs argued that the test cycles have insufficient consideration for low loads and idling time, where a large amount of emissions occurring are not captured. This is particularly relevant for buses, who run at low loads and spend an important amount of time idle.
- **In-service conformity:** As part of the new testing parameters, in-service conformity testing using PEMS measurement has also been identified as one of the most important aspect of the Euro VI (ICCT, 2015b), with significant positive impact on the achievement of the objectives. Hooftman et al (2018) concluded that it has been an essential tool in Euro VI regulation to gauge its effectiveness, and TU Graz (TU Graz, 2013) also interprets the positive results from Euro VI vehicle emission tests as a confirmation of the effectiveness of real-world emission tests as part of the type-approval to complement the legislation.
- Stakeholders that contributed to the targeted consultation also indicated at least a somewhat successful impact on the achievements observed; 39 out of 40 in relation to lorries and 37 out of 37 for buses. An automotive parts supplier highlighted that "on-road measurement has had the largest effect on vehicle emission improvements". An EU environmental NGO also acknowledged that the introduction of PEMS testing on-road at type-approval has been "instrumental" in reducing emissions, though its specific parameters still ignore a large amount of emissions that may be emitted by busses dung their idle time, such as the 20% power threshold.

- **The introduction of a cold-start test** and the amended Euro VI test cycles (more idling time and less engine load) is also considered as the main differentiating factor between Euro V and Euro VI, allowing for the reduction in NOx emission levels below limits (ICCT, 2015b). For both buses and lorries, this was mostly considered as somewhat successful rather than highly successful (25 out of 37 stakeholders indicated it was somewhat successful for buses and 27 out of 40 for lorries). An international transport research organisation provided further details on the need to align the definition for cold start should align with that of dynamometer testing. This was in the meantime introduced in the latest HDV legislation[87].

- **The effective control of defeat devices** for HDVs is also identified as a factor of success in reducing emissions, differentiating them from LDVs. Unlike LDVs, HDVs manufacturers were required to disclose and justify their emission strategies, and this has facilitated control of defeat devices, as reported in the "Report on the inquiry into emission measurements in the automotive sector" (Gieseke & Gerbrandy, 2017).

- Input on other factors that may have also contributed to the achievements observed for HDVs in terms of the reduction of emissions was less positive:

- **Tampering[88] -** As per our analysis in section (Section 5.1.3), stakeholders from all groups pointed to the lack of effectiveness of anti-tampering measures. Two stakeholders from the authorities and technical services group claimed that the measures had a "somewhat negative impact"[89] on lorries, and one stakeholder from civil society identified a "highly detrimental impact" on them. This can be interpreted as per an EU fuel suppliers' association's statement that "anti-tampering regulation improvement needed", or an automotive parts supplier claim that "tampering is still widespread and measures have not been sufficient to limit its occurrence". For buses, one stakeholder from NGOs and research organisations considered it had a "somewhat detrimental impact", and one from technical services considered it a "somewhat detrimental impact".

- The above conclusion is also supported by the responses provided by stakeholders in the context of the public consultation. The large majority of respondents from all stakeholder groups (131 out of 159) agreed with the statement that "Euro standards for lorries and buses have been appropriate for reducing pollutant emissions from road transport", suggesting a positive impact from the standards.

- **On-board diagnostics** – 14 out of 33 respondents reported only a somewhat positive impact of OBD on achievements observed in the case of lorries with 6 out of 33 reporting no impact at all, mostly authorities and technical services. Similar input was provided in the case of buses, with 12 out of 31 reporting a somewhat successful impact and 6 out of 31 reporting no impact. A limited role of OBD was also suggested by a large share of respondents to the public consultation (42 out of 120 respondents agreed that the limited effect of OBD contributed to a great or very great extent to an increase in pollutant emissions; with 36 more somewhat agreeing that this is the case). Industry representatives were less supportive of this conclusion (less than 20% of respondents while more than 75% of respondents from civil society agreed.

- Elaborating on their input, an international transport research organisation suggested that the current OBD program in Europe leaves the requirements for monitoring several emission control systems open to interpretation and can fail to identify malfunctions that can lead to high emissions. Moreover, as indicated by an EU environmental NGO, the OBD limits for CO, NOx and PN remain significantly higher than the Euro VI emission limits. This is especially the case for the diesel threshold for CO emissions which is set at 3.3 times the PEMS emissions limit. In order to ensure that emission control systems perform as advertised and emission limits are respected at all times on the road the OBD thresholds should be closely aligned with the emission limits for each pollutant.

- **Periodic technical inspections (PTI)** – The input provided in relation to the role of the Periodic technical inspections (PTI) towards the reduction of emissions was also quite negative. Regarding buses, 9 out of 26 stakeholders reported no impact from PTI on the achievements observed, while 3 stakeholders from the authorities and technical services reported a "somewhat negative impact"[90]. The same conclusions can be drawn from answers regarding lorries, with 11 out of 30 and 3 out of 30 respectively indicating no impact of a "somewhat detrimental one". Respondents to the public consultation also seem to agree with this conclusion. 99 out of 115 consider that

[87] Regulation (EU) 2019/1939

[88] Defeat devices is defined as any calibration change done by the manufacturer that increases emissions under conditions normally encountered in-use. In contrast, tampering is defined as removing or making inoperable any system or device used to control emissions from a motor vehicle engine and is performed by the user of the vehicle.

[89] By "negative"/"detrimental" impact, we understand "lack of effectiveness" based on stakeholders' replies to open-text questions

[90] Ibid.

inadequate periodic technical inspections may contribute to an increase in pollutant emissions to some level, including 62 that consider that this was the case to a "great" or "very great" extent. Furthermore, 101 out of 114 considered that inadequate technical roadside inspections for vehicles contribute to an increase in pollutant emissions to some extent, with 69 considering that this was the case to a "great" or "very great" extent. In both cases industry representatives were less supportive of such statement, while Member States and civil society representatives were more.

- Elaborating on their input as part of the targeted consultation, a national authority representative reported insufficient legislative tools to check compliance, especially on software, to prevent manipulation. A representative of a vehicle testing supplier also stated that PTI emission standards should be regulated not only under roadworthiness but also in relation with type-approval legislation, as the introduction of PN and NOx limit values in PTI would greatly reduce the number of gross emitters over the lifetime of a vehicle. On the other hand, 16 out of 30 stakeholders reported at least a positive impact. No comment was provided to justify the positive impacts. These reservations expressed exclusively for PTI, but apply to RSI to an even greater extent[91].
- **Durability requirements -** The standards set requirements for manufacturers to check the in-service conformity (ISC) and durability of their vehicles (300,000 km or 6 years for mid-size trucks and buses and 700,000 km or 7 years for heavy duty trucks). Such requirements do not properly reflect the actual normal lifetime of a HDV. Currently the average age of vehicles across Europe estimated at 12.3 years (ACEA, 2020b) with increasing trends (3% in the last two years). Furthermore, regarding mileage, the average lifetime mileage in the EU is around 510,000 for a bus, 570,000 km for a 12 tonnes rigid lorry, and 800,000 km for a 40 tonnes artic lorry, significantly above the requirement set in the Regulation (Ricardo , 2020).
- Thus, as in the case of LDVs, the time limits of the durability requirements appear to be significantly lower than the average fleet age and lifetime mileage for HDV and are not representative of the average useful life of EU's HDVs fleet. This means that important part of the current fleet is effectively left outside the scope of the Euro 6/VI requirements.
- Although their answer is not specific to HDVs, respondents to the public consultation support the conclusions above, as 72 out of 124 respondents agree with the statement "real-world emissions are not adequately monitored [and not adequately limited] over the entire lifetime of a vehicle". Only respondents from the industry stakeholder group indicated disagreement in relatively large numbers, as 19 out of 58 "completely disagreed" that real-world emissions were not adequately monitored throughout the entire lifetime. However, though 24 industry representatives still agreed.
- **The gradual phasing-in of the standards** – Regarding the gradual phase-in, 6 out of 34 stakeholders considered it as having a somewhat to relative detrimental impact on the achievements observed on buses, and 8 considered in had no impact. For lorries, 7 out of 36 considered a negative impact and 9 no impact. According to an EU environmental NGO, this stepwise introduction has been detrimental to the reduction of pollutant emissions from buses by allowing buses to continue exceeding the emission limits on the road. For instance, they report that reduction of the PEMS power threshold to 10% only from step D means that, on average around 26% of the emissions emitted from buses type-approved under the EURO VI step A, B and C emission standard will be omitted due to the higher 20% threshold.
- **Absence of separate regulatory frameworks for lorries/buses** – Input from the targeted consultation suggest that it had no specific positive impact on the achievements on the objective, and potentially prevented greater achievements. An international transport research organisation and an EU environmental NGO suggest that further differentiation between the two vehicle types would have led to further improvements in emissions. The current standard testing procedure are intended to reflect the average driving condition of both vehicle types. However, given that buses are mostly idle, with low-load levels and driven in lower temperature than lorries, the differentiating results in ignoring a large part of the emissions from buses.

5.1.4.3 *To what extent have other external parameters/factors played a role in terms of achieving cleaner vehicles on EU roads*

Simultaneously to Euro 6/VI, external parameters may have played a role in the achievements observed. In particular, evidence of the potential influence was identified for the following:

[91] The questionnaire specifically asked about PTI, although Roadworthiness is both PTI and RSI. PTI involves the regular systematic checking of all vehicles, whereas RSI uses the same emissions assessment procedure as PTI but only applies to a sub-set of vehicles in use. Therefore, the reservations expressed regarding PTI will apply similarly to RSI, but to an even greater extent.

- Low emission zones
- CO_2 emission targets

They are analysed in turn in the following paragraphs.

5.1.4.3.1 Low emission zones

The effect of low (or ultra-low) emission zones ((U)LEZ) on the total level of emissions is still debated, as most studies of LEZs not adequately taking confounding factors into account (Holeman, et al., 2015). Still, some evidence suggests that they have a positive impact on the achievements of the standards by encouraging the use of Euro 6 vehicles:

- In Berlin the introduction of a LEZ considerably sped up the turnover of the vehicle fleet towards cleaner vehicles. Based on traffic data, on Berlin's vehicle registration data base, on video recordings at representative locations on the main road network and on air quality monitoring data, experts identified a significant drop in the number of vehicles registered with high emissions. Specifically, they identified 10% less high polluting passenger cars and 50% less high polluting commercial vehicles. At the same time, they identified no changes in traffic flow. Hence, they conclude that the reduction in emissions observed in the LEZ (-24% of PM and 14% of NOx emitted) is due to a replacement of the fleet (Lutz, 2009).
- Another study recorded pollutants emissions on 14 stations following the introduction of Amsterdam's Low Emission Zone (LEZA). It shows significant decreases in air pollution concentration at the monitoring sites, including NOx and particles, and a renewal of 49% of the HDV fleet (Panteliadis, et al., 2014).
- Similar effects are expected in London ULEZ, where all diesel cars, vans and minibuses need to comply with Euro 6 standards while all lorries, buses and coaches need to comply with Euro VI standards (Transport for London, 2020).

On their side, most stakeholders from the targeted consultation considered that low emission zones have had a positive impact, often considered as even greater than Euro 6/VI standards themselves. An EU environmental NGO highlighted the positive contribution of ULEZ in London to reduce NOx emission levels (reportedly down by 31% in the first six months of operation), for as long as tightening of vehicle emissions regulation ensures that fewer polluting vehicles are available on the EU market. An EU health NGO also reports an increase in consumer awareness and in "cleaner vehicle" purchases following the introduction LEZ, as consumers remain interested in driving LDVs in urban areas.

- However, it should be also noted that, as long as the LEZ restrict the use of older vehicles (i.e. Euro 5 or earlier versions) but do not differentiate between pre-RDE Euro 6 (b/c) and RDE Euro 6d-Temp and Euro 6d, the relative impact should be expected to be limited (as already shown in the analysis in EQ2).
- In contrast, among stakeholders from the public consultation, restricting access to urban areas for air polluting vehicles is considered as non-successful by almost half of the of the respondents from all categories (71 out of 151). Among those who consider it successful, only one considered it as the most successful measure to limit pollutant emissions from vehicles, and 16 considered it as the second most efficient measure. In contrast, strict regulations on vehicle air pollutant emissions was considered the most successful measure by the greatest number of stakeholders (56 out of 149).

5.1.4.3.2 Role of CO_2 emission targets

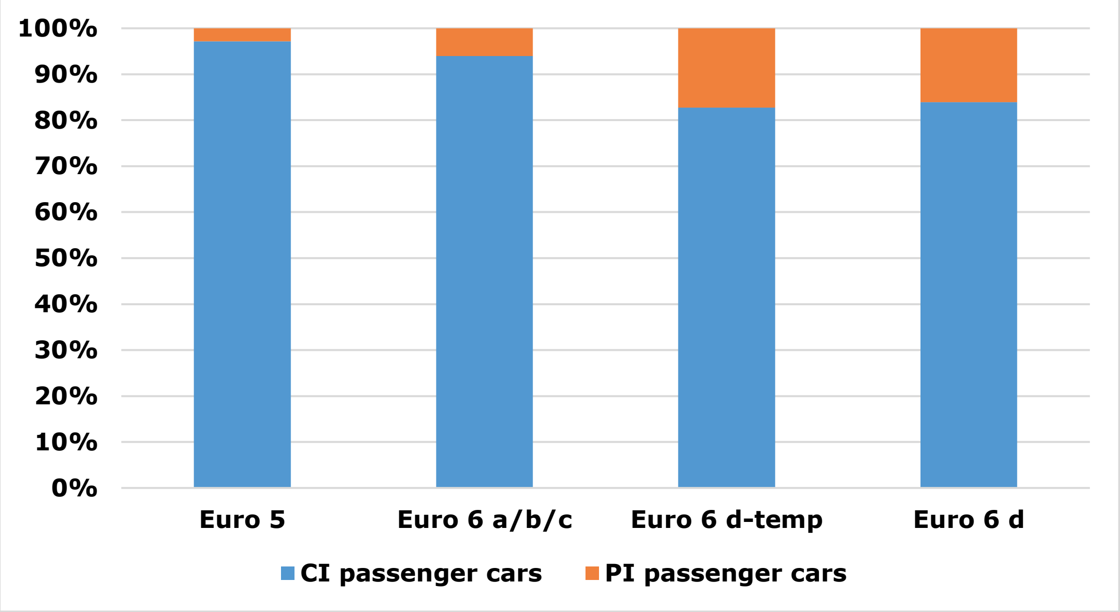
Another factor mentioned in the literature as influencing the achievements observed is the parallel introduction of more demanding CO_2 emission and fuel efficiency targets for LDVs (cars and vans) as part of Regulation (EC) No 443/2009 and (EU) No 510/2011 (both repealed and replaced by Regulation (EU) 2019/631 since 1 January 2020).

There are two main aspects to consider in relation to this:

- The impact of the CO_2 emission targets on the fleet composition and the resulting impact on total pollutant emissions.
- The possible impact of the use of technologies intended to meet CO_2 standards on pollutant emissions.
- Concerning the first point, it has been argued that the adoption of the CO_2 standards led to "dieselisation" of the European car fleet, with CO_2 ambitions taking precedence over NOx reduction goals (O'Driscoll , et al., 2018). A number of stakeholders that participated in the targeted consultation supported this view, suggesting an increase in the share of CI vehicles that are more fuel efficient but also emit more NOx than PI engines (and also have higher emission limits under Euro 6). These stakeholders include OEMs, automotive parts supplier, one national authority and one TAA.
- According to our analysis, diesel cars contribute to the majority of NOx emissions, even though their share of total NOx emissions has decreased since the introduction of RDE

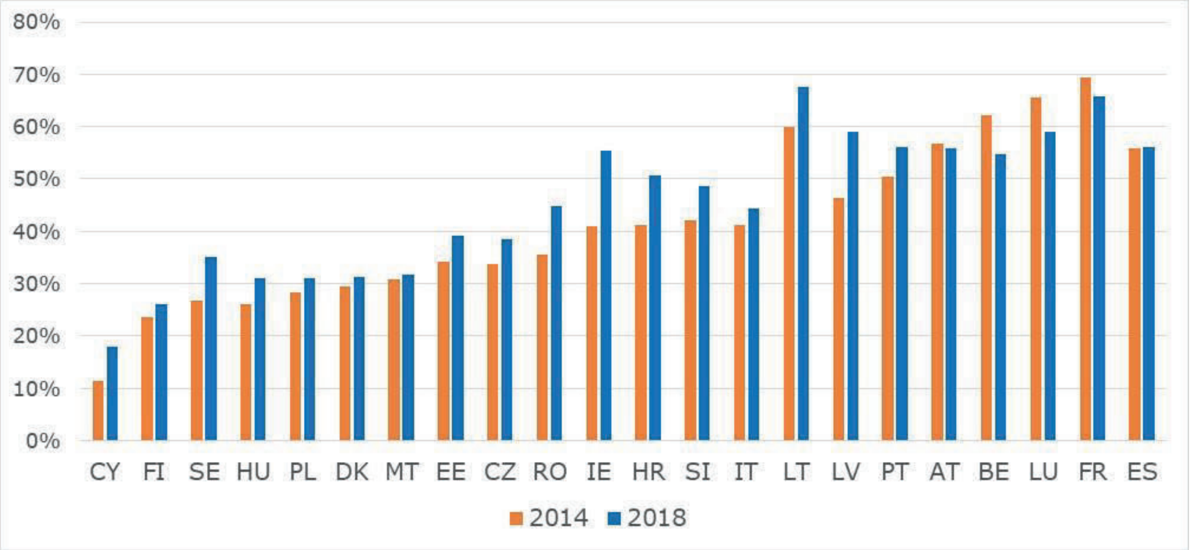
(Figure 5-7). In terms of the share of CI vehicles, this varies significantly among Member States (see Figure 5-8) driven by other factors such as fuel prices and fiscal incentives provided in each Member State. [92].

Figure 5-7: Passenger car share of total NOx emissions by fuel type in 2020[93]



Source: Own analysis based on COPERT model

Figure 5-8: Share of diesel cars in passenger car fleet (selected Member States)



*Source: Own elaboration based on Eurostat Passenger cars, by type of motor energy [ROAD_EQS_CARPDA] *Data on number of diesel cars for NL exclude hybrid-diesel*

Earlier analysis by Ricardo (Ricardo, 2015) also suggested that there is no conclusive evidence that the CO_2 standards can be directly linked with the increased uptake of diesel vehicles in Europe. As indicated, a large body of economic literature using econometric models point to the role of factors other than the Regulations with much greater impact on the trend towards dieselisation, such as national vehicle registration taxes and consumer preferences.

Further to that, the CO_2 emission standards (including the more demanding targets set for post-2020 and the targets set from 2020 onwards for certain lorries) are expected to promote the adoption of zero- and low emission vehicles (e.g. hybrid, battery electric vehicles and plug-in hybrid light duty vehicles and alternative fuelled vehicles such as LNG, hydrogen or electric heavy duty lorries) with low or zero levels of pollutant emissions (including NOx). As such, there is also a significant positive contribution should to be expected on the reduction of total pollutant emissions (Ricardo, 2015). This point was also made by two suppliers (an automotive parts supplier and an equipment supplier) that indicated that in some technologies (such as battery electric vehicles) reductions in both CO_2 and pollutants emissions can be achieved.

Concerning the second point on the use of technologies, one type approval authority considered that the focus on CO_2 reduction though targets and taxation encouraged OEMs to develop small efficient and power-dense turbocharged CI engines (“downsized”) which increased engine-out NOx outside of the drive-cycle zone, and allowed CO_2 savings over the type approval test to be traded for increased pollutant emissions while remaining within the allowable limits under test. While the justification for this view is not clear, the authority went

[92] Please see Text box 5-1 for caveats on country data representativeness for the EU27.

[93] CO_2 standards did not affect the diesel share in the van fleet which always was above 98%.

on to comment that the RDE (including ISC) is now the main driver towards technology for cleaner vehicles.

Industry representatives (including one EU OEM, one supplier, one supplier association and two other individual manufacturers that participated in the targeted consultation) also argued that there are potential trade-offs when it comes to improving fuel efficiency and reducing pollutant emission. One OEM referred to the use of SCR aftertreatment technology in the case of cold-start and urban operations, where there is a need for quickly warming-up the SCR system to ensure that it effectively operates with a price in increased CO_2 emissions – which is especially significant over shorter cycles. The use of exhaust gas recirculation systems (EGR) in a CI engine can also lead to increase CO_2 emissions[94] (Posada, et al., 2020).

However, we note that these observations actually highlight the reverse effect: the possible impact pollutant emissions control technologies have on the CO_2 emissions. As such, it does not provide evidence of a negative impact of the CO_2 standards. Furthermore, a few stakeholders (including one component supplier and two environmental NGOs) considered that available technologies allow to address the two objectives without trade-offs. They commented that a reduction in both CO_2 and NOx is nowadays achievable and it is only an issue of a choice of the relevant technology package by OEMs. In a recent analysis by ICCT of a range of engine and aftertreatment technologies available to reduce NOx emissions, (Posada, et al., 2020), it concluded that while specific technologies may lead to an increase in CO_2 emissions, there are alternatives available (such as cylinder deactivation, closed-coupled SCR systems, heated urea injectors or mild hybridization) that can achieve a reduction of both NOx and CO_2 emissions.

In addition, although the introduction of GDI petrol engines to improve fuel efficiency of positive ignition vehicles directly led to increase in PN numbers, specific PN limit for GDI engines were introduced in the Euro 6 standards and were typically met with the use of GPF filters.

All in all, while a few industry representatives refer to possible trade-off between NOx emission reductions and CO_2, we conclude that there is no evidence to suggest a negative impact of the adoption of CO_2 emissions on the achievement of the pollutant emissions' targets. On the contrary, it can be argued that the adoption of more demanding CO_2 standards has had a positive impact on pollutant emission through the promotion of zero and low emission vehicles.

5.1.4.3.3 Other external parameters/factors

Finally, in the context of the consultation, stakeholders were also asked to provide input on the role that other external parameters played towards the effectiveness of the Euro 6/VI standards. We provide a summary below:

- ***Role of the autonomous/ connected vehicles technology improvement in the automotive sector*** - The majority of stakeholders considered that autonomous, connected vehicles had no impact on the achievements observed 38 out of 54 respondents across all stakeholder groups responded that they played no role and 2 saying that their role was about the same (an automotive component supplier and an equipment supplier). However, 13 indicated a positive contribution, including 1 consumer organisation, 2 industry/businesses association, 4 OEMs, 3 public authorities and one type approval authority association. While no explanation was provided, such input possibly relates to the expected increased efficiency from the use of autonomous vehicles (for private transport and for commercial operation). Autonomous vehicles allow for better logistics operations, saving vehicle-km, enable progress tracking and route planning on an overall scale, saving emissions by avoiding hold-ups and congestions, and may include a "super-economy" mode enabling smoother driving (Society of Motor Manufacturers & Traders, unknown). However, as indicated by a fuel research organisation "autonomous / connected car technologies are not mature enough to have a major role on car emissions".
- Differentiation in congestion charges or road-user charges based on vehicle emissions standards/technology and differentiation in vehicle circulation taxes based on vehicle emission standards - Overall, the majority of stakeholders considered that differentiating congestion charges or road-user charges based on vehicle emissions standards/technology played a positive role towards the achievements observed, though less significant than the vehicle emission standards (36 out of 52). 16 respondents (including automotive component suppliers, OEMs, NGOs and a public authority) indicated a contribution greater than the vehicle emission standards, including an automotive component parts supplier which highlighted that congestion charges had an impact by influencing consumers' choices of vehicle and hence, impacting on overall level of emissions. An EU consumer organisation BEUC (an EU consumer organisation) highlighted that access restrictions and road charges based

[94] EGR in a CI engine reduces available oxygen, which can reduce combustion efficiency (leading to increased soot) and so increase required fuel. Often an inlet or exhaust throttle or a variable nozzle turbo is required to drive/control EGR, which increases pumping work of the engine.

on vehicle technology/emissions levels have been necessary in some cities because the European emissions standards have not delivered the expected progress in real life.

- Similar to congestion charges, the majority of stakeholders considered that differentiating vehicle circulation taxes based on vehicle emission standards played a positive role towards the achievements observed, though less significant than the vehicle emission standards (50 out of 55).
- Responses provided by stakeholders in the context of the public consultation also indicate no significant effects of such measures. Only 40 stakeholders out of 144 (8 from Industry and 7 citizens) considered differentiating taxes on the basis of vehicle emissions as the most or second most successful measure to limit pollutant emissions from vehicles.
- ***Consumer preference for less polluting vehicles*** - Most respondents considered that consumer preference played a positive role towards the achievements achieved, though only 4 considered that it played a greater role than Euro 6/VI emission standards themselves (two NGOs, an OEM and an automotive component supplier). 28 out of 62 indicated a positive role but less significant than the standards, and 25 indicated no role at all. According to an EU environmental NGO, consumer preference for less polluting vehicles is mainly due to increased consumer awareness surrounding vehicle emission due to dieselgate, but preferences remains less significant in Euro 6/VI emissions standards in reducing vehicle pollutant emissions. They suggested that the dieselgate scandal has shifted consumers preference from buying CI to PI cars (which also have a lower NOx emission limit 80mg/km vs.60mg/km), which is likely to have somewhat improved air quality.
- This conclusion is also supported by the responses provided by stakeholders in the context of the public consultation. The majority of respondents from all stakeholder categories (79 out of 148) considered increasing consumer awareness of cleaner vehicles as the least or second least successful measure to limit pollutant emissions from vehicles.
- ***Green public procurement****:* For the majority of respondents across all stakeholder categories (37 out of 57), green public procurement is considered to have a positive impact on the achievements observed, though not as significant as Euro 6/VI. Amongst them, an EU environmental NGO differentiates between the impact of green public procurement on vehicle categories. According to them, "public procurement is likely to have a bigger impact on reducing emission from buses as, in 2012-2014, public procurement accounted for 75% of new bus sales in the EU". 8 respondents indicated an impact greater than that of the emission standards, though no justification was provided (an NGO, OEMs, and automotive component suppliers).
- ***The price of oil and fuel taxes -*** Overall, the price of oil is considered to have played no role in the achievements observed (according to 27 out of 49 respondents). Similar conclusions are drawn for fuel taxes, as 26 out of 55 respondents highlighted no role. 16 indicated a positive role (including engineering services providers, technical services, automotive parts supplier suppliers, a national authority, an international vehicle testing association and an EU Consumer organisation) and 8 a negative role (an international transport research organisation, an EU environmental organisation, an EU health organisation, an automotive parts supplier, a public authority and fuel supplier associations)..
- Amongst the comments provided, 8 OEMs highlighted that, while a higher price of oil or fuel taxes have an effect on the behaviour of passenger car drivers, it has no impact on the HDV sector as the need for mobility of goods and people of this sector remains the same. An EU consumer organisation representative also indicated that it did not have a more positive role than Euro 6/VI because, even though increasing price of oil/fuel taxes play a role in incentivising more efficient and lower emitting cars, consumers often found themselves in a situation where they had no other choice than to pay more for fuel because of the lack of alternatives or the high price of cleaner cars.
- On the other hand, an automotive component supplier considered that these parameters had a negative impact because higher fuel taxes on gasoline cause vehicle owners to operate with lower volumes of fuel in the tank on average, which increases evaporative emissions. An EU environmental NGO also highlights that many consumers continue purchasing diesel cars due to lower fuel taxes.
- Finally, a fuel industry representative from an EU fuel suppliers' association highlights the difference in taxation levels between diesel and petrol and claims that "levelling taxation on petrol and diesel fuels would represent an important leverage to nudge consumers towards cleaner petrol-fuelled alternative technologies"
- ***Vehicle labelling schemes (showing consumers fuel economy and CO_2 emissions of new vehicles)*** - The majority of stakeholders of all types consider that vehicle labelling played no role towards the achievements of the objective (34 out of

58). This is expected, since vehicle labelling schemes (showing consumers fuel economy and CO_2 emissions of new vehicles) do not include information on pollutant emissions from these vehicles. Thus, referring largely to a hypothetical scenario, a national authority considered that it had a positive impact by delivering relevant information to consumers, which the regulation does not. A TAA also highlighted that labelling serves to influence public behaviour. However, an EU consumer organisation representative reported that current vehicle labelling schemes has had a good potential but mostly failed to deliver until now, as the EU car labelling directive has been left untouched since its adoption in 1999 and is unevenly implemented across Member States.

- ***Subsidies for clean vehicles -*** The majority of stakeholders indicated that subsidies for clean vehicles had a positive impact on the achievements observed, though not as significant as Euro 6/VI itself (36 out of 59). Still, 14 representatives from all stakeholder groups believed that subsidies had a greater impact than the regulation itself. However, none of them provided explanation for this statement. An EU consumer organisation representative stated that subsidies role in reducing emissions is equivalent to that of Euro 6/VI, because it ensures that consumers have an alternative to traditional fuel. In turn, an EU environmental NGO reported that subsidies aimed at the purchase of zero emission vehicles will have been the most effective as these subsidies encourage the purchase of vehicles which produce zero pollution.
- This echoes the view of an EU fuel suppliers' association, who indicated that levelling taxation on petrol and diesel fuels would represent an important leverage to nudge consumers towards cleaner petrol-fuelled alternative technologies*.* Another EU fuel suppliers' association answered that subsidies for clean vehicles can only be efficient if they are conjugated with the disposal of an old highly pollutant vehicle as it helps the fleet turnover
- The above conclusion is also supported by the responses provided industry by stakeholders in the context of the public consultation. "Subsidies for cleaner vehicles" is the measure considered the first or second most successful in limiting pollutant emissions from vehicles by 58 out of 153 respondents. However, we note that most of the support comes from the industry with other stakeholders (Member States, civil society or citizens) being less supportive of such a measure.

5.1.4.4 *Conclusions*

Drawing on the conclusions from sections 5.1.2 and 5.1.3, we analysed the role that different parameters may have played in reducing the emission factors and the total level of emissions on EU roads, as well as reducing the gap between type-approval and real-world emissions. We examine the role of the emission standards themselves in comparison to the testing procedures, components of the testing procedures, other components of the legislation and other external factors that had a positive and/or negative impact.

Out of the factors which positively influenced the achievements observed, the testing procedures stand out as the parameter bringing the most significant contribution to emission reduction. Within the testing procedures, in-service conformity testing is widely reported to be the most effective in ensuring low emission levels, both for LDVs and HDVs. The introduction of a cold-start emissions to the testing data was also considered highly effective in ensuring that most emissions are accounted for, both for LDVs and HDVs.

- Specific parameters from the regulation have also contributed to the emissions reduction albeit at different levels. These include the level of stringency of the Euro 6/VI limits on the regulated pollutants themselves given that emission reductions are also observed pre-RDE, and in particular the introduction of PN limits which ensured that diesel vehicles were fitted with particulate filters (which could not be achieved under PM limit alone). Other factors include on-board diagnostic thresholds, in-use performance monitoring, periodic technical inspections.
- Other external parameters to the regulation were considered to have somewhat positively contributed to the reduction in emissions observed. These include: low emission zones, differentiation in congestion charges or road-user charges based on vehicle emissions standards/technology and differentiation in vehicle circulation taxes based on vehicle emission standards, consumer preferences, green public procurement, subsidies for clean vehicles.
- In turn, the following parameters were considered to have a negative impact on the achievements observed, and may represent obstacles to cleaner vehicles on the road:
- For LDVs: the introduction of conformity factors, the presence of similar parameters for cars/vans, the gradual phase in of standards, the overall complexity of tests and legislation, durability requirements.
- For HDVs: the control of defeat devices, the gradual phasing in of the standards and the presence of separate regulatory parameters for lorries/buses (limits and test procedures), durability requirements.

5.1.5. EQ4 To what extent has Euro 6/VI achieved other specific objectives?

5.1.5.1 *Introduction*

Looking beyond the impact on emissions analysed above, in this section we examine whether the regulations have achieved the remaining specific objectives as identified in the intervention logic, namely:

- The presence of harmonised rules on the construction of motor vehicles; and
- The contribution of the standards to achieving NECD targets

In answering this question, we primarily rely on stakeholders' replies to this study's consultation, while referring to supporting literature and emissions data reported by Member States for the EU emission inventory report.

5.1.5.2 *To what extent has the adoption of the standards ensured the presence of harmonised rules on the construction of motor vehicles?*

In general, it should be expected that the introduction uniform emission standards at the EU level in the form of a Regulation, to limit distortions in competition across Europe. This is clearly favourable in comparison to a situation whereby decisions would be taken on a case by case basis by Member States alone (de Sadeleer, 2016).

However, while it is recognised that Euro 6/VI regulations has improved harmonisation, existing analysis also points to outstanding distortions in the market due to discrepancies in the implementation of testing procedures. More specifically:

- In the report on the inquiry into emission measurements in the automotive sector (Gieseke & Gerbrandy, 2017), the rapporteurs highlight that the level of technical expertise and resources available to type-approval authorities vary significantly across Member States. They also highlight that the lack of harmonised interpretation of the rules leading to competition between TAAs, with car manufacturers selecting the authority with the least stringent interpretation of existing rules. This conclusion was drawn from questionnaires sent to type-approval authorities, market surveillance bodies and responsible ministries of the Member States and fact-finding missions at testing sites.
- In his analysis, de Sadeleer (2016) also draw similar conclusions, highlighting that the current type-approval procedure does not prevent manufacturers from requesting approval from a Member States if its request has been rejected in another. As it is argued, heterogenous interpretation of type-approval rules encourages manufacturers to make use of the system, hence leading to competition amongst authorities and a lack of harmony in the type-approved European fleet.
- The input to the targeted stakeholder consultation also provides a similar picture, particularly in relation to Euro 6 standards. There were also negative assessments among industry representatives (seven provided a negative assessment, see Annex 9, Figure 10-4) and some scepticism among members of the civil society in relation to the effectiveness of Euro 6 in that respect (from one consumer organisation, three NGOs and one academic and research institution).
- In their comments, a large number of stakeholders reported that there is still place for interpretation given the many test procedures. This was notably reported by a French OEM, by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (pointing to inconsistent interpretation of the term "illegal defeat device" through different European TAAs), T&E (EU nongovernmental organisation) and the ICCT (EU research organisation).
- According to a vehicle testing supplier, an example of where room for interpretation remains is the authorisation to disable emission control devices to protect components (below 15°C). A representative from a vehicle manufacturer also mentioned possible interpretation due to measurement devices' errors. An international transport research organisation pointed to the problem of the ongoing financial relationships between TAAs and manufacturers as a potential factor for differences in interpretations, a point also raised in the European Parliament report (Gieseke & Gerbrandy, 2017). An EU environmental NGO indicated that, while the regulation led to improvements, uniformity in the application of the regulation would best be supported by the Type-Approval Authorities Expert Group (TAAEG)[95] compiling a yearly list of non-acceptable auxiliary emission strategies.

[95] This group referred to by the questionnaire respondent was since replaced by "Forum for Exchange of Information on Enforcement"

The above picture is also confirmed by responses to the question on whether there have been other impacts as a result of Euro 6/VI, including in terms of the room for interpretation of the requirements by TAAs (see Annex 9, Figure 10-5). In the case of Euro 6, around half of respondents (17 out of 35 that responded), mainly from industry (13) considered that there was a negative impact. The picture was more balance in the case of Euro VI with the majority of respondents (14 out of 24) indicating no impact.

This conclusion is reflected in the responses of stakeholders to the public consultation. Most respondents from all categories consider that the complexity of the Euro 6/VI standards leads to misinterpretations among type-approval authorities (52 out of 104 respondents) while only 12 indicated they disagreed with this statement. Among them, 22out of 48 industry stakeholders agreed that the complexity of the standards leads to misinterpretation among type approval authorities, as well as 10 out of 13 civil society representatives.

Responses concerning the effect on the functioning of the European internal market were more balanced. 55 out of 143 respondents considered that Euro 6/VI standards had only had a partial effect on the functioning of the European internal market, while 28 that it had limited or not at all. On the other hand, 60 respondents considered that it has contributed to ensuring the functioning of the market to a great or very great extent. The share of different responses were largely similar among all stakeholders groups with only national authorities appearing clearly more positive (6 out of 10).

Hence, while there is an overall understanding that Euro 6/VI led to a level of harmonisation which would not have been possible if only conducted at the MS level, outstanding discrepancies are reported, triggered by differences in interpretations of the regulation amongst TAAs, which prevent full harmony amongst the EU fleet.

5.1.5.3 *What has been the contribution of the standards to achieving National Emission Ceilings Directive (NECD) targets?*

By setting limits to vehicles’ emissions of CO, NOx, PM, THC, NMHC, NH3, CH4, Euro 6/VI has an important possible role to play in meeting some of the emission limits set by Member States in the context of the NECD (2016/2284/EC). The Directive requires the setting of emission ceilings to the amount of SO2, NOx, Non-Methane Volatile Organic Compounds (NMVOCs), NH3, CO, PM2.5 and particles emitted per Member State (European Union, 2016).

In our answer to EQ1 (Section 5.1.2) and in Annex 3, we identify emission savings achieved in EU-28 in those pollutants thanks to the introduction of Euro 6/VI. Through the introduction of new vehicles on EU roads, the analysis indicates that Euro 6/VI contributed to achieving NECD targets by enabling the following savings since 2014 (total for the 2013-2020 period):

- Large savings in CO emissions from HDVs (1.5 Mt), and slight savings from LDVs (0.08Mt)
- Large savings in NOx emissions from both LDVs (0.52 Mt) and HDVs (4.0 Mt)
- Slight savings in PM (total) emissions from HDVs (0.01 Mt))

Furthermore, despite not being regulated by Euro 6/VI, small savings were also identified in terms of NMVOC[96] emissions from HDVs (0.01 Mt) as a result of the Regulation (EMISIA, 2020). In contrast, an increase in NH_3 has been is reported for both LDVs and HDVs, though Euro 6/VI has enabled to limit this increase for HD vehicles. These variations in other pollutants are further analysed under EQ5, considered as unintended consequences to the regulations (Section 5.1.6).

On the other hand, data reported by Member States to the air pollutant emission inventory shows no changes in the contribution of road transport emissions to the total emission levels reported from all sectors in EU-28 (Table 5-8). This is likely explained by the rate of fleet renewal, given that Euro 6/VI emission standards address emissions from new vehicles put into service on EU-28 roads, rather than all road transport emissions.

Table 5-8: Contribution of the transport sector to the total emission levels reported in the EU emission inventory report

	2014	2015	2016	2017	2018
NH3	1%	1%	1%	1%	1%
NMVOC	8%	9%	9%	9%	10%

[96] It is useful to separate methane emissions from other hydrocarbon emissions because of its greenhouse gas contribution, expressing emissions as the methane, and non-methane components. This has become increasingly important with the increased use of methane fuelled vehicles. Air Quality Directives (Directive 2008/50/EC), the National Emissions Ceilings Directive (Directive 2016/2284/EU) and the EEA air pollutant emissions inventory guidebook all use the term “volatile organic compounds” (VOCs) whereas vehicle emission standards use the term “hydrocarbons”, and then describe an analysis methodology that detects the volatile (and semi-volatile) hydrocarbons. Therefore, while there are differences in their definitions, in terms of the masses emitted, (NM)VOCs and (NM)HCs are close to being interchangeable. In this study, focussing on vehicle emission standards, we use the term (NM)HCs, and THC as methane + NMHC. However, when referring to conclusions from emissions inventories we use the term (NM)VOC consistent terminology used in the EEA guidance on inventory compilation.

	2014	2015	2016	2017	2018
NOx	39%	39%	40%	40%	40%
PM2.5	11%	11%	11%	11%	12%
SO2	0%	0%	0%	0%	0%
CO	22%	20%	19%	19%	-

Source: Own analysis based on EEA data (EEA, 2019c)

Hence, although Euro 6/VI contributed to an overall reduction in the level of emission of pollutants regulated under the NECD, emission reductions in other sectors mean that this reduction is not reflected in the share road transport's contribution to overall pollution levels, except for CO.

In 2018, total level of NOx emissions from road transport was 2,833 Gg (out of a total of 7,272 Gg of NOx emitted from all industries) (EEA, 2019c). As presented in Section 5.1.2.4, (Table 5-3), 44.19 Mt of net savings in NOx emissions in 2021-2050 are associated with Euro 6, and 60.5 Mt are associated to Euro VI (totalling 104.69 Mt). This is the equivalent of 104,690 Gg. In the same amount of time, and assuming that NOx emission levels remain constant since 2018, total level of NOx emissions from all industries between 2021 and 2050 would amount 210'888 Gg. Hence, if the savings of Euro 6/VI are realised, we expect that Euro 6/VI would contribute to at least 49.6% savings on the total level of NOx emissions from all industries by 2050.

Stakeholders consulted also share the same conclusions (Annex 9, Figure 10-6). Most agreed that the adoption of the standard has improved air quality overall, as intended by the NECD. 40 out of 60 respondents (in the case of Euro 6) and 33 out of 42 respondents (in the case of Euro VI) agreed that the standards have improved air quality, fully or to a significant extent. Only four of them indicated that this was achieved by Euro 6/VI only to a limited extent. Amongst them, an EU environmental NGO points to the still important contribution of road transport to the total level of emissions in the EU. An EU health NGO also highlighted that the decrease in road transport-related pollutant was only moderate in comparison to the overall pollutant decrease.

5.1.5.4 *Conclusions*

Looking beyond the impact on emissions analysed above, we examine whether the Regulations have achieved the remaining specific objectives as identified in the intervention logic. Other specific objectives of Euro 6/VI include the harmonisation of rules on the construction of motor vehicles and the contribution of the standards to achieving NECD targets.

On the former, Euro 6/VI led to a level of harmonisation which would not have been possible if only conducted at the MS level, limiting distortions in competition across Europe through uniform emission standards. However, discrepancies remain due to differences in TAAs resource and capacity, and differences in TAAs interpretation of the standards and testing requirements. Inconsistent interpretation of the term “illegal defeat device” is reported through different European TAAs.

On the latter, emission savings of NOx, CO and PM2.5 brought by Euro 6/VI contributed to the efforts in achieving NECD targets. On the other hand, data reported by Member States show no changes in the share of road transport's emissions to total emission levels. However, this is likely due a decrease on emission from other sectors as well. All other things equal, if the savings of Euro 6/VI are realised, we expect that Euro 6/VI would contribute to at least 49.6% savings on the total level of NOx emissions from all industries by 2050.

5.1.6. EQ5 Has Euro 6/VI had unintended positive or negative consequences or collateral effects?

5.1.6.1 *Introduction*

Other unintended positive or negative impacts may have arisen from the implementation of Euro 6/VI standards. The following main impacts have been reported by stakeholders and are explored in more details:

- Impacts on vehicle prices
- Unintended impacts on non-regulated pollutants (CO_2, NH_3). Other unregulated pollutants are discussed in EQ10, Section 5.2.3.
- These impacts have been considered in light of relevant data and literature and complemented by stakeholders' contribution. Other potential consequences are also explored on the basis of stakeholders' input.

5.1.6.2 *Have there been any impacts from the Euro 6/VI in relation to: prices of vehicles, CO_2 and other emissions?*

5.1.6.2.1 Impact on prices of vehicles

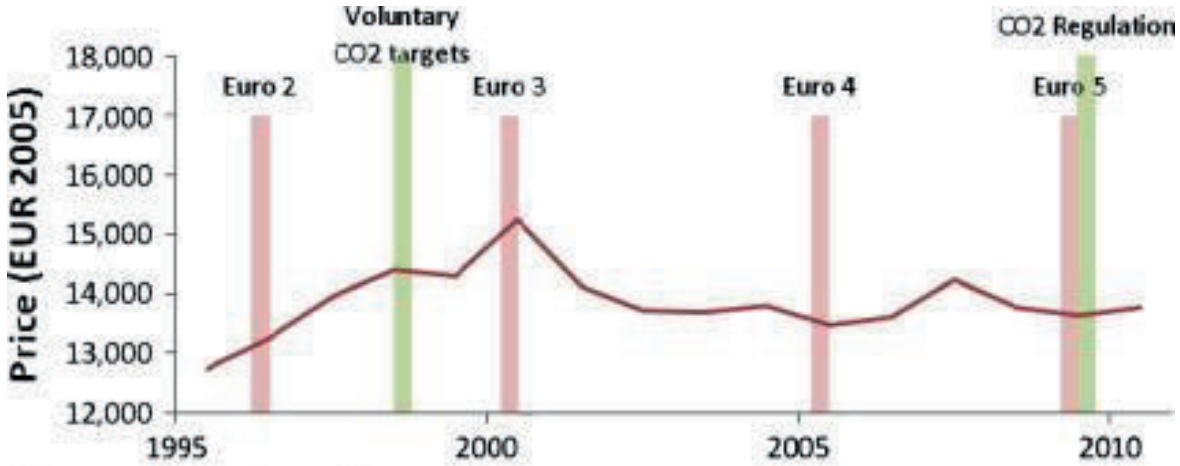
The IA support study for Euro 6 and Euro VI indicated that a certain increase in prices should be expected as a result of the costs of new technologies integrated in the vehicles. This was explained by the structure of the automotive market (monopolistic competitive market with product differentiation but a high degree of competition among many firms), as automotive manufacturers are expected to pass to consumers any increase in the production costs in the long term (Mamakos, et al., 2013). At the same time, in the case of HDVs, any increase in the costs[97] was expected to be small in comparison to the price of a bus or lorry. In the case of LDVs, the additional costs of technology for meeting Euro 6 standards (in comparison to Euro 5) for diesel vehicles[98] were also expected to represent a small share of the vehicle price.

Our analysis of the cost of technologies is presented in detail in section 5.2.1 (EQ8). It points to significant additional costs of technologies fitted to LDVs to ensure compliance with Euro 6, mainly as a result of the introduction of the RDE testing that required additional improvements and new equipment installed to ensure compliance with the limits. The estimated technology costs are higher than what was identified in the Euro 6 Impact Assessment and, on top of these, other regulatory costs need to be considered. In the case of HDVs, the analysis presented in EQ8 points to costs that are in a similar range with that in the Euro VI IA support study together with a significant increase in other regulatory costs (including both in terms of testing and type approval) that were not considered in the IA support study. As such, the total cost per vehicle for both Euro 6 and Euro VI is higher than what was considered in the IA studies. Nonetheless, on a per vehicle basis, the estimated regulatory costs are still relatively small in comparison to vehicle prices, less than 3% for most light duty vehicles, less than 4% for HDVs (see comparison with vehicle prices in section 5.2.1.5).

However, it is difficult to tell with certainty whether these regulatory costs have actually had an impact on vehicle prices. Earlier studies on the impact of environmental legislation suggest that it is not possible to make a clear connection between additional costs of regulation and vehicles prices. In their analysis Wells et al. (2013) found limited evidence that the cost of regulations on emission controls have a direct impact on list prices. Using a regression analysis based a dataset of car prices of the top 10 selling models in 2010 for six Member States they concluded that:

- In the case of the progressive tightening of standards which were not linked to new technology, standards were met without impact on list prices.
- In the case of requirements that required the incorporation of new technologies such as catalytic converters, this led to increases in car prices. There was a small price peak in the lead up to Euro 3 (3.6% for one year), presumably associated with the costs of introducing catalytic converters. However, it was possible for OEMs to amortise costs across larger markets rather than through increased prices. There was not similar increase observed in the case of Euro 4 or Euro 5.

Figure 5-9: Change in the average price of new cars (in Euro 2005) in the supermini segment across six Member States 1995–2010 with environmental legislation overlaid.



Source: Wells et al. (2013) on the basis of data from JATO dataset

Another study on "the effect of regulations and standards on vehicle prices" (AEA, 2011) examining historical vehicle prices and vehicle features did also not find a definite relationship between car prices and vehicle emission standards. The extent to which additional costs are passed on to consumers reportedly depends on environmental standards but also market conditions (tax levels, consumers' purchasing powers, etc) and competition and can vary

[97] Expected to be in the range of €2,539 and €4,009 (2012 values) per vehicle depending on engine size.

[98] There were estimated at EUR 213/vehicle (2005 prices) in comparison to Euro 5. In addition, the IA SWD states that this represents an upper estimate of the costs.

depending on brand and type of vehicle sold. It was concluded that manufacturers often absorb the costs or employ other strategies to reduce vehicle costs or recuperate the costs such as by charging extra for additional features/options to a basic model.

Having said that, the above conclusions may not necessarily apply in the case of Euro 6/VI, especially in view of the sizeable increase in the costs associated with the adoption of new emission control technologies described in section 3.5.2 and the reported significant relative increase in the other regulatory costs (enforcement and administrative costs as analysed in EQ8).

Analysis of data on average prices based the ICCT's annual European vehicle market statistics points to an increase in the average prices of passenger cars in the period since 2014. Table 5-9 presents the retail price increases between 2014 and 2018. The latter are derived from ICCT (2014c). Nominal prices (as stated in the ICCT Pocket book) were adjusted to real values by applying the annual EUR inflation rate for the same period[99]. As can be seen, there is an increase in the average prices in the period after 2014, in comparison to an actual decrease in the previous period (2007-2014). Among the 20 manufacturers for which we data is available, most (16) increased the average price and only 4 decreased the average retail prices over the same period. In contrast, 17 out of 19 manufacturers decreased their average prices over the period 2007-2014[100]. (see detailed table with data per manufacturer in Annex 10)

We should note the limitations of such analysis. Average price data for each year are affected by fleet composition changes that can lead to an average increase that is not a result of actual increase in prices (e.g. increased prominence of SUV and heavier vehicles as well as the gradual introduction of more expensive hybrid and electric vehicles).

Table 5-9: Average change in retail price increase of passenger cars and vans in the period 2007-2014 and 2014 – 2018 (2018 prices).

	2007-2014		2014-2018	
	Absolute [EUR]	CAGR	Absolute [EUR]	CAGR
No of OEMs	19	19	20	20
Mean	-1,015	-0.4%	1,549	+1.3%
Min	-5,021	-1.9%	-3,920	-4.6%
Max	2,287	2.7%	5,604	+3.3%
Median	-691	-0.4%	2,145	+1.8%
No of OEM with increased average price	2		16	

Source: Own analysis based on ICCT European vehicle market statistics (ICCT, 2019a)

With these caveats in mind, the available data point to an increase in the average vehicle price that during the period 2014-2018 that may, among others, be linked to the increase in the costs associated with Euro 6 standards. This increase may or may not be related to the Euro 6 standards although the general assumption of the monopolistic competitive market structure would suggest that vehicle prices should be affected.

Qualitatively, input from stakeholders who responded to the targeted consultation also suggests some negative (i.e. increase) in the prices in both cases (Euro 6 and Euro VI) (Annex 9, Figure 10-7). Two stakeholders (a national public authority and a supplier) considered that Euro 6/VI had a limited positive impact (i.e. reduction), with the latter suggesting that any impact from Euro 6 had probably been offset by the fuel savings (presumably a result of CO_2 legislation). Another automotive parts supplier commented that that engineering costs have increased significantly but that the full cost increase was not passed on to the end users. Similar input was provided by the majority of respondents to the public consultation. 121 out of 139 respondents considered that the Euro 6/VI standards led to the increase of the price of cars, 47 of which consider it has increased "significantly". The responses were very similar across all stakeholder group and they were also very similar responses in terms of the impact of the prices of vehicle categories, including vans (112 out of 130), lorries (101 out of 113) and buses (96 out of 109).

[99] There are no similar data available for HDVs.

[100] Data available from Statista on Average price (including tax) of passenger cars in the EU in 2014 and 2018 by brand also indicate an increase in the prices over the same period. Only two out of 18 brands experienced an average reduction in prices. (Statista, 2019)

All in all, while not conclusive, the input from stakeholders and some evidence on the basis of average prices suggests that there has been an impact on vehicle prices, in line with the general expectation of a pass through of costs to consumer. This appears to be driven by the increase in the compliance costs of the standards. Nonetheless, it is not clear whether a full pass-through of the costs has occurred. Past experience and analysis of the impact of environmental regulation suggests that it is difficult to make a direct connection between the increased costs and the impact on vehicle prices.

5.1.6.2.2 CO_2 emissions

The IA support study that supported the adoption of Euro 6 suggested there would be no discernible impact on CO_2 emissions relative to Euro 5. This was mainly because there was no impact on the fuel efficiency expected from the adopted technologies for diesel vehicles. In the case of Euro VI, a possible negative impact was expected due to some forms of engine technology and after-treatment resulting in slightly higher CO_2 emissions in comparison with Euro V, mainly as a result of using diesel particulate filters.

In the targeted stakeholder consultation, ten vehicle manufacturers as well as an EU vehicle manufacturers' association argued that the emissions control systems and calibration necessary to comply with Euro 6d have had an adverse effect on CO_2 emissions, that filtration efficiency required to be compromised for CO_2 standards, and that the strict NOx limits reduce the potential for CO_2 reduction. In an evaluation study on the CO_2 emission standards for LDVs (2015), Ricardo found that technologies primarily aimed at reducing NOx and PM emissions (e.g. engine-based measures or exhaust aftertreatment systems) may increase CO_2 emissions from vehicles (Ricardo, 2015). Such increases in CO_2 emissions are caused by increases in backpressure required for filtration or SCR units. Consequently, a direct impact of the stricter NOx limits is to possibly increase CO_2 emissions.

However, the addition of this technology does also offer the potential for recalibrating the engine, particularly with respect to fuel injection timing, to improve efficiency and reduce CO_2 emissions at the expense of slightly increased NOx emissions, which are subsequently removed by the addition of the SCR unit. Automotive suppliers and NGOs also pointed towards the existence of solutions that allow the reduction of NOx and CO_2 emissions, such as battery electric vehicles, cylinder deactivation, closed-coupled SCR systems, heated urea injectors or mild hybridization. Further to that, as already described in section 3.5.2, in order to achieve better NOx control OEMs have often introduced better fuel injection systems which also allow them to improve engine efficiency. In addition, while it was generally considered that diesel vehicles are more fuel efficient, recent studies (ICCT, 2019b) suggest that current PI vehicles can be more or equally efficient.

Data on CO_2 emission factors from the COPERT model comparing the Euro 6/VI with the Euro 5/V baselines points to small net impact on the level of CO^2 emissions overall, coming from HDVs (see Figure 5-10 and Figure 5-11).These are in line with the expectation of a limited overall impacts in the IA support studies.

Figure 5-10: Evolution of CO_2 emission factors of Euro 6 passenger cars (average values) (g/km)

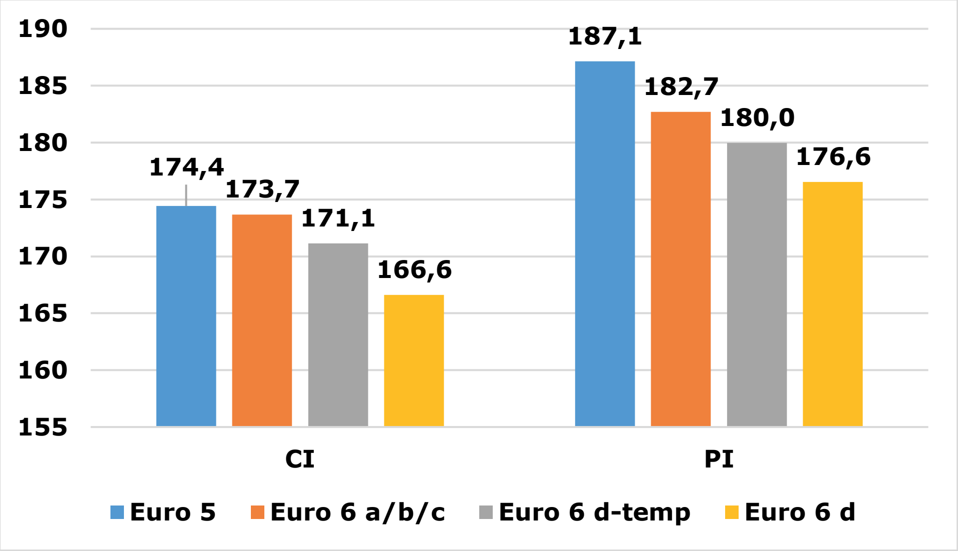
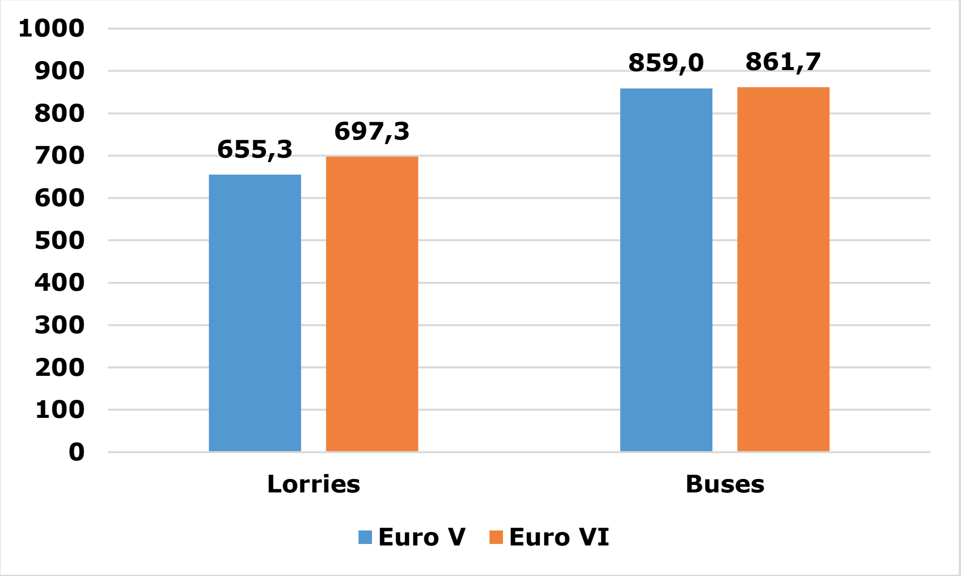


Figure 5-11: CO_2 emission factors of Euro VI vehicles (in g/km)



Source: Own analysis based on SIBYL model

The above conclusion is also supported by the responses provided by stakeholders in the context of the public consultation. The majority of respondents (96 out of 162) from all stakeholder groups considered that Euro 6/VI did not contribute to reducing greenhouse gas emissions at all (50 out of those 96), or only very little (46 out of those 96). Responses to the targeted consultation were more balanced when it come to the related issue of the impact on fuel consumption from vehicles:

- In relation to Euro 6, 15 out of 50 respondents indicated a positive impact (including 4 public authorities, 5 automotive parts supplies, academic institutions, and technical services) and 16 indicated no impact. However, a total of 21 respondents indicated a negative impact, including 13 that suggested a limited negative impact (6 OEMS, 2 fuel suppliers' associations, an international vehicle testing association, a TAA, an EU consumer organisation and an automotive parts supplier) and 8 the suggested a significant negative impact (only OEMs).
- In the case of Euro VI, 9 out of 34 suggested a positive impact (including public authorities, automotive parts suppliers and academic institutions), 14 no impact and 11 out of 34 a limited negative impact (8 OEMs, a public authority, a TAA and an automotive parts supplier).

Notwithstanding the above input by some stakeholders, we consider that there is no strong evidence to suggest that that the adoption of Euro 6/VI has led to an increase of CO_2 emissions. There is potential impact on CO_2 emissions from the choice of specific emission control technologies which increase the backpressure required for filtration or SCR units, but these are rather the result of technology choices by OEMs and it is not necessarily caused by Euro 6/VI, as the technology to improve CO_2 emissions and NOx emissions exists.

5.1.6.2.3 NH_3 emissions for LDVs

NH_3 emissions are not regulated for LDVs, despite passenger cars being the largest contributor of ammonia emissions from the transport sector in Europe (EEA, 2019a).

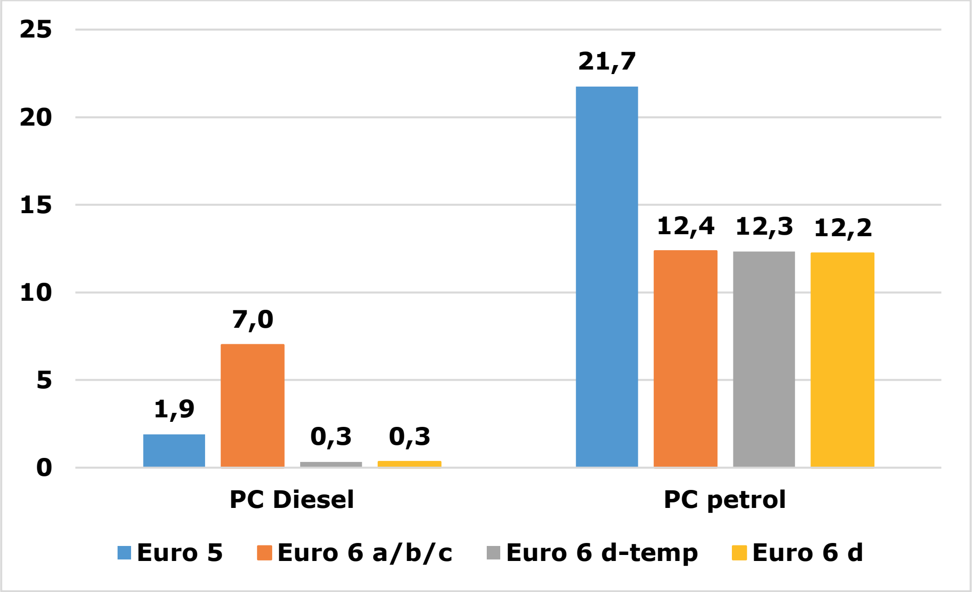
Side reactions in three-way catalysts used to be the main source of these emissions. However, it is also a possible side effect of the technologies used to limit NOx emission. Recent studies point to the fact that NH3 emissions are produced by LNT during regeneration and cold starts, and by SCR, both causing "ammonia slip" (ICCT, 2019c). The use of ammonia slip catalysts (ASC) has increased in more recent Euro 6d diesel vehicles (see 3.5.2) to mitigate this.

In that respect, several studies have found that NH_3 emissions increase based on the technology used to comply with Euro 6/VI, at least for earlier versions:

- Through PEMS and WLTP laboratory procedures, Suarez-Bertoa, et al. (2020) measured emissions of five Euro 6 vehicles with different technologies fitted. They find that Euro 6 d-TEMP vehicles have higher NH_3 emissions in gasoline vehicles and in diesel vehicles equipped with SCR only, as opposed to those equipped with SCR and ASC.
- As reported in the Part (A) report on the evaluation of the effectiveness of current European emission standards, particularly high NH3 emissions have been observed on cars equipped with three-way catalysts (CLOVE, 2020) and N2O.

The available emission factors from the COPERT model suggest that there has been limited change in the case of NH3 in the case of LDVs, following an increase in the initial stages of Euro 6 indicated above (see Figure 5-12).

Figure 5-12: Evolution of emission factors for NH3 for passenger cars (mg/km)



Source: Own analysis based on COPERT

This is also reflected in the estimated impact on the total emission levels, as presented in Table 5-10 and Table 5-11 below.

Table 5-10: Net impact of Euro 6 on total NH3 emissions (in comparison to Euro 5 and Euro 6 pre-RDE) [101]

	Euro 6 RDE to Euro 6 pre-RDE			Euro 6 (total) to Euro 5		
	Up to 2020	In 2020	2021-2050	Up to 2020	In 2020	2021-2050
LDVs (cars and vans)						
NH3 (in MT)	1.83	1.08	400.1	4.21	2.03	149.8
% change	1.9%	6.9%	41.8%	4.4%	12.2%	21.2%

Source: Analysis based on SIBYL model

Table 5-11: Net impact of Euro 6 on total NH3 emissions by fuel type (in comparison to Euro 5 and Euro 6 pre-RDE)

	Euro 6 RDE to Euro 6 pre-RDE			Euro 6 (total) to Euro 5		
	Up to 2020	In 2020	after 2020	Up to 2020	In 2020	2021-2050
	CI LDVs					
NH3 (absolute)	0.00	0.00	-0.27	0.01	0.00	-0.04
% change	-6%	-19%	-82%	79%	92%	-40%
	PI LDVs					
N3 (absolute)	0.00	0.00	-0.13	-0.02	0.00	-0.11
% change	0%	0%	-21%	-20%	-29%	-18%

5.1.6.3 *Other potential unintended impacts*

In the context of the targeted consultation, stakeholders were also asked to provide input on other potential impacts resulting from the introduction of Euro 6/VI. These included:

- Contribution towards the achievement of air quality targets set per Member State
- Contribution towards controlling/reducing tampering by consumers/garages (e.g. removal of DPFs)

Another potential indirect impact identified – consumer awareness of air pollution problems – is considered in detail in section 5.1.8.6 (EQ7).

Considering the contribution towards the achievement of air quality targets set per Member State, this is linked with the extent that Euro 6/VI vehicles are indeed cleaner and

[101] Impact projected for 2021-2050 may differ depending on the final vehicle fleet composition available at the end of 2020.

they effectively replace the more polluting Euro 5/V across the EU. In that respect, the evidence presented in section 5.1.2 (EQ1) suggest that Euro VI HDVs and the most recent Euro 6d LDVs are indeed significantly cleaner. However, it also pointed out that they still represent a small share of the total fleet across the EU, especially in relation to Euro 6d LDVs. As such, so far, their contribution should be positive towards the achievement of air quality targets but probably limited.

This is also reported by the majority of stakeholders from the targeted consultation. 52 out of 56 indicated that Euro 6 standards for LDVs had at least a small positive impact on the achievement of air quality targets. These include representatives from all stakeholder groups, including vehicle manufacturers, TAAs, suppliers, academic and research institutions and public authorities. Among those that indicated a significant positive impact, vehicle manufacturers are the most represented (11 out of 30) following automotive parts supplier (8 out of 30). Only four stakeholders indicated no impact at all. According to two vehicle manufacturers, this is due to the low share of vehicles in the fleet, while a national authority considered that the impact is only limited due the late implementation of RDE. Similar answers were also provided in relation to the contribution of Euro VI, with 35 out of 36 stakeholders indicating at least a small positive impact. 14 of them from a broad range of stakeholders (six vehicle manufacturers, three automotive parts suppliers, two type approval authorities and two national authorities) indicated significant positive impact.

In terms of the impact on the level of tampering by consumers/garages (removal of DPFs for LDVs and of DPFs and AdBlue Systems for HDVs) most stakeholders considered that the introduction of Euro 6/VI has had a negative (i.e. increase) impact on tampering by consumers/garage. In relation to Euro 6, 19 out of 34 respondents reported a negative impact (which would mean increase in tampering), including 8 OEMs, 3 TAAs and 2 public authorities. 12 reported no impact. Only 3 reported a positive impact (decrease) (2 automotive parts suppliers and 1 EU vehicle testing suppliers' association). In relation to Euro VI, 17 out of 31 report a negative impact, while 3 report no impact and 11 a positive impact.

The proposed negative impact is linked to the increasing need of consumables (e.g. SCR needing AdBlue) or the significant capital costs (e.g. of a DPF) that, as argued, provide greater scope for tampering with, and more financial incentives to tamper relative to pre-Euro 6/VI. It is also suggested that the tampering measures in place, including OBD, can help detect some of these behaviours, but not all. As already indicated in Section 5.1.4.2 current OBD provisions are still not robust enough to be able to avoid all possible manipulation. At the same time, the EU vehicle testing suppliers' association commented that existing measures against fraudulent manipulation of DPFs and AdBlue systems have been too timid and measures against fraud professionals (those who carry out these clean-up system degradation operations) are non-existent. However, we note that the above point to aspects that are mainly associated with the implementation of the roadworthiness legislation and not the Euro 6/VI standards.

All in all, stakeholders input points to the fact that the adoption of more demanding requirements under Euro 6/VI has increased the scope and incentives for tampering while the current OBD requirements are not robust enough and provide room for possible manipulation going unreported. However, it still the case that that important part of the problem of capturing such tampering is mainly related to the implemented of the roadworthiness legal framework.

5.1.6.4 Conclusions

Other unintended positive or negative impacts may have arisen from the implementation of Euro 6/VI standards (apart from emission reductions and the reduction in the gap between type-approval and real-world emissions). For each of them, the evidence available points to the conclusions that are summarised in the table below.

Table 5-12: Summary of Euro 6/VI unintended impacts

Unintended impacts	Type and level of impact
Main impacts identified	
Impact on vehicle prices	Increase in prices expected as a result of higher compliance costs (driven by increases in regulatory costs and significant additional costs of technologies to comply). Level of increase is still expected to be limited (0.6%-4.3% for LDVs; 4.2-5.0% for lorries and 2.1%-3.0% for buses) and will also depend on whether OEMs pass-through costs to consumers
CO_2 emission levels	No strong evidence of Euro 6/VI impact on CO_2 emissions. Potentially small negative impact (increase) due to the choice of specific emission control technologies, which can increase the backpressure required for filtration or SCR units. However, these are the result of technology choices by OEMs as the technology to improve CO_2 emissions and NOx emissions exists.
LDVs' NH_3 emissions	The available emission factors from the COPERT model suggest that there has been no negative impact in the case of NH3 for LDVs. Emission factors have largely decreased upon the introduction of RDE testing, following the slight initial increase in the initial stages of Euro 6.

Other potential impacts identified by stakeholders	
Achievement of air quality targets per MS	Positive but limited impact up to now associated with the recent introduction and low uptake of the cleaner Euro 6d vehicles
Impact on the level of tampering by consumers/garages	Increased incentives for tampering as a result of the more demanding and costly requirements. Limitations of the OBD requirements.

5.1.7. EQ6 What are the benefits of Euro 6/VI and how beneficial are they for industry, citizens and the environment?

5.1.7.1 *Introduction*

Euro 6/VI benefits to the environment have already been demonstrated by a reduction in the level of real-world emissions thanks to tighter emissions limits and a gradual tightening of the testing procedures. In this section, we assess the impact that such reductions have had on EU citizens, and particularly on their health. We also examine the possible impact on the competitiveness of the EU automotive industry. To do so, we answer the following questions:

- Have there been observed health impacts as a result of Euro 6/VI?
- What has been the impact of the Euro 6/VI standards on competitiveness of the EU automotive industry?
- Has there been any direct impact (positive/negative) on employment?

In our assessment we use input from the relevant literature and data sources and input from stakeholders.

5.1.7.2 *Have there been any changes in the levels of observed health impacts as a result of Euro 6/VI?*

Road-transport is the main contributor to NOx emissions and third contributor to PM emissions, out of nine potential sources sectors (EEA, 2019a). By reducing the emission levels of pollutants as seen in section 5.1.2, the adoption of Euro 6/VI standards were expected to lead to a decrease in the level of health impacts from road transport. These include respiratory diseases (e.g. bronchitis, asthma, lung cancer) and cardiovascular diseases that are associated with the inhalation of air pollutants regulated by Euro 6/VI such as particles (particles, PM2.5), nitrogen oxides (NOx) (European Commission, 2019c).

In monetary terms, this would translate in the reduction in the associated external costs from transport, as negative health effects lead to medical treatment costs, production loss at work (due to illness) and even to death. The health-related costs represent most of the total external cost from traffic (over 90%), with only 10% of other costs related to biodiversity and building and material damages (CE Delft, 2018).

Analysis from the literature already points to the important positive savings arising from the introduction of Euro 6/VI standards. The 2019 Handbook (European Commission, 2019c)[102] points to a 17% reduction in external costs per diesel LDV vehicle-km in all areas (metropolitan, urban, rural), associated with the reduction in NOx emissions imposed by Euro 6 regulations on diesel cars. In contrast, no improvements were observed overall for PI light duty vehicles. In the case of heavy duty vehicles (which are predominantly diesel), Grigorators et al. (Grigoratos, et al., 2019) concluded that external costs have reduced from Euro V to Euro VI by 90% on average, across vehicle type and driving conditions,.

Based on the SIBYL/COPERT model we have been able to analyse the monetised benefits following the introduction of Euro 6/VI in some greater detail, differentiating between pre-RDE and post-RDE Euro 6 vehicles (Table 5-13)[103]. The detailed cost savings from the reduction in emissions of the dangerous pollutants form Euro 6 and Euro VI are summarised in Table 5-13 below[104]. Data are presented for NOx and particles that are the main contributors according to the Handbook's data (European Commission, 2019c), but does not include PN that is not covered by the model.

We estimate that the total impact on external costs from Euro 6 vehicles associated with the reduction of NOx and particles amount to €28.5bn up to 2020. The introduction of RDE testing

[102] The Handbook uses emission data from the SYBIL model to estimate the costs per vkm for the different vehicle categories of road transport. Costs are calculated to reflect health impacts (WHO 2013) taking into account "concentration response functions", population size and structure based on Eurostat data, population density, relationship factor between damage and emissions for various emission scenarios, and the most recent valuation of human health (European Commission 2019).

[103] The savings identified from the SIBYL emission model have been monetised using the same monetisation values-scheme as the 2019 "Handbook on external costs", while taking the weighted averages of the activity shares of the different vehicle categories, weighted over the activity (in km/year) of the different categories and taking into account fleet composition data.

[104] The table presents the impact of NOx and particles emissions that are the most "costly" air pollutants in the EU in 2016 according to the Handbook (European Commission, 2019c). Other pollutants impacting health are referred to in the conclusion. NH3 is discussed below, NO2 is discussed in EQ10. Other harmful regulated and unregulated pollutants are presented in annex 3.

accounted for €2.1 bn, driven by the reduction of NOX emissions, though it had less effect on monetised benefits from particles emissions reduction up to now (2bn overall). For heavy-duty vehicles, Euro VI regulation translates into €65.1bn total monetised benefits up to 2020. In both cases, the reduction in NOx emissions correspond to the majority of the benefits. The monetised benefits are expected to be significant greater in the period 2021-2050, exceeding in total over one trillion, mainly associated the reduction of NOx emissions.

Table 5-13: Impact on external costs from Euro 6/VI vehicles [billion EUR]

Vehicle Category	Benchmark for savings	2010- 2020	2020	2021-2050
NOx				
Light duty vehicles	Euro 6 pre-RDE over Euro 5	26.4	6.4	446.3
	Euro 6 RDE over Euro 6 pre-RDE	2.1	1.3	305.8
	Total Euro 6 over Euro 5	28.5	7.6	752.2
Heavy duty vehicles	*Euro VI over Euro V*	65.1	15.1	979.8
Total monetised benefits from NOx reductions		**93.6**	**22.8**	**1,732.0**
Particles (total)				
Light duty vehicles	Euro 6 pre-RDE over Euro 5	1.9	0.5	31.4
	Euro 6 RDE over Euro 6 pre-RDE	0.1	0.0	7.8
	Total Euro 6 over Euro 5	2.0	0.5	39.2
Heavy duty vehicles	*Euro VI*	1.4	0.4	40.0
Total monetised benefits from particles reduction		**3.4**	**0.9**	**79.2**

Source: Own analysis based on SIBYL/COPERT model

The above conclusions are also supported by the responses provided by stakeholders in the context of the public consultation. 100 out of 160 respondents considered that Euro 6/VI contributed to protecting human health to a great or very great extent, with the remaining being more sceptical (somewhat or not at all). Responses were largely similar among stakeholder groups with the exception of national authorities, all 13 of which suggested strong positive impact.

Despite the positive impacts indicated, the literature also highlights outstanding risks to health related to higher emissions potentially not being properly captured during regeneration at short intervals (although the weighted average remains below the regulatory limit) (Valverde & Giechaskiel, 2020; Giechaskiel, 2020). Other pollutants with important health impacts, such as NO_2 which is associated with mortality and morbidity impact on human health (US EPA, n.d.) are not currently regulated under Euro 6/VI. In that respect, it is not clear whether the reduction in NOx external costs achieved is not offset by an increase in its share of NO2 observed in recent decades (Transport & Environment, 2015; ICCT, 2019c; Carslaw, et al., 2016).

Further information on potential health impact of non-regulated pollutants is discussed in EQ10. Monetised benefits of other harmful pollutants, included non-regulated ones, are presented in Annex 3.

5.1.7.3 *What has been the impact of the Euro 6/VI standards on the competitiveness of the EU automotive industry?*

In analysing the impacts of Euro 6/VI standards on the competitiveness of the EU automotive industry on the global market, we considered the following interlinked aspects that are critical for the competitiveness of the sector:

- The possible impact of the standards on the relative costs and profitability vis a vis non-EU competitors (cost competitiveness)
- The role of the standards in terms of ensuring access to markets (i.e. the capacity to sell) (international competitiveness)
- The contribution to the development of new technologies and innovation (innovation competitiveness).

5.1.7.3.1 In terms of the impact of costs

The impact on the costs for the sector are analysed in detailed in section 5.2.1 (EQ8). Overall, the analysis suggested that the stricter requirements resulting from the Regulations together with the changes to the testing requirements have had led to a significant increase of the total regulatory costs for OEMs (i.e. costs incurred to ensure compliance, enforcement/monitoring, administrative costs) as they required the development and/or integration of new technologies in Euro 6 vehicles (Ricardo Energy and Environment, 2017).

Such costs are generally expected to be passed to consumers without eroding the profit margins. However, input from stakeholders – mainly from industry - point to the increased costs and a possible negative impact on profitability resulting from the introduction of the standards (see also Annex 9, Figure 10-8):

- 22 out of 31 respondents (including 14 OEMs and 4 suppliers) indicated that the introduction of the Euro 6 standards for LDVs had a negative impact of on the profitability of the EU automotive sector. An automotive parts supplier explained that there were small negative impacts on profitability due to the increased complexity of technologies and calibration processes. Another supplier commented that the increased costs were not passed on to end users, having a negative impact on profitability. However, other stakeholders (not including any OEM) considered that any costs implication could be offset an increase in car prices.
- In the case of Euro VI, 12 out of 20 respondents indicated that the introduction of Euro VI standards had a limited negative impact of on the profitability. The combination of additional technologies/hardware included, the high initial development costs, as well as calibration efforts were identified by one vehicle manufacturer as having a clear impact on vehicle costs and manufacturers profitability.

Available data for the period 2013-2019 point to a decrease in the profitability of the EU automotive sector since 2017 (see Figure 5-13). However, besides the fact that it is not possible to make a direct connection, similar trends are also observed in the automotive sector in the US and globally.

Figure 5-13: Evolution of Pre-tax Unadjusted Operating Margins in the automotive sector (comparison of EU, US and global)

	2013	2014	2015	2016	2017	2018	2019
Europe Auto & Truck	5.7%	6.2%	6.8%	7.3%	7.9%	7.2%	5.7%
Europe Auto Parts	7.4%	7.7%	8.4%	7.9%	8.6%	7.1%	5.1%
Global Auto & Truck	5.7%	5.9%	6.4%	6.3%	6.0%	5.9%	4.8%
Global Auto Parts	6.6%	6.7%	6.9%	7.0%	7.6%	6.7%	5.3%
US Auto & Truck	3.3%	2.3%	4.4%	5.3%	3.9%	4.2%	3.4%
US Auto Parts	7.4%	6.6%	7.0%	8.5%	9.0%	8.9%	7.2%

Source: Own elaboration based on data provided from Damodaran online[105]

Further to that, any increase in the costs directly associated with meeting the Euro 6/VI standards should, in principle, be applicable to all vehicle manufacturers that place vehicles in the EU market. This should generally be the case to the point that other OEMs do not have access to existing technologies and cheaper resources to meet the requirements. There is no evidence that relevant technologies were not available to EU manufacturers but they may be at a disadvantage as a result of the higher labour and other indirect costs when compared to competitors in lower cost countries (e.g. China) (Ricardo Energy and Environment, 2017). As such, the higher regulatory costs arising from Euro 6/VI legislation may a possible negative indirect effect on the competitive position of EU manufacturers.

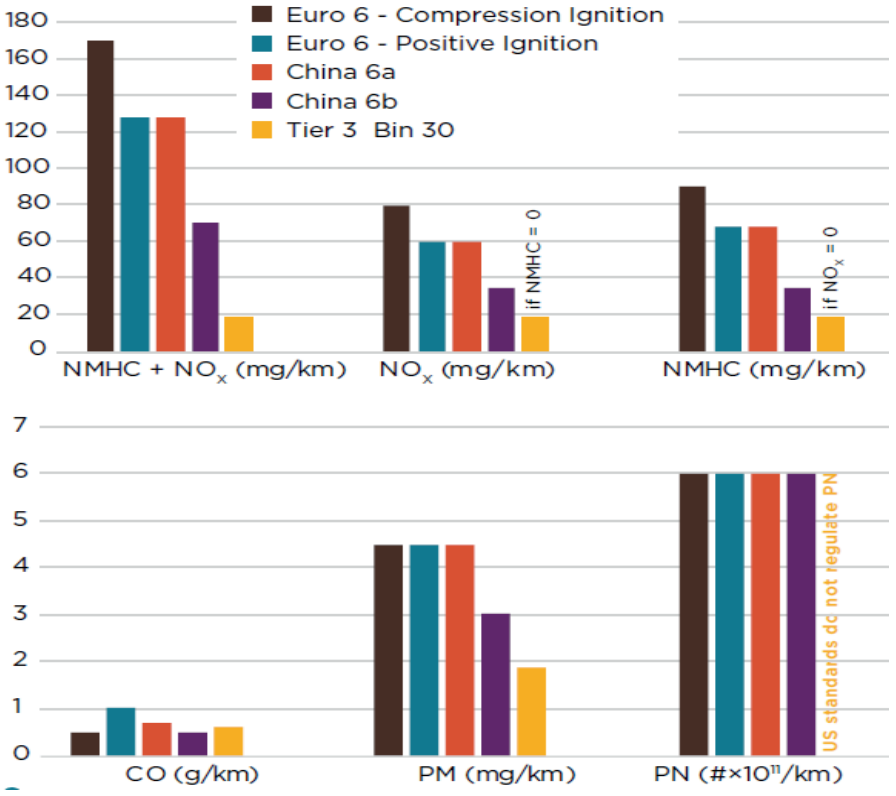
[105] http://people.stern.nyu.edu/adamodar/New_Home_Page/databreakdown.html - Data provided are collected from annual financial statements

5.1.7.3.2 Impact of Euro 6/VI in supporting the innovative capacity of the automotive sector

As is analysed in more detail in EQ8 (Section 5.2.1), the adoption of the standards is linked to a sizeable level of investment in R&D activity to support the adoption and further development of the technologies needed to ensure compliance with the requirements. Costs related to R&D, including both work on the development/upgrade of technologies as well as the vehicles calibration, represent a significant share of the total costs to industry. The majority of stakeholders consider that the adoption of the standards played an important role in promoting such activity and that this should not have been expected in the absence of the standards. As such, it appears to be the case that the standards have had a certain positive role in supporting the innovative capacity of the EU automotive sector.

Considered against the standards set in other markets, the picture is mixed. EU standards are no longer in the forefront in terms of the strictness of the limits set for a number of key pollutants. The limits values set in Euro 6/VI lag behind those already in place or those expected to be introduced in the coming years in other key markets. With the exception of particulate matter, both US and China's regulations have adopted more ambitious limit values than the current EU standards in the post-2020 timeline, as presented in Figure 5-14 below. Tier 3 Bin 30[106] in the US is being rolled out since 2017 although it is not expected to become dominant before 2025, while China 6 standards will be implemented in July 2020. Korea and Japan have identical or more relaxed limits that the EU when it comes to CI vehicles but more stringent limits for PI vehicles, especially for NOx (CLOVE, 2019). Other pollutants are also regulated in other regions, such as N_2O in China, CH_4 in the US, or NH_3 on CI LDVs in Brazil (CLOVE, 2019).

Figure 5-14: Overview of the US-China-EU limits comparison



Source: 1st AGVES meeting – ICCT input (2019)

Furthermore, in the case of evaporative emissions, the emission standards in the EU remain less stringent compared to the most other regions (including US, China, Brazil, South Korea). Despite the recent advances in evaporative emission regulations in the EU (Euro 6d-Temp step), the standards remain less demanding both in terms of the limit value set and the testing requirements (CLOVE, 2019).

Having said that, limit values are only one element determining the strictness of the standards and the testing procedures are equally important. In that respect, the adoption of RDE - intended to ensure that limit values are more closely related to real world emission – has placed the EU in the forefront as a leader with one of the most robust and advanced regulatory frameworks developed globally with other regions around the world following EU's policies and methods on RDE. While limit values may be higher, the RDE testing requirements means

[106] Tier 30 emission standards require that manufacturers must certify vehicles to one of seven available "certification bins" and must meet a fleet-average emission standard for their vehicle fleet in a given model year. Bin 30 corresponds to a NMOG+NOx emissions limit if 30 mg/mi. The fleet average must achieve this by 2025.

that on-road emissions targets are actually significantly more demanding for the OEM to meet robustly. China, Japan and South Korea are implementing RDE testing and using the MAW method, with testing parameters at best similar to current RDE regulation in Europe. However, the Chinese Conformity Factors are higher than in the EU[107] essentially allowing for higher level of emissions while Japan's driving cycle does not include extra-high speed) (CLOVE, 2019). Similarly, the EU regulations for HD ISC testing together with the NTE approach for HDVs under Euro VI set the standard for other regions of the world (CLOVE, 2019). On the other hand, while the testing cycle in place in the US is comparable to the European WLTP, enforcement of Tier 3 requirement in the US are considered more stringent, with standards being very detailed to eliminate loopholes and OBD enforcement mechanisms both reduce ability to cheat and increase information to regulators (defect reporting requirements) (ICCT, 2015d). For HDVs, European MAW method captures more test time and emissions and will decrease overall pass rates compared to the existing US NTE method (CLOVE, 2019).

Overall, while this may vary depending on the specific pollutant under consideration, the role of the Euro standards appears to have mainly been towards that the adoption of existing technologies and ensuring that manufacturers do not fall behind third country competitors. They have had less of a role in the adoption of new breakthrough technologies which could provide an early technological advantage vis a vis their competitors based in other regions.

5.1.7.3.3 Ensuring access to other markets

In principle, the strengthening of the emissions standards and the adoption of more advanced technologies to ensure compliance should also help EU manufacturers in their access to also ensure easier access to third markets, giving them a possible early lead in the adoption of relevant technologies and gaining a external mature and emerging markets competitive position vis a vis other competitors.

To the extent that EU standards have gradually fallen behind certain regions (at least vis a vis the US) it can be argued that they have not had the supporting role expected. Pointing to this developments, the report of the High Level group on the on the Competitiveness and Sustainable Growth of the Automotive Industry (European Commission, 2017a) concluded that, in this context, European manufacturers would not be expected to benefit from competitive gains with Euro 6/VI regulation given that global competitors gradually implement tighter standards. However, given the picture presented in the previous section, such a conclusion should be treated with caution as the combination of limits and testing requirements could be considered as putting the EU standards at the forefront against competitors in many respects.

The level of the impact of such development is also indicated by the reliance of EU manufacturers on EU sales. In that respect, EU manufacturers still have a relatively high level of reliance on the EU market with only 23% of the total vehicle production in 2019 (circa 4.3 million out of total sold production of 18.5 million) exported. This represented 33% percent of the production value. A very similar level applied in 2013 (26% of production volume and 34% of production value exported) (Eurostat, 2020)[108]. Having said that, local production is the most common approach to accessing external markets (Copenhagen Economics, 2014). As such, most EU manufacturers should be expected to be affected by the tighter requirements of external markets as well and be forced to adopt more advanced technologies.

All in all, it is difficult to tell with certainty if there is a direct impact in terms of market access and, if so, how significant it is. At best, Euro 6/VI standards (i.e. combination of emission limits and testing requirements) have possibly had a positive role in supporting access to the markets of certain key regions/countries on the basis of the more demanding testing procedures (and despite less strict limits). However, it is probably the case that their role in this respect has been rather limited.

5.1.7.3.4 Conclusion – overall impact on global competitiveness

Put together, the analysis of the combined role of the Euro 6/VI standards on the costs and profitability of the sector, development of the innovative capacity of the sector and supporting access to other markets suggests that they have had a relatively limited role in strengthening their competitive position of the EU automotive sector vis a vis competitors. It seems reasonable to conclude that the Euro 6/VI standards had not had a negative impact and that they may have even helped to ensure that they are in the forefront when it comes to the adoption of emission control technologies.

From the side of stakeholders, the views expressed suggest a more positive role of the standards than what is proposed above. On a general basis, 43 out of 60 stakeholders that contributed to the targeted stakeholder consultation agreed that encouraging the development

[107] The Chinese CF is higher than EU, but the emission limits are stricter for NOX. Ultimately this leads to lower emission limits in China.

[108] This is based on analysis of data on Sold production, exports and imports by PRODCOM [DS-066341] comparing annual volumes and value of complete motor vehicles for the transport of persons or goods (Including with PRODCOM Codes : 29102100 to 29104140).

of lower emission vehicles is indeed beneficial for the competitiveness of EU industry (Annex 9, Figure 10-9). More importantly, 33 out of 42 indicated that the introduction of Euro 6 standards had a positive impact on the competitiveness of the EU automotive sector, and 21 out of 30 respondents reported the same for the Euro VI standards (Annex 9, Figure 10-10). However, comments provided suggest that the proposed role is primarily that of ensuring that the EU manufacturers do not fall behind and lose market access. An EU consumer organisation highlighted that more ambitious standards reinforce the competitive advantage of EU's automotive sector, "especially in a context where other major markets (such as the USA or China) are also developing standards which are sometimes even more ambitious than the EU ones". An international transport research organisation also reported that "without those standards [OEMs] could have lost the ability to develop and produce desirable vehicles for US and China". Other respondents (including two automotive parts suppliers) were more critical and pointed to a significant difference in the level of standards in the EU, US and China suggesting that EU has stayed "much behind the other regions". One of them highlighted that "by not keeping up with regulations that force best achievable control technology, innovation lags and reduces the competitiveness of European manufacturers globally". Among the respondents to the consultation, 9 out of 42 reported no or a limited negative impact of Euro 6 on the competitiveness of the sector, and 9 out of 30 reported the same for Euro VI.

The above mixed conclusions are reflected in the responses provided by stakeholders in the context to the public consultation. Most respondents from all stakeholder groups considered that Euro 6/VI had "somewhat" of an impact on reinforcing the competitiveness of the industry. 43 out of 159 respondents considered it contributed to a great or "very great" extent, while 7 considered it did not contribute at all, and 28 considered it contributed very little. Only Member State's stakeholder group indicates a clear contribution, with most representatives considering that the standards contributed "to a great extent" to reinforcing the competitiveness of EU OEMS (6 out of 13). In contrast, among industry representatives' respondents, 31 out of 80 considered it only "somewhat contributed, 14 out of 73 considered it contributed very little, and 3 considered it did not contribute at all.

All in all, we consider that the tighter standards and stricter testing procedures of Euro 6/VI have primarily contributed towards maintaining the competitive position of the EU automotive sector and market access. Their role in providing a competitive advantage and strengthening their market access has probably been more limited.

5.1.7.4 *Has there been any direct impact (positive/negative) on employment?*

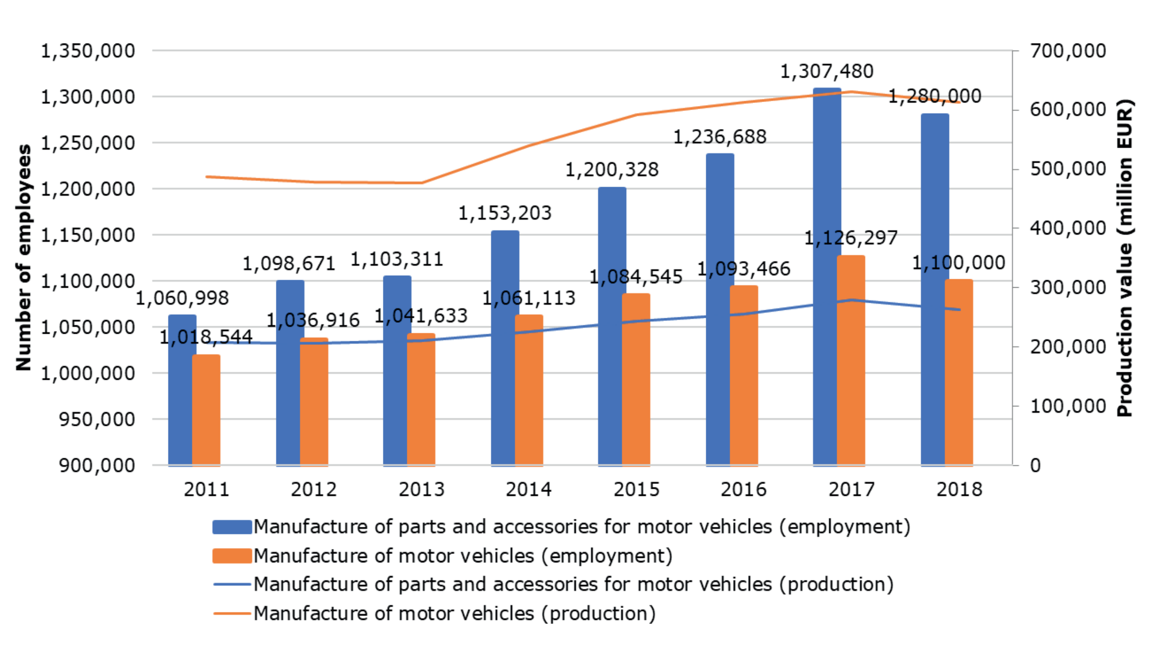
There is no compelling evidence indicating a direct impact of Euro 6/VI standards on employment and this was not an issue raised by any stakeholder as part of the stakeholder consultation.

Overall, data for the period 2011-2017 suggests a decrease in the total level of employment in the automotive sector[109] in 2017. However, these are mainly linked to changes to levels of activity, as production slightly increases and productivity remained largely stable over the same period (see Figure 5-15 and Figure 5-16) according to data from Eurostat (Eurostat, 2020).

Employment data at a more granular level is not available (such as for emission control technology and internal combustion engines manufacturing). However, responses to the stakeholder consultation indicate an increase in the staff hired for activities such as homologation, planning and regulatory affairs, as well as new inspectors hired among authorities and technical services as a result of Euro 6/VI, as discussed below.

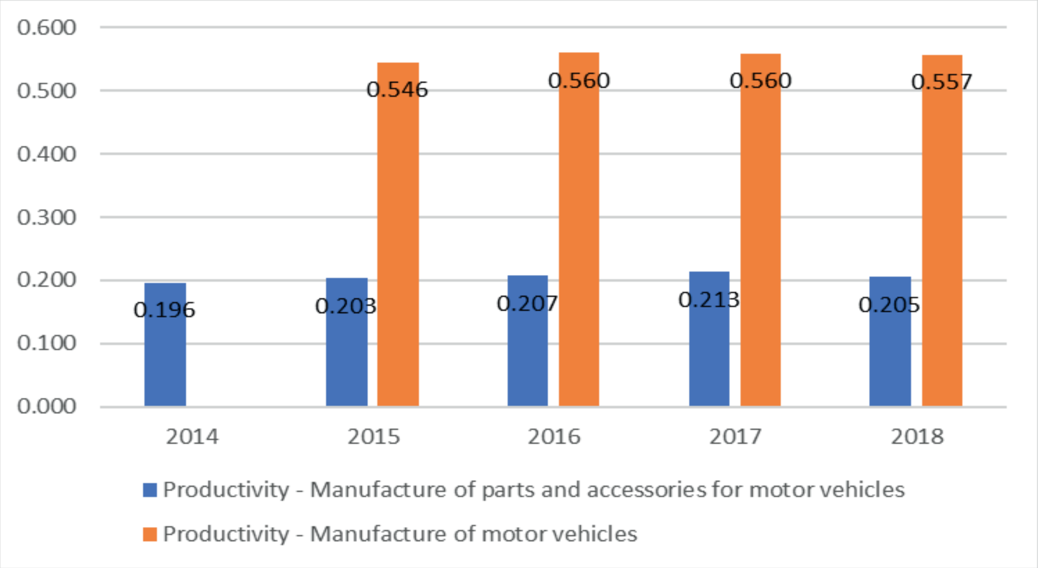
[109] "The number of persons employed is defined as the total number of persons who work in the observation unit (inclusive of working proprietors, partners working regularly in the unit and unpaid family workers), as well as persons who work outside the unit who belong to it and are paid by it (e.g. sales representatives, delivery personnel, repair and maintenance teams). It excludes manpower supplied to the unit by other enterprises, persons carrying out repair and maintenance work in the enquiry unit on behalf of other enterprises, as well as those on compulsory military service."

Figure 5-15: Evolution of number of persons employed in the EU per sector, and production value (€ million)



Source: Eurostat (2020) *Annual detailed enterprise statistics for industry [sbs_na_ind_r2]*

Figure 5-16: Evolution of productivity level in the automotive sector (€ million per employee)



Source: Eurostat (2020) *Annual detailed enterprise statistics for industry [sbs_na_ind_r2]*

In a previous modelling exercise, Ricardo identified that the introduction of regulation and the higher costs associated could have some negative effects on employment in the short-term, due to higher labour costs induced by the requirements to incorporate additional technology/equipment (Ricardo Energy and Environment, 2017)[110]. As the regulatory costs gradually decline over time, short-term negative effects in employment diminish and even become positive in the longer-term. This is explained by changes in the industry's composition of GDP, development of wages and labour productivity over time, while total wage ratio remains constant (Ricardo Energy and Environment, 2017). However, it is not possible to disentangle the effects of the standards from the effects of other factors (including other legislation) that may have had an impact on the labour costs.

At a smaller scale, the Euro 6/VI standards may have created new employment in R&D related activities and in activities directly associated with the homologation/regulatory process or for those suppliers directly affected by increase in the demand for control equipment.

- In relation to the former, as already indicated, the regulation has already prompted efforts in research and development which may have led to new R&D jobs among some OEMs, suppliers, and providers of relevant technical services. Available data on the level of R&D personnel in the automotive sector suggest a significant increase over

[110] The exercise accounted assumed an increase in stringency of the regulation, moving incrementally from Euro 3 to the current Euro 6 RDE, followed by China 6b and US Tier 3 regulations which are stricter than Euro 6 RDE.

the period 2013-2018[111]. However, there are no specific data available that would allow to make a direct connection with the R&D activity focusing on Euro 6/VI.

- Similarly, additional jobs may have arisen in the relevant regulatory/homologation departments of OEMs, technical services and the TAAs that reflect the increasing effort associated with the type approval process. The input from the targeted stakeholder consultation suggests this has been the case for some TAAs and OEMs, though not for all. In total, 4 OEMs vehicle manufacturers (out of 20 OEMs that provided responses to the stakeholder targeted consultation) and two industry/business associations reported additional costs for staff hired, and two type-approval authorities reported additional costs incurred for new staff/inspectors (out of 4 TAAs that responded)[112]. However, we do not have specific sufficient data that would allow to develop an overall estimate of the level of aggregate impact.

All in all, we consider that, at an aggregate level, the impact of the adoption of the standards has been positive but relatively limited within the broader context of the size of the sector (over 2.7 employees in 2018). Nonetheless, we can conclude that the introduction of Euro 6 – and particularly the new testing procedures – has led to additional R&D jobs among industry along with staff in the relevant homologation regulatory departments.

5.1.7.5 *Conclusions*

We assessed the impact that of emission reductions achieved through Euro 6/VI on EU citizens, and particularly on their health. We also examined the possible impact of Euro 6/VI emission standards on the competitiveness of the EU automotive industry.

On the basis of the analysis presented above we can conclude that the adoption of Euro 6/VI has led to improvements in terms of road transport's impact on health, as reflected in a reduction in air pollution external costs, of which health expenditure represents 90%. In monetary terms, our analysis suggests that the adoption of Euro 6/VI led to a total savings of around 97 bn EUR up to 2020 in external costs (66.5 bn EUR coming from HDVs' emissions reduction alone).

Despite this positive impact on the regulated pollutants, there remains unregulated pollutants causing important health issues, including NO2 and non-methane organic gases (NMOGs). Long-term exposure to NO_2 has significant impacts on mortality, respiratory symptoms, asthma and lung function (WHO, 2016)

All in all, the analysis of the combined role of the Euro 6/VI standards on the costs and profitability of the sector, supporting access to other markets and developing the innovative capacity of the sector suggests that the standards have had a limited role in strengthening the competitive position of the EU automotive sector vis a vis competitors. We consider that the tighter standards and stricter testing procedures of Euro 6/VI have mainly contributed towards maintaining the competitive position of the EU automotive sector and market access until now, but that Euro 6/VI was less effective in providing a competitive advantage and strengthening market access, as regulators in some of the key markets (US, China) have adopted even stricter and more demanding requirements. This has also occurred with some cost implications, albeit with limited indication that this has had a negative impact on profitability vis a vis manufacturers from other reasons.

Finally, there is no indication of a sizeable impact on employment that can be associated with the standards. However, the increase in the R&D activity reported and the additional enforcement and administrative effort that has resulted from introduction of more demanding testing procedures should have led to new jobs in the regulatory/homologation departments, the technical services and the type approval authorities.

5.1.8. EQ7 To what extent has Euro 6/VI supported innovative technologies and other technological, scientific or social development? Are adaptation mechanisms in place to allow Euro 6/VI to do so?

5.1.8.1 *Introduction*

This section explores the relevance of Euro 6/VI standards for spurring innovation and other technological, scientific or social developments, and considers the role of adaptation mechanisms.

[111] According to Eurostat total R&D personnel and researchers in the manufacturing of motor vehicles, trailers and semi-trailers (NACE 29) at EU28 increased by more than 30% between 2013-2018 (from around 155k to 212k) Source: Eurostat: Total R&D personnel and researchers in business enterprise sector by NACE Rev. 2 activity and sex [rd_p_bempoccr2] (data are only available at national level and have been aggregated).

[112] One of the three major TAAs (on the basis of the Type approval per year granted) reported a 30% increase in the workforce (ca. 19 FTE) as a result of the increase in the WVTA and emission type approval activity (reported increase from 339 type approvals in 2017 to 1133 in 2019) and the additional workload per type approval as a result of the introduction of RDE and WLTC. In comparison, the increase in resources needed for Euro VI was much more moderate at around 2 FTE.

As described in Section 2.3, there was a need for the Regulations to consider the implication of the emission standards for the competitiveness of markets and the manufacturers, including the role that standards can play in terms of fostering innovation. At the same time, there was also a need to provide clear information on emission limits early on such that the industry could pursue the required technical developments to meet the targets.

This section considers the following questions:

- To what extent did the introduction of Euro 6/VI incentivised public and private research activity towards the development of new clean vehicle technologies and emissions control technologies?
- To what extent did the introduction of Euro 6/VI incentivise the adoption of new clean vehicle technologies and emissions control technologies?
- Has the adoption of the standards provided sufficient time for industry to develop the relevant technologies?
- Were there relevant mechanisms in place to support the development of relevant technologies?
- Have the standards contributed towards raising awareness on vehicle-related air pollution and influenced public attitude?

5.1.8.2 *To what extent did the introduction of Euro 6/VI incentivised public and private research activity towards the development of new clean vehicle technologies and emissions control technologies?*

Section 3.5.2 referred to the range of new or improved emission control technologies required in order to meet the new pollutant emission limits in the EU (see also text box below). Some of the technologies were already in place even at the time of the adoption of the Euro 5/V standards (e.g. SCR) although further improvement was needed to meet more demanding performance levels needed as part of the RDE testing procedures. Others (e.g. GPF for GDI) were not generally used prior to the adoption of the relevant requirements (PN limits).

Text box 5-2: Technologies required to ensure compliance with the standards

In the case of Euro 6 for LDVs, this varied with the engine technology (PI /petrol or CI/diesel):

- PI Euro 6 LDVs did not require substantially new technology nor adjustments to existing technology compared to the Euro 5 standard as there were no changes to the emission limits for NOx. However, the introduction of RDE testing in the Euro 6d step required the use of more advanced TWC systems. In addition, the PN limits for GDI petrol engines required the introduction of GPF filters.
- CI LDVs, on the other hand, required new aftertreatment technologies to deal mainly with the new NOx emission limits and, in some cases, more advanced in-cylinder control technologies. In particular, the move from pre-RDE (Euro 6b/c) to RDE (Euro 6d-Temp and Euro 6d) led to the use of more aftertreatment technologies in combination (e.g. SCR, SCRF and ASC).
- In the case of HDVs, compliance with Euro VI most often required the refinement of in-cylinder control technologies and the use of more advanced and new technologies (closed-loop SCR system and ASC).

Manufacturers that wanted to sell vehicles in the EU had to invest in additional technology or calibrate existing technology for a sizeable share of the vehicles in their portfolio: both diesel LDVs and HDVs, which required new/improved technology, represent a significant share of sales in the EU; diesel cars represented 53% of all new registrations, and 96% of all new registrations of vans in the EU28 in 2014 (ICCT, 2019a).

The question examined here is whether the requirement to effectively adopt this new/improved technology to meet the new emission limits fostered public and private research towards the development of these technologies. Thus, we consider the evolution of the following indicators following the adoption of Euro 6/VI and compare against the Euro 5/V baseline scenario (see Section 2.6) to isolate the effect of this change in the regulatory framework:

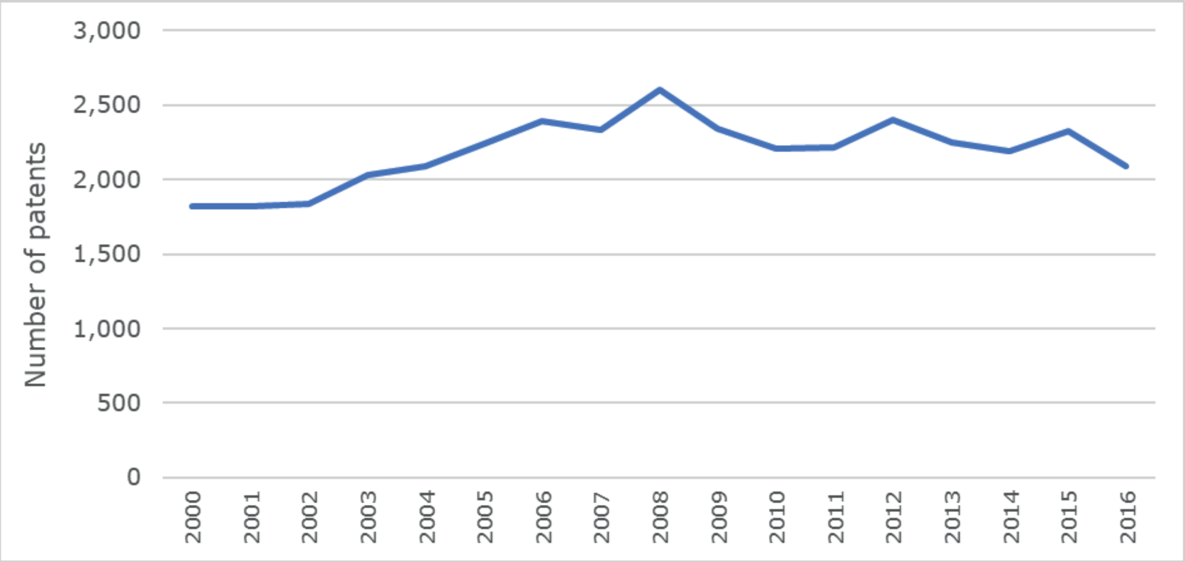
- Number of research and development (R&D) projects related to new clean vehicle technologies and emissions control technologies
- Number of patents related to new clean vehicle technologies and emissions control technologies
- Extent to which the required technology was already available or under research

In relation to the **number of R&D projects**, the available evidence suggests that the standards have partly incentivised research activity. We have identified a number of EU and national R&D projects directly linked with the Euro 6/VI standards in the data from the TRIMIS portal. In addition, in the report on the inquiry into emission measurements in the automotive sector of the European Parliament (Gieseke & Gerbrandy, 2017), the European Investment Bank (EIB) confirmed that loans were provided to car manufacturers for R&D activities related to emission control technologies between 2005 and 2015 amounting to €13.6 billion. More recently, a recent JRC report (JRC, 2020) carried out an analysis of publicly funded research and innovation projects in Europe addressing vehicle emissions. The focus of this analysis was on more recent projects to understand the potential to set post Euro 6/VI emission standards (i.e. only projects staring after 2015 were considered, plus they also considered other aspects not relevant for ensuring compliance with the current standards such as non-regulated pollutants, and ultrafine particles). As such, only a number of the projects captured would be relevant and directly linked to the current standards. It nevertheless demonstrates that there seems to be significant research activity in the EU prior to the adoption of new standards (i.e., 66 relevant projects were identified from the TRIMIS database, representing an investment of over €250 million since 2015).

Further to that, the input provided by OEMs and suppliers on the costs of compliance (see also EQ8; section 5.2.1) pointed to sizeable level of investment in R&D activities associated with the development or adaptation of new engines and control technologies to ensure compliance with the standards. According to the data from a few OEM, up to €1 billion for LDVs and €2.2 billion for HDVs was invested in R&D activities related to Euro 6/VI since the adoption of the standards and up to 2020. Even though such a reported level of investment is not only related to the Euro 6/VI standards and is probably not common among other OEMs, it is still an indication of the role of the standards in driving R&D activity. Other sources also indirectly point to the R&D activities that supported the adoption of the standards. The literature makes reference to costs for R&D with certain technologies to meet the Euro 6/VI requirements, both for LDVs (see (ICCT, 2012a))and HDVs (see (ICCT, 2016b)) (see also 5.2.1). The latter source also denotes that savings could be achieved following the investments and learning done in the EU, which, in turn, suggests that the technology needed by manufacturers selling vehicles in the EU required a certain level of R&D activity (unlike in other countries which, by adopting similar standards later, can benefit from the outcomes of these activities).

In relation to the **number of patents**, it is not clear to what extent the Euro 6/VI standards have played a role in the patenting activity observed but these are likely to have had a small influence. The OECD collects patent statistics on emissions abatement from mobile sources (e.g. NOx, CO, HC, PM emissions from motor vehicles), which are reproduced in the Figure below. It shows that between the adoption of the Regulations (in 2007/9) and the entering into force of the standards (in 2013/14), the patenting activity oscillated, increasing in certain periods and decreasing in others, with an overall downward trend observed. A most steady increase in this activity is apparent for the period running up to 2007, namely before the Regulations were adopted, although the Commission impact assessments undertaken in 2005 and 2006 already suggested the potential tightening of the emission limits. As such, it is not possible to make any direct connection with the level of patenting activity.

Figure 5-17: Patents on emissions abatement from mobile sources (e.g. NOx, CO, HC, PM emissions from motor vehicles) in EU28



Source: (OECD, n.d.)

Finally, it is also relevant to check whether the required technology was already available or under research prior to the announcement of the Euro 6/VI standards. This helps determine the extent to which the standards could have incentivised additional research activity. If the required technology was available, then research activities would be expected to have focused more on calibration and integration of those technologies rather than on the development of radically innovative technology.

In the case of LDVs, it is worth noting that whilst the Euro 6 standard was first proposed at the same time as the Euro 5 standard (European Commission, 2005a), the emission limits were only developed later. According to the subsequent impact assessment for the proposal of Euro 6 emission limits (European Commission, 2006), relevant technology (i.e. SCR) had been further developed since the first impact assessment for Euro 5 and 6 standards that allowed the compliance with more stringent emission limits which had not been considered to be feasible at the time of the preparation of emission limits for Euro 5. The impact assessment refers to a "greater flexibility in the choice of technology options for meeting lower NOx limits for diesel cars", which suggests that the technology was already available at the time of the announcement of Euro 6 emission limits (in 2006) but not at the time of the announcement of the Euro 6 standard (prior to 2005). It is not clear to what extent the announcement of the standard with unknown emission limits (although expected to be more stringent than Euro 5) has led to additional research activity that resulted in new technology developments. However, it seems this was driven in part by the existence of more stringent standards in other markets. The Euro 6 limits impact assessment makes reference to the developments in the US where manufacturers were planning to also introduce diesel cars that would meet the more stringent Tier 2, Bin 5 standard (European Commission, 2006).

In relation to the need for further improvement as a result of the introduction of the RDE testing requirements, the 2016 report on the inquiry into emission measurements in the automotive sector (Gieseke & Gerbrandy, 2017) suggested that the technology for European OEMs of diesel cars to comply with strict NOx limits was already used, albeit selectively, given that manufacturers were already selling vehicles in the United States, where NOx emission limits are lower. Similarly, current US Tier 3 emission regulation is considered to be equivalent to post Euro 6 standards due to its greater stringency (ICCT, 2017a). Although those standards have been implemented since 2017, EU-owned manufacturers built 3m passenger cars in the US in 2018, representing 27% of total US production, and the country accounted for 29% of the total EU car exports (ACEA, 2019b).

As such, whilst the expectation of stricter limits imposed by Euro 6 in the near future might have prompted more research into new technologies, this was also a direct consequence of similar regulatory developments in other countries.

In the case of HDVs, the impact assessment for Euro VI (European Commission, 2007) and the supporting technical study undertaken by TNO (TNO, 2006) do not point to the lack of technology to meet the proposed emission limits. This suggests that the required technology was also already at a mature stage. In fact, emission limits are only proposed if they are deemed to be cost-effective to be attained by the industry. The impact assessment demonstrates that the scenario (sub-option) chosen considered also the costs of the technology.

Overall, the above analysis suggests that the Euro 6/VI standards had a positive effect on the research activities in the EU, with specific R&D projects and patents linked directly to Euro 6/VI. However, in most cases these seem to have mainly on improvements on existing technologies than on the development of completely new technologies. It is also possible that some research activity would have happened even if the standards had not been adopted as the industry would have to adopt similar technology to meet emission limits in other markets.

Input from stakeholders seems to suggest an even stronger role of the standards than what is suggested in the analysis above. The majority of stakeholders consulted for this study also indicated that the Euro 6/VI standards have provided an incentive for research activities (Annex 9, Figure 10-11): 64 out of 73 respondents strongly or partly agreed that the Euro 6/VI standards provided an incentive for R&D activities towards the development of new clean vehicle technologies, and 73 out of 73 that the provided an incentive for the development of emissions control technologies, respectively. No relevant differences are observed across the different stakeholder groups consulted, except in the case of civil society and R&D organisations where a large share only partly agrees with the statements (i.e., 5 and 4 out of 8 responding, respectively). Responses provided by stakeholders in the context of the public consultation also suggest that the standards have encouraged the *development* of *innovative* technologies for cleaner vehicles. The large majority of stakeholders (154 out of 165) agreed or strongly agreed that "regulations on air pollutant emissions encourage the development of innovative technologies for cleaner vehicles".

The comments from stakeholders provide further insight into their views. A number of stakeholders highlighted the relevance of the standards to foster technology developments:

- According to an automotive parts suppliers' association, an automotive part supplier, and an international transport research institution, RDE testing led to the development of more advanced technologies such as SCR, DPF and LNT.
- An automotive parts supplier, indicated that "Euro 6/VI represents regulatory certainty for driving investments, especially at the side of automotive suppliers, which are responsible for 80% of innovation in the entire sector "
- A number of stakeholders (including three emission control suppliers, one non-EU industry association, a type-approval authority, an international transport research organisation, and an EU environmental NGO) referred to the important role that the adoption of the PN limits for GDI vehicles had as the driving force for the market uptake of GPF filter technology.

In contrast, other stakeholders suggested that technology already existed on the market and innovation achieved was limited to improvements to existing technology:

- A vehicle manufacturer indicated that the legislation did not foster the development of new technology as the standards could be met by existing technology.
- An automotive parts supplier also denoted that the technology required already existed on the market.
- According to an EU vehicle manufacturer, and a fuel research organisation, whilst technology might not be completely innovative, the standards were still relevant to foster additional research activity to decrease technology costs and improve reliability and efficiency of existing technologies.
- An automotive parts supplier noted that Euro 6 accelerated the technology developments and commercialisation of new technologies at a lower cost. For them, regulation can foster innovation.

In addition, other factors were also seen as having played a role to the increase in research activities:

- An international transport research organisation suggested that Euro 6/VI standards has not led to the development of a number of technologies that are actually innovative and targeted at cold-start.
- A number of EU vehicle manufacturers that submitted the same/similar statements indicated that manufacturers are "always pursuing technical developments to improve reliability, efficiency and cost of their components and systems".
- An automotive parts supplier suggested that more stringent standards in the US played a more important role in incentivising research, giving as an example the SwRI work with CARB and MECA here.

Finally, stakeholders distinguished between the role of Euro 6 prior and post RDE testing, suggesting that the RDE period was more important to incentivise innovation:

- A testing equipment supplier and an EU consumer organisation also pointed to differences in the relevance of Euro 6 to drive innovation, highlighting that RDE increased the incentive to innovate
- According to an EU environmental NGO, both in-cylinder control technologies and aftertreatment technologies were further improved following the introduction of the Euro 6/VI standards and, in particular, following the introduction of RDE testing and independent in service-conformity testing requirements; in the case of HDVs, the Euro VI standard and the PEMS testing have also driven improvements in emission control technologies.

Overall, we can reasonably conclude that Euro 6/IV standards have been relevant to foster additional research activity. The focus was primarily on ensuring the effective and efficient integration of the new technologies in vehicles although most stakeholders still seem to consider that they have played a broader role in the promotion of innovation. In the case of Euro 6, it is also likely that R&D activities accelerated following the adoption of RDE testing. At the same time, it is reasonable to expect that some of the research activity would have taken place even in the absence of the standards, driven by the need to introduce similar technologies in vehicles sold in other markets, where emission limits are similar (or more stringent).

5.1.8.3 *To what extent did the introduction of Euro 6/VI incentivise the adoption of new clean vehicle technologies and emissions control technologies?*

In addition to the contribution of the Euro 6/VI standards to incentivise research activity, it is also relevant to explore whether the use of new/improved technology was in effect driven by the adoption of Euro 6/VI standards.

As described earlier, new/improved technology had to be introduced in an important share of new vehicles sold in the EU. However, it is possible that the same technology would have been adopted in EU vehicles even in the absence of the standards. This could be expected depending on:

- The extent to which the technology is available off-the-shelf.
- The extent to which vehicle manufacturers would voluntarily introduce this technology, which, in turn, depends on the extent to which the technology costs are low and have limited effects on profit margins, as well as, the extent to which there is customer demand for cleaner technologies.
- The extent to which the technology must be adopted by vehicles in other markets and whether this would foster adoption of the same technology in the EU.

In terms of the availability of the technology, the analysis presented above concludes that some of the technology required to meet the new emission limits was already available (e.g. SCR), although further calibration and/or improvements were required. This suggests that, in the absence of Euro 6/VI standards, the availability/existence of the technology would have facilitated adoption as less significant investment would be required for their introduction. In other cases (e.g. GPF), there had not been widespread use of the technology in vehicle prior to the adoption of the RDE testing requirements. The first GPF system in vehicles were introduced by one OEM in 2014 but were adopted more generally after 2017 (Majewski, 2020).

Regarding the potential for vehicle manufacturers to adopt the technology voluntarily, previous experience has shown that voluntary technology adoption is not necessarily realised. This was the case of the voluntary CO_2 emission targets that European car manufacturers failed to meet, leading the European Commission to develop mandatory CO_2 emission standards (ICCT, 2018b). Although this example refers to a different type of emissions, it illustrates the weaknesses of a voluntary emission reduction programme. This suggests that new/improved technologies might not have been adopted without mandatory pollutant emission standards in place.

Voluntary adoption of emission control technology is also in part determined by the impact of the technology costs in the vehicle's total cost and profit margin as well as by customer demand for such technologies.

The analysis provided in Section 5.2 (EQ8) demonstrates that emission control technologies increased the costs of vehicle production. Similarly, as covered in EQ6, the stakeholders consulted for this study are also of the view that integration of new technology required to meet the Euro 6/VI standards increased costs and had a potential impact on the profitability of vehicle OEMs.

In response to the question of how likely technical developments would have taken place to address pollutant emissions in the absence of the Euro 6/VI standards, the majority of stakeholders considered it unlikely or highly unlikely that technical development addressing pollutant emissions would have taken place in the absence of Euro 6/VI (42 out of 66 respondents for passenger cars, 45 out of 62 for vans and 41 out of 61 for heavy duty vehicles) (Annex 9, Figure 10-12). In particular, 15 stakeholders from all groups except OEMs[113] provided comments according to which technological improvements "would not have happened" in the absence of Euro 6/VI and that emissions standards and new testing procedures were "decisive" and "instrumental" for new technologies and innovation in the sector. In particular, 1 engineering services provider claimed that "having reached Euro 5, progress would simply have stopped [without Euro 6/VI]". From their side, the 11 OEMs that contributed questioned this indicating that "Vehicle manufacturers are always pursuing technical developments to improve reliability, efficiency and cost of their components and systems". However, such a statement is quite generic (i.e. it does not necessarily refer to emission control technologies) and points more to incremental improvements to existing technologies rather than adoption of technologies aiming to reduce pollutant emissions.

Related to the added cost of emission control technologies, vehicle manufacturers could still consider their inclusion even in the absence of the standards if there was demand for the use of cleaner technologies in vehicles by customers. However, this is unlikely to have been the case as consumers obtain limited direct added value from such technologies. A number of stakeholders (including a national authority, a technical services provider, a type-approval authority, and an automotive parts supplier) commented that vehicle manufacturers would not have introduced technology that is expensive and that emission control systems only add costs with little perceived value for consumers. According to the automotive parts supplier, "customers do not value cleaner vehicles by themselves". According to another supplier, the willingness to pay for emission control technologies could be even smaller compared to CO_2-reducing technology – the perceived value of the latter would be higher as consumers can understand its benefits through improvements in fuel economy. Only one vehicle manufacturer suggested that emission reductions could still have been achieved driven by customer needs and the environmental reputation of manufacturers.

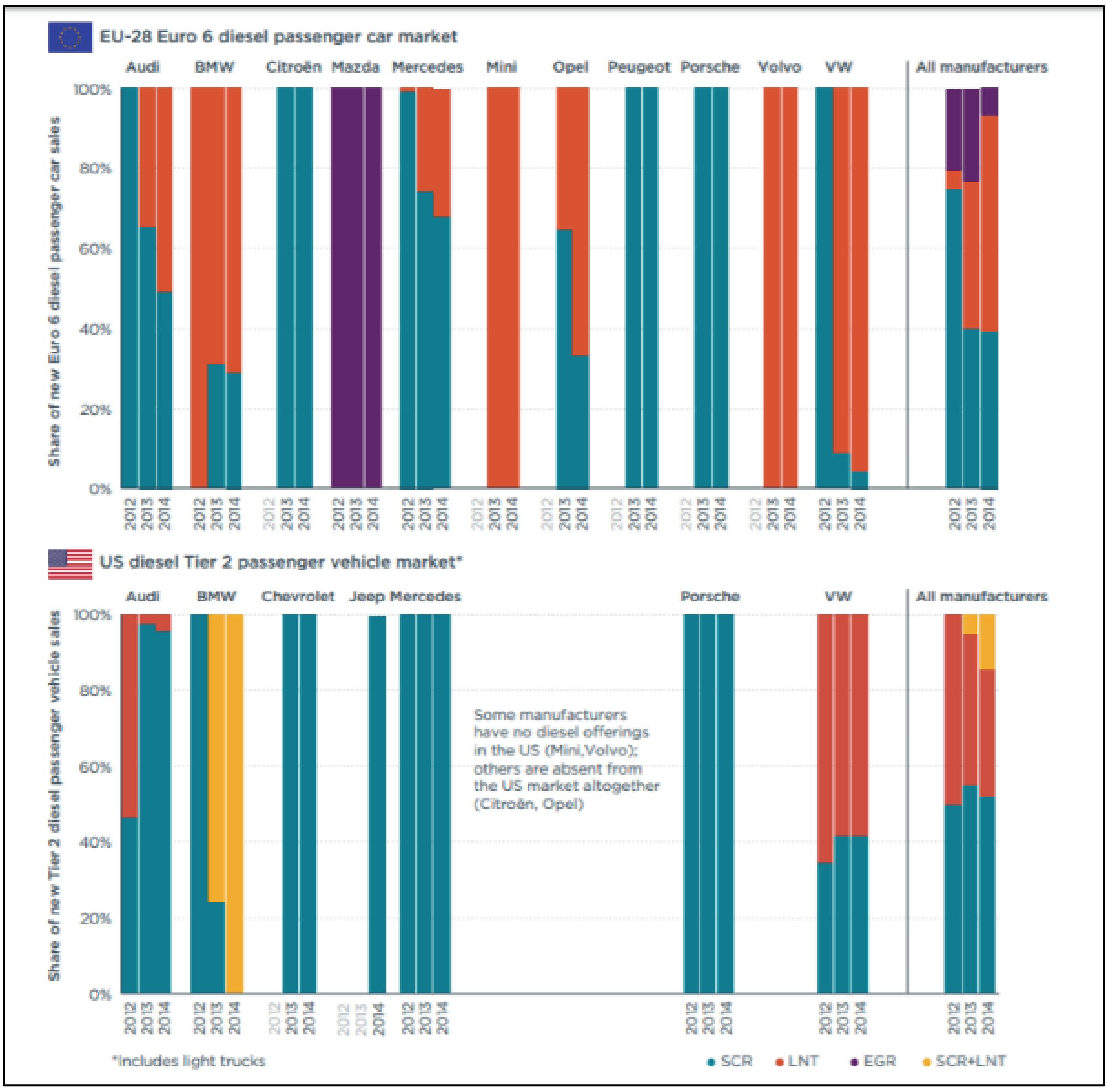
Overall, it can be concluded that relying on manufacturers to voluntarily introduce new technology would only be realised if this would not increase the cost of the vehicle or if there was demand for such technologies. Given that these factors are likely not to be favourable to voluntary technology adoption, we can conclude that technology would not have been fully introduced without the Euro 6/VI standards.

Finally, we consider the extent to which the technology must be adopted by vehicles in other markets and whether this would also foster adoption of the same technology in the EU. The available evidence suggests that even if technology is adopted in vehicles sold in other markets, this does not necessarily mean that it will be adopted in the same models sold in another market. A study from ICCT (ICCT, 2015c) concludes that the technologies adopted to control NOx emissions from diesel passenger cars manufactured by European OEMs for sale in the EU and in the US varied, showing that different regulatory frameworks have an effect on technological choices (Figure 5-18). We can therefore conclude that, in the absence of the Euro 6/VI standards, it is likely that the same technologies would not have been adopted, even

[113] 2 automotive component supplier, 4 public authorities, 1 consumer organisation, 2 technical services, 1 type approval authorities, 2 academic/research institutions, 1 test/measurement equipment supplier, 1 fuel industry business and 1 engineering services provider

if they are available and integrated into the vehicle portfolio of the same manufacturers in other vehicle markets.

Figure 5-18: Market shares of control technologies for compliance with Euro 6 and Tier 2 NOx limits in the EU and the US, 2012 - 2014



Source: ICCT (2015c)

This is also in line with stakeholder input received during the targeted consultation on the Euro 6/VI evaluation. According to a regional authority, more advanced emission control technologies were only adopted in the European market following the changes driven by the dieselgate. They added that technology that has recently become more widespread in the EU (such as SCR) had been adopted 10 years earlier in the US market, and even when initially applied in Europe in pre-RDE times, it was often not fully exploited, with low urea injection rates. In addition, in relation to the evaporative emissions, an automotive parts supplier also indicated that European manufacturers use different technology in different markets: “Euro 6c canisters [for capturing evaporative emissions] have capacity over 60% lower than US and Chinese canisters, and even Euro 6d canisters have capacity about 46% less. Purge rate calibration increases by about 240% with Euro 6d; however, purge rates on US and China vehicles are still 50-65% higher than Euro 6d vehicles due to ORVR and 72-hour diurnal requirements. OBD leak detection is only found on vehicles in the US and China”. For another automotive parts supplier, whilst technology developments could have taken place in the absence of the standards, driven by the requirements from other markets, these would not necessarily have been implemented in Europe. However, they indicated that there are examples of the introduction of emission reduction technologies in the absence of standards. On the other hand, an automotive parts supplier suggested that to reduce costs the automotive industry would adopt the same technologies from markets that are regulatory leaders.

Overall, the stakeholders consulted in the targeted consultation for the Euro 6/VI evaluation were largely of the view that the Euro 6/VI standards have played a role in the integration of existing innovative technologies (Annex 9, Figure 10-13). Out of 67 stakeholders responding, 33 and 29 strongly and partly agreed, respectively, that the standards have provided an incentive to adopt existing innovative cleaner vehicle technologies; 38 and 22 strongly and partly agreed, respectively, that the standards have also provided an incentive to adopt existing innovative emission control technologies out of 64 stakeholders responding. There are some minor variations in the responses across groups, with a larger share of industry stakeholders and civil society and R&D organisations only partly agreeing with the contribution of the standards to the adoption of cleaner vehicle technologies, whilst the largest share of authorities and technical services strongly agreed.

In addition to the comments summarised above, stakeholders also indicated potential differences in the strength of the Euro 6 standards to incentivise the adoption of new technologies:

- According to an EU local transport NGO, changes to legislation following dieselgate led to integration of technologies already available in other markets – for example, SCR post-treatment.
- Similarly, an EU environmental NGO argued that only the introduction of RDE led to a reduction in on-road emissions – which suggests that new technology started being fully utilised.
- An automotive parts supplier also indicated that without Euro 6 in place the rate of adoption of technologies would be slower.

Overall, we can conclude that adoption of new clean vehicle technologies and emissions control technologies are not expected to have happened at the same rate as it occurred following the introduction of the Euro 6/VI standards. Although the technology is largely available, its voluntary adoption would depend on costs and customer demand – both factors appear to be unfavourable to this end and so we conclude that vehicle manufacturers would most likely not have adopted the same technology as required under Euro 6/VI standards. In addition, despite the need to integrate these technologies to ensure compliance with similar/more stringent requirements in other markets, this does not necessarily imply that the same technology would be deployed in vehicles sold in the EU in the absence of these emission limits. Evidence shows that more advanced technology was/is deployed in other markets but not in the EU.

5.1.8.4 *Has the adoption of the standards provided sufficient time for industry to develop the relevant technologies?*

In both Regulations, the importance of providing sufficient time for the industry to adapt and meet the new requirements were underlined.

As a first step, we have investigated what was the average lead time for the development of these technologies against which we can compare the timeframes provided by the legislation.

Evidence available suggests that more than two years of lead time is required for these technologies. The opinion of the European Economic and Social Committee (EESC) in response to the Euro 5 and 6 proposals by the Commission (European Economic and Social Committee, 2006) noted that the industry requires at least three years to bring the relevant technology into production, whilst criticising the lead time for Euro 5 (i.e., 18-month period following the entry into force of the regulation). A recent publication in the Automotive World journal (Automotive World, 2019) suggests that the industry requires more than two years to adapt however this was based on the requirements for previous standards – they also reported on previous criticism from vehicle manufacturers on the timetable for past standards including Euro II and Euro III due to their tight timelines (less than two years). Stakeholder input received during the consultation for this study also confirms this: an EU vehicle manufacturer indicated that the industry requires two to five years to develop further the “most promising technologies” but breakthrough innovation can have a lead time of five to ten years.

Given that Euro 6/VI standards have entered into force more than two years after their official announcement (seven years in the case of Euro 6 and four years in the case of Euro VI), we can argue that, in principle, industry had ample time to adapt available technologies. This is particularly the case when considering that relevant technology (e.g. EGR, SCR) was already available at the time of the adoption of the Euro 6/VI standards (as already indicated in the IA support studies). Other sources also support these conclusions. The report on the European Parliament mentioned above (Gieseke & Gerbrandy, 2017) indicates that “the majority of invited experts claimed that sufficient time was given to car manufacturers to reach the Euro 5 and Euro 6 targets”. In relation to Euro VI, the EESC opinion on the Commission’s proposal for Euro VI (European Economic and Social Committee, 2006) indicates that the timetable is appropriate for the industry lead times.

More questions were raised in relation to the subsequent introduction of the RDE testing procedures and the introduction of requirements in different stages within a short period of time (2016-2019). This limited the time available given the need for further improvements to ensure compliance on the basis of on-road testing. A number of stakeholders (including three automotive part suppliers, an EU automotive parts suppliers’ association and one OEM) suggested that the time made available due to the different steps introduced significant burden within a brief period of time. However, the experts consulted for the report on the inquiry into emission measurements in the automotive sector of the European Parliament (Gieseke & Gerbrandy, 2017) concluded that the technology required to meet the NOx emission limits for diesel cars was already available at the time the standard entered into force and emission limits could be met both in a laboratory environment and in real-world conditions. They suggested that “some car manufacturers have opted to use technology that assures compliance with emission limits only in laboratory test, not for technical reasons but for economic reasons”.

All in all, we can conclude that the initial adoption of the standards appears to have provided sufficient time for industry to develop and adapt the relevant technologies. The timeframes allowed by the legislation of seven and four years for Euro 6 and Euro VI, respectively were sufficient, especially in view of the fact that relevant technologies were already in place in the market. However, the adoption of Euro 6 in steps due to the changes in the testing procedures have introduced more stringent requirements which, according to some stakeholders, have not allowed for sufficient time for the industry to adapt.

5.1.8.5 *Were there relevant mechanisms in place to support the development of relevant technologies?*

All available evidence points to the fact that the mechanisms were in place to support the development of the relevant technologies. As discussed above, the technology developments required by the adoption of the standards most likely focused on smaller advances and improvements in technology rather than on breakthrough innovation. For this type of developments, there is no data to show that mechanisms were lacking. In addition, this was not an issue raised by stakeholders.

Evidence described above illustrates that the European Investment Bank has also provided loans to finance Euro 6-related projects by OEMs (Gieseke & Gerbrandy, 2017).

Stakeholders were also asked during the consultation for this study whether they had made use of one or more of the support instruments available at EU level or national level (Annex 9, Figure 10-14). The input they have provided demonstrates that certain types of mechanisms were more popular:

- Out of 40 stakeholders responding, only 13 have made use of Horizon 2020 projects focusing on the development of cleaner engine technologies and aftertreatment technologies. In terms of the industry, 10 of 26 have made use of these projects.
- 20 of 42 stakeholders responding used nationally funded research and innovation support projects focusing on the development of cleaner engine technologies and aftertreatment technologies. Focusing on the industry, 16 of 30 have made use of these projects.
- In terms of EU support instruments/mechanisms (e.g. EIB) to finance own R&D activity focusing on the development of cleaner engine technologies and aftertreatment technologies, only 8 of 35 have made use of these. In the case of the industry in particular, 7 of 24 have made use of these instruments/mechanisms.
- Finally, only 8 of 36 resorted to financial incentives by Member States for the development of clean vehicles. Focusing on the industry, 6 of 25 have also relied on these incentives.

All in all, the limited available evidence points to the existence of relevant support mechanisms for the adaptation and further development of technologies. Some have been more utilised than others.

5.1.8.6 *Have the standards contributed towards raising awareness on vehicle-related air pollution and influenced public attitude?*

In order to assess the extent to which the standards contributed towards raising awareness on vehicle-related air pollution and influenced public attitude, we first investigated whether the public awareness of air pollution issues related to vehicle use has increased over time and, if so, whether this can be attributed to the introduction of the standards. We focus our analysis on the Euro 6 standards for LDVs as these are the most relevant for the general public.

The available evidence suggests that the public is aware of air pollution issues and that they understand this is related to the use of vehicles. According to the last Eurobarometer survey conducted in 2017 (European Commission, 2017b), air pollution is the second most important environmental issue, following climate change, as voted by 46% of those surveyed. In addition, we can also infer that a share of the public is aware that this pollution is partly caused by vehicles as 29% of the respondents have suggested applying stricter controls on emissions from new vehicles as an effective way of tackling problems of air quality.

Whilst it is not possible to measure the evolution of public awareness over time as the questions have changed from the previous Eurobarometer survey (European Commission, 2014), it is nevertheless possible to conclude that even in 2014 air pollution was considered to be one of the environmental issues respondents were most worried about, according to 56% of those surveyed.

Although concrete evidence is limited, it is likely that the public is now more aware of air pollution issues related to vehicles. With the advent of dieselgate in September 2015 and the infringement cases against seven Member States on account of their breach of the rules on air pollution limits and type approval for cars (European Commission, 2018a), air pollution issues have made headlines and so it is likely that the public has become more familiar with them. In addition, as discussed in the earlier section on EQ10, more than 250 European cities have a Low Emission Zones (LEZs), which charge and/or restrict access to urban centres for the more polluting vehicles. Citizens facing this type of schemes on their cities are therefore likely to have become more aware of these issues.

In addition to raising awareness, these events/factors have also affected consumer behaviour observed in terms of the decline in the sales of diesel cars in EU. Recent EEA data for 2019 (EEA, 2020) shows that diesel cars consist of 31% of all new registrations, which represents a decrease of 23 percentage points from 2011 when the share of diesel cars in the new car fleet was the highest. According to an Autovista Group poll (Autovista Group, 2019), the portrait of the dieselgate in the media is the principal factor for this decline, followed by city bans of these vehicles. Interestingly, awareness of NOx and health issues surrounding diesel was only the third factor, albeit being closely linked to the first two.

However, all these events/factors are only partially linked to Euro 6 standards and therefore the standards are only expected to have had a limited contribution to raise awareness on vehicle-related air pollution and influenced public attitude:

- The dieselgate is intrinsically linked to Euro 6 standards however, as indicated in the section 2.6 on the baseline definition, it is expected that such an event would have happened even in the absence of the Euro 6 standard. As such, the same event under the baseline scenario would have been linked to the Euro 5 standards but would still have resulted in the dissemination of information on vehicle-related air pollution that would have affected consumer attitudes towards these vehicles.
- Similarly, the use of LEZ is often linked to the Euro standards as a basic criterion for granting access or determining the charge to be applied. However, in the absence of the Euro 6 standards, the previous standards could still be used for a similar purpose, contributing to raising awareness on these issues and influencing public behaviour.

This is also the view of stakeholders that participated in the consultation for this study. Over one-third (24 of 65 respondents[114]) partly agreed that the focus on reducing vehicle emissions through the Euro 6 / Euro VI has increased public awareness in relation to the issues of vehicle-related air pollution. In addition, 16 strongly agreed with this. Similarly, over one-third (24 of 65 respondents) partly agreed that the focus on reducing vehicle emissions through the Euro 6 / Euro VI has influenced public behaviour towards the use of cleaner vehicles. No major differences are apparent across stakeholder groups with the largest share of respondents in each group also only partly agreeing with the statements. The comments received provide further insights into their views:

- A large number of stakeholders, including five public authorities, six civil society organisations[115], and ten industry members[116] mentioned the dieselgate and its role in raising awareness and influencing public behaviour.
- EU vehicle manufacturers and an EU vehicle manufacturers' association (submitting similar/identical answers) were of the view that standards play no role as evidenced by consumer surveys that demonstrate that consumers assign little value to environmental performance of vehicles. They added that only when these are linked to incentives or taxes, they can play a bigger role. Similarly, a public authority noted the importance of fiscal incentives to raise awareness – as these were not in place for LDVs, there was little change in the consumers' willingness to pay for the emission control technologies.
- A range of stakeholders also mentioned the role of tax benefits and Urban Vehicle Access Regulations (UVARs) to raise public awareness of air pollution issues related to vehicles. In particular, an EU environmental NGO, five automotive part suppliers, one automotive part suppliers' association, an international vehicle testing association and one EU vehicle manufacturer highlighted the role of low or zero emission zones or limits in the access to urban centres.
- Two authorities pointed to the discussions of bans on diesel vehicles in German cities in response to the breach of emission limits that have raised awareness on air pollution issues.
- Vehicle manufacturers and an EU vehicle manufacturers' association (submitting similar/identical answers) and an EU automotive parts suppliers' association added that the phased introduction of Euro 6 created confusion amongst consumers.
- On the other hand, an automotive parts supplier added that there has been an increase in attention to air quality, especially in urban areas, that made the public more aware of the negative effects of air pollution on health.

[114] Total respondents exclude those indicating 'no answer' and 'don't know'

[115] Including an EU local transport NGO, a EU health NGO, an EU consumer organisation, an EU environmental NGO, a national consumer organisation, an international transport research institution.

[116] One OEM, a technical services provider, a fuel research organisation, an EU vehicle testing suppliers' association, three automotive parts suppliers' association, three automotive parts suppliers.

- An international transport research organisation added that changes towards cleaner vehicles have been mostly the result of awareness of real-world performance of diesel vehicles and that the transition towards electric vehicles has been driven by climate change concerns. The last point was also supported by a Finnish public authority.
- Two automotive parts supplier and an EU automotive parts suppliers' association also made reference to other policies such as the Paris agreement and the European Green Deal that affect public awareness.

All in all, we can conclude that Euro 6 standards have had a limited contribution towards raising awareness on vehicle-related air pollution and influenced public attitude. Whilst society seems to be more aware of air pollution issues and the role of vehicles in creating those, there are other events and trends such as the dieselgate, the growing use of LEZs in cities, fiscal taxes and benefits that are likely to have more strongly contributed to raising awareness and influencing attitudes. As the Euro 6 standard is directly linked to these events and trends, it was important but similar effects in terms of raising awareness of these issues could have been expected even in the absence of the standard (i.e. in a scenario with Euro 5 standards as the most stringent requirements).

5.1.8.7 *Conclusions*

This section considered:

- The relevance of Euro 6/VI standards for spurring innovation and other technological, scientific or social developments,
- The role of adaptation mechanisms to enhance the relevance of Euro 6/VI in achieving this.

Overall, we conclude that:

- Euro 6/VI standards have been relevant to accelerate the adoption of new clean vehicle technologies and emissions control technologies. Without these standards, voluntary adoption would not have been expected as technology is costly and not valued by customers. Their introduction in other markets – driven by measures in other regions - does not imply that it would have been adopted in the EU.
- In terms of the specific role in the development of technology, Euro 6/IV standards appear to be been particularly relevant to adoption and further development of existing technologies rather than fostering innovation. R&D work conducted in relation to Euro 6/VI was significant but in most cases it primarily focused on technology improvements and refinements, such that the industry could achieve higher reliability and greater efficiency of the technologies, rather than on breakthrough innovation.
- Some degree of innovation is also expected to have taken place even without the adoption of Euro 6/VI standards due to the need to introduce similar technologies in vehicles sold in other markets, where emission limits are similar (or more stringent).
- Industry was provided with lead time between the adoption of the Euro 6/VI standards and their initial entry into force that, in most cases, was sufficient and allowed to develop and/or adopt relevant technologies. However, the latest steps in the implementation of Euro 6 with the changes in the testing procedures (i.e. RDE) came with a more limited lead time. This probably means that some manufacturers have not had sufficient time to adapt, a point also made by some industry stakeholders in their input to the study. Having said that, other experts point to the fact that most of the technology to comply with the requirements under both regulatory and real word conditions was largely available at the time of their introduction.
- In terms of social developments, Euro 6 standards appear to have had a limited contribution towards raising awareness on vehicle-related air pollution and influenced public attitude, with other events/trends (such as the dieselgate , the growing use of LEZs in cities, fiscal taxes and subsidies) likely to have been more relevant in this respect.
- There is limited evidence on the existence of mechanisms to support innovation and other technological, scientific or social developments however these appear to have been in place and some have been more utilised than others.

5.2. Efficiency

5.2.1. EQ8 What are the compliance and administrative costs? Is there evidence that Euro 6/VI has caused unnecessary

regulatory burden? Are they affordable for industry and approval authorities?

5.2.1.1 *Introduction*

In this section we present an analysis of the costs incurred by industry and authorities as a result of the introduction of Euro 6/VI regulations. The analysis focuses on the costs incurred of ensuring compliance with the provisions (substantive compliance costs) as well as other regulatory costs, including costs associated with enforcement (type approval, conformity of production and in-service conformity process), any fees and other administrative costs. We present the costs for industry (mainly OEMs) and authorities separately. The cost estimation aimed to capture one-off costs as well as ongoing/recurring costs which were then used to estimate the total costs for the industry.

The analysis of the costs has been based on a bottom-up approach aiming to identify unit costs for each cost element considered and scale them up to estimate the costs for the whole sector. This is considered the most appropriate approach to capture costs that can be directly associated with the legislation and its requirements. An alternative, top-down approach, aiming to discern the impact of the legislation on the overall costs was not considered appropriate to identify the regulatory costs of the legislation and it was also not feasible due to data limitations[117].

We used information collected from desk research (i.e. studies that have examined the costs of compliance with Euro 6/VI standards), input from stakeholders provided in the context of the consultation (i.e. vehicle manufacturers, suppliers of equipment, technical services and type approval authorities) on the costs incurred and other relevant information) and input from CLOVE consortium experts with relevant experience. We aim to cross-check information and cost estimates in order to develop a higher level of confidence.

We note though that, despite repeated requests by the study team, input from vehicle manufacturers (i.e. OEMs) was limited. In total, only three OEMs provided partial input on the costs incurred in relation to Euro 6 and three more on the costs for Euro VI. Furthermore, input provided by each of them was not always directly comparable[118]. The study team asked for further clarifications that would allow to cross-check estimates and increase the level of confidence. Nonetheless, this was not always possible. As a result, a conservative approach was often adopted using broad cost ranges allowing for a higher margin of error.

Finally, while a top-down approach was not used to assess the compliance costs, data at the sector level (such as total turnover, total R&D expenditure) were used to sense check the cost estimates developed. This provided an additional check to ensure that these cost estimates were realistic/plausible but also supported our assessment of the extent that the regulatory costs are reasonable or excessive.

Finally, the main assumptions on the unit costs per cost category was presented to stakeholders that participated in the AGVES meeting of November 26th 2020. Input was provided by three industry stakeholders that has been was also reflected in the analysis.

The following sections provide a summary of the analysis of the cost estimates making use of available qualitative and quantitative information available. As a first step we present the qualitative input provided by the participants in the stakeholder consultation on the impact of the introduction of the Euro 6/VI Regulation and the implementing legislation on the regulatory costs. This is used to provide a context of the overall analysis although it has not been particularly useful in terms of analysing the actual costs. Following that we present our estimates of the regulatory costs for Euro 6 and Euro VI. A more detailed presentation of the input provided, the assumptions made and the relevant calculations are presented in Annex 6. We note that we received very limited input from industry and authorities concerning the compliance and administrative cost incurred. As a result, in a number of cases we had to rely on own expert judgment or literature sources to develop relevant estimates.

5.2.1.2 *Overall picture on the impact of Euro 6/VI on compliance costs*

In the context of the targeted stakeholder consultation, industry representatives (including OEMs, suppliers) and type approval authorities were asked to comment on the impacts of the introduction of Euro 6/VI to their cost of operation.

Overall, the responses provided by vehicle manufacturers almost unanimously suggest that the introduction of Euro 6/VI had a significant negative implication (i.e. increase) to the various regulatory costs (see Annex 9 presenting the responses provided). More specifically:

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[117] Such an approach would require relevant cost data for the sector and the use of a control group (i.e. a sector where the only difference from the automotive sector would be the absence of Euro 6/VI standards). To the best of our knowledge, such a control is not available. Furthermore, even if such a control group existed, a top down analysis would only be able to give a sense of the total cost incurred. It would not be able to support an analysis aiming to identify the different regulatory costs, as it expected under the Better Regulation Guidelines.

[118] Some OEMs provided costs estimates on an annual basis, rather than on a per unit basis making cross-checking and developing average estimates more challenging.

- In the case of Euro 6, the responses provided by eight vehicle manufacturers suggested that the various compliance and enforcement costs for Euro 6 increased significantly (by over 50%) when compared with the respective costs under Euro 5. Furthermore, in a separate question, three out of three manufacturers reported that the administrative costs also increased, albeit by less than 50%.
- In the case of Euro VI, responses from two manufacturers also confirmed that the various compliance, enforcement costs for Euro VI increased significantly (by over 50%) when compared with the respective costs under Euro 5. In the case of administrative costs, two out of two respondents indicated that the cost increased moderately (<50% increase in comparison to Euro 5).

The above responses provide an overall picture of the cost implications of the Euro 6/VI standards that are seen as more demanding than their predecessors both in terms of the compliance (i.e. the technologies needed to meet the requirements) as well as in terms of the additional costs associated with the testing procedures. Explaining the reason for the alleged increase of the costs, one major EU OEM indicated that the multiple stages to the type approval procedures and requirements in the last years (i.e. staged introduction of changes to EVAP, ISC and OBD testing procedures) has led to significant additional costs to monitor requirements and ensure compliance.

Having said that, some stakeholders also pointed out that a clear attribution of incurred costs to the Euro 6/VI standards is difficult and there are possibly risks of overstating the associated costs. Given the global scale of operation of most vehicle manufacturers, ensuring compliance with applicable legislation in multiple markets/regions is often a centralised function. As a result, certain costs may be relevant to the applicable standards in multiple regions. One OEM highlighted that, as a global manufacturer, they have to "*work well in advance in many different areas to develop common emission technologies that are suitable to meet a variety of anticipated emission requirements from regulations around the world. While substantial contributions and costs associated with the development of advanced emissions systems are known, requirements directly linked to Euro 6 are often not specifically identifiable*". Referring to the R&D activities for the integration of Gasoline Particulate Filters (GPF) they pointed out that this technology is expected to help ensure compliance with the more recent Euro 6 requirements [in relation to particle numbers], but also the U.S. and Chinese standards requirements. These are developed in engineering centres around the globe that aim to develop and certify vehicles, propulsion systems, and components with staff that work on Euro 6 as well as other regulations, including those relevant for other countries/regions outside of the EU. Thus, it was added that, "*an assessment of time and resources associated with Euro 6 comprehension, implementation, and certification was not seen as practical*". Further to that, we note that the compliance with the Euro 6 standards for LDVs has taken place (and continues doing so) in parallel with improvements in the levels of fuel consumption and CO_2 emissions to respond to more demanding CO_2 standards. Investments in R&D in relation to development of new engines or in-cylinder control technologies should be expected to serve both objectives (reduction of pollutant emissions and improved fuel efficiency). Similarly, calibration and testing (especially following the introduction of WLTP) is also linked with the reporting of CO_2 emissions. Put together, there are risks that some of the cost implications of the Euro 6/VI may be overstated.

From the point of view of **type approval authorities**, qualitative input provided by four of them also suggests that there was an increase in their costs. All of them referred to increased costs associated with the increased complexity of the testing procedures that meant that additional human resources had to be hired. According to two of them, particularly the requirement for verification of Auxiliary and Base Emission Strategy for LDVs as part of Regulation 2016/6462 (RDE2) was seen as adding to the costs. Given that the above input came from the most important TAAs (i.e. TAAs within the top five in terms of number of type approvals granted) and the fact that there was no input on the contrary, we can conclude that there were indeed certain cost implications for Type approval authorities.

Finally, among other relevant stakeholders that provided input (national authorities and industry association), the consensus was again that there has been a significant increase in the regulatory costs, including compliance and testing costs for Euro 6 and Euro VI (see Annex 9, Figure 10-15 and Figure 10-16). In the case of administrative costs, industry representatives (i.e. associations) indicated that there has been a moderate increase (four out of four respondents), whereas national authorities (ministries) provided a more balanced range (two out of four stated that they remained the same and two that costs increased significantly). There were no stakeholders indicating that the costs reduced.

Overall, the input provided by a range of stakeholders points to the same conclusion, suggesting an increase to the costs of compliance for Euro 6 and Euro VI. According to the majority of respondents this increase has been significant (>50% in comparison to the respective Euro 5 costs) although there are possible questions as to whether these costs can be fully apportioned to the Euro 6/VI standards.

5.2.1.3 *Analysis of regulatory costs for industry*

The analysis has identified and attempted to identify all the costs associated with the implementation of Euro 6 and Euro VI legislation, including substantive compliance costs, enforcement costs, fees to authorities and administrative costs. Table 5-14 presents in more detail the costs falling under the various categories.

Table 5-14: Description of cost categories considered

Cost category	Description
Substantive compliance costs	
Hardware costs	These are the ongoing costs arising from the need to fit engine control and emission control technologies fitted to all Euro 6/VI compliant vehicles to meet the tailpipe and evaporative emission limits. Even though the entry into force of Euro 6 was in 2014, these hardware costs also apply to Euro 6 vehicles introduced earlier (2013) since they had to comply with the relevant requirements.
Research and development and calibration (R&D) costs	These include one-off costs associated with the development of new systems (engines and emission control systems) or the upgrade of existing ones and other systems (e.g. software) intended to ensure compliance with the new requirements. This takes into account additional man-effort, computer simulation, prototyping and experimental testing work associated with such work. It may also include R&D work conducted in coordination with suppliers of specific equipment or with the support of technical services. Given the nature of the activities and the fact that Euro 6 standards were introduced in stages, in practice these costs were incurred over a period of time (up to 2020) in response to the changes to the legislation. We note that a similar approach was also followed in the case of Euro VI given the stepwise introduction of some testing requirements. It also includes the calibration costs and related testing for each new vehicle variant (in the case of Euro 6) or new engine (for Euro VI) to ensure that it meets the new requirements. Calibrations cover a lead variant as well as derivative models that typically require less testing. In contrast to R&D, calibration costs are ongoing costs that take place for each new model. They should be expected to continue in the future as manufacturers bring new models to the market and will need to ensure that they meet the requirements.
Facilities/equipment costs	Any one-off costs for new facilities, equipment, tools and logistics investments required to support R&D and calibration that can be directly linked to the adoption of Euro 6/VI (i.e. as a result of new tests introduced or increased demand for testing).
Enforcement/Certification costs	Costs for the Type approval, ISC and Conformity of Production (CoP) tests performed either by Type Approval authorities (TAAs) or witnessed by the TAAs (i.e. witnessing costs) in the facilities of OEMs and technical services. These are ongoing costs that are incurred as new models need to be certified according to the new standards before entering the market.
Type approval fees	Include the certification fees paid to type approval authorities, excluding the costs of the witnessing mentioned earlier (ongoing costs)
Administrative costs	Include costs for reporting and to fulfil other information provision obligations as part of the certification process (ongoing costs)

The analysis focused on identifying and quantifying the incremental change in comparison to the Euro 5/V standards, i.e. the additional costs incurred as a result of the new rules. However, in our analysis we considered the cost increase moving from the pre-RDE Euro 6 standards (Euro 6 a/b/c) to RDE Euro 6 (i.e. Euro 6d-Temp and Euro 6d). Furthermore, in the case of Euro 6 standards we have differentiated costs depending on engine type, i.e. positive ignition (mainly petrol vehicles but also CNG and LPG) and compression ignition (diesel vehicles).

There is variation in the costs incurred depending on the vehicle type and size and the manufacturer. We have used ranges (low/moderate/high) for most cost estimates in order to be able to capture this variation as well as the uncertainty of any estimates. Due to the absence of more detailed data we have also assumed similar costs between passenger cars and vans (of the same vehicle technology, PI or CI), and between engines used for buses and lorries.

For the scaling of the costs to the whole sector we have used relevant data including number of new vehicle registrations per year, number of manufacturers affected, number of engine/model families and number of emission type approvals. Possible limitations arising from the use of these data to develop an estimate of the total costs are also discussed.

5.2.1.3.1 Costs for vehicle manufacturers

Regulatory costs of Euro 6

Hardware costs

As described in section 3.5.2, OEMs had to introduce and integrate new technologies as the Euro 6 standards evolved from Euro 6b/c (pre-RDE) to Euro 6d-Temp and then to Euro 6d.

The table below (Table 5-15) summarises the typical technology package used (based on the detailed analysis presented in 3.5.2) and estimates of the total costs developed on the basis of input from one OEM, available earlier cost estimates in the literature (ICCT, 2012a) and a bottom up analysis of the costs from experts within the CLOVE consortium. There was significant variation among the cost estimates with the costs provided by OEMs being most often higher than our own estimates. These often reflected differences in the specific technology package used by the OEM[119] (which were typically the more advanced) but also the fact that the CLOVE estimates covered mainly aftertreatment systems and OBD sensors necessary but did not include any additional equipment/system within the engine or the cost of packaging of the hardware. Thus, values are provided in ranges to cover this variation as well as the fact that there the costs may vary depending on the size of the vehicle engine used.

As can be seen, the additional hardware costs for CI engines were more significant at the early stages, mainly driven by the introduction of Selective Catalytic Reduction (SCR) technologies. In the later stages, additional hardware was also required for PI vehicles (including the use of GPF) that introduced moderate additional costs per vehicle. The range covers both passenger cars and vans.

We note that the cost estimates are higher than that the weighted average cost per diesel vehicle estimated in the Euro 6 IA SWD (€213 in 2005 prices; €280 in 2020 prices). However, that analysis only focused on the cost of the key technology expected to be needed (SCR or LNT) and did not cover other aspects such as the costs of sensors and other supporting hardware (e.g. Lambda or NOx sensors used to control emission). As such, a direct comparison can be misleading. Furthermore, it only relevant for the Euro 6 pre-RDE costs as RDE testing was not taken into consideration in the IA support study.

In total, we estimate costs in the range of €17.3 billion- €43.3 billion for the period up to 2020. We consider that a cost closer to the lower end is most probable as the higher-end cost estimates for diesel control technologies were based on input from high-end OEMs that could not be considered as typical of the costs for the sector (see also analysis in the Annex 6). Thus, our moderate cost estimate for the whole period is around €22 billion.

[119] The OEM did not provide a detail breakdown of the costs per equipment. They only provided estimates of the total cost. As such, it was not possible to make a one-to-one comparison.

Table 5-15: Summary of hardware costs per light duty vehicles associated with Euro 6 (technology package and incremental cost from Euro 5/VI) (bold denotes key new equipment)

	Euro 6 pre-RDE	Euro 6 RDE	
		Euro 6d-Temp	Euro 6d
PI			
Assumed technology package (see section 3.5.2)	TWC + Lambda sensors	TWC**+ GPF** Lambda + **Pressure sensors**	**Advanced TWC** + GPF Lambda + Pressure
Net cost range per vehicle (€s)	0	84-103	228- 465[120]
Number of vehicles sold (2013-2020) (million)	27.5	10.6	4.6
Total cost per stage (€ billion)	0	0.9-1.1	1.0-2.2
Total cost for period 2013-2020 (€ billion)	**0**	**1.9-3.2**	
CI			
Assumed technology package (see section 3.5.2)	**LNT &** DPF or DOC, DPF, **SCR, Urea Kit**[121] Lambda and Pressure sensors	**LNT &** DPF or DOC, DPF, **SCR, Urea Kit**[122] Lambda and Pressure sensors	DOC, DPF, SCR, Urea Kit[123] Lambda, **NOx** and Pressure+ **Temp sensor**
Net cost range per vehicle (€s)	341-937[124]	630-1536	751-1703
Number of vehicles sold (2013-2020) (million)	28.1	6.2	2.4
Total cost per stage (€ billion)	9.6-26.3	3.9-9.6	1.8-4.1
Total cost for period 2013-2020 (€ billion)	**15.3-40.0**		
Total for CI & PI for period 2013-2020 (€ billion)	**17.3-43.3**		

Sources: Combination of input from one OEM, literature (ICCT, 2012a) *and analysis of experts from within CLOVE consortium; Data on Euro 6 vehicle sales based on SIBYL model*

R&D and calibration costs

An estimate on R&D costs was more challenging as this is not information that is generally available outside the industry and only one high OEM was willing to provide relevant input[125]. Furthermore, relevant literature sources (ICCT, 2012a), provide only estimates on the basis of Euro 6 costs based on previous experience from the US that may only be partly transferable to Euro 6. We also note that, besides the necessary calibration activities, it is not necessarily the case that OEMs conducted own R&D and did not simply rely on the R&D activities of their suppliers with the costs of activity embedded in the hardware costs analysed above.

In the absence of additional information, we have used the input from ICCT report as a lower cost estimate and that from the OEMs as a higher R&D cost estimate (see Table 5-16). We used a cost per vehicle basis to scale up the costs to the whole sector[126]. On the basis of

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[120] Following the presentation in the AGVES meeting of November 26th 2020, one automotive association suggested that hardware costs were higher than this figure. However no specific evidence or other figures were provided to support this.

[121] Estimated 40:60 ratio of each package

[122] Estimated 40:60 ratio of each package

[123] Estimated close to 100% for this package

[124] The specific OEM uses only SCR technologies.

[125] They reported a total cost of €990 million (€650 million for all CI/diesel models and €340 million for PI/petrol) for the period 2014-2020.

[126] This is done as a way to estimate the level of costs for the total sector assuming that R&D activity is proportionate to the sales volume. It is similar to using the market share to extrapolate from the total investment.

these figures we estimate the total R&D costs incurred up to 2020 in the range of €3.2 billion - €10.6 billion with a central estimate of €6.9 billion[127].

Table 5-16: Euro 6 R&D costs estimation

	PI engines	CI engines
R&D cost (estimated average per vehicle) (€s)	36-108[128]	43-156
Total vehicles sold (2014-2020) (million)	36.8	42.8
Total per vehicle technology (2014-2020) (€ billion)	**1.3-4.0**	**1.8-6.7**
Total (2014-2020) (€ billion)	**3.2-10.6**	

Source: Own elaboration based on input from targeted stakeholder consultation on Euro 6/VI evaluation and input from experts within CLOVE consortium; Data on Euro 6 vehicle sales based on SIBYL model

The above cost estimate captures the total R&D costs including both the initial development costs as well as the calibration costs. To understand the share of the calibration costs we used information from the IHS Markit Database to identify new models introduced since 2014 and assess the total calibration effort[129]. Based on an analysis of available data on new models introduced since 2014[130] combined with estimates on the calibration costs effort between Euro 5 and Euro 6d[131] found that total calibration costs during the period 2014-2020 was up to €5 billion[132]. While a direct comparison between the total R&D cost estimate and the total calibration costs may not be possible, we can reasonably conclude that calibration costs represent more than 50% of the total R&D costs incurred. The latter should be considered as ongoing costs on the basis that manufacturers will need to calibrate any new models brought to the market to ensure that they are in compliance with the Euro 6 standards. However, if there are no future changes these should be probably be more limited[133]. In the absence of additional information on this point, we have assumed ongoing calibration costs at a level of around 50% of the current calibration costs.

Finally, we note that the above total R&D costs include the one-off costs in new facilities/equipment including new test cells and chassis dynamometer that came from the more demanding testing procedures[134].

Enforcement costs

Enforcement costs relate to the certification costs that include the cost for testing for type approval, in service conformity and conformity of production together with the costs of The changes to the certification requirements for Euro 6 were detailed in Section 3.2, and a simplified view of the impact in terms of the required tests (for an ICE vehicle family) is summarised in Table 5-17 below. Thus, the number of witnessed type approval tests by Type Approval authorities for each vehicle family increased significantly with the move to Euro 6 RDE. This is in addition to the changes brought up with the CoP, ISC, and other changes around the type approval process.

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[127] These estimates possibly include also R&D activity that has been used for the development of engines and compliance with other standards outside the EU although the OEM indicated that the total figures provided referred to Euro 6 specific projects and should not be considered as R&D costs for other standards.

[128] Following the presentation in the AGVES meeting of November 26th 2020, one automotive association suggested that these costs were probably 2-4 times higher than the upper range. However no specific evidence or other figures were provided to support this. Furthermore, we discussed the proposed figures with one OEM that contributed to the study which considered that the proposed estimates were reasonable.

[129] The analysis identified new “lead” applications (i.e. based on a new engine and aftertreatment system) and derivative applications (i.e. using the same engine but with different transmission or vehicle type). It was assumed that lead applications required a full calibration while derivatives required a small share of the effort.

[130] Information extracted from IHS Markit Database for light duty (https://ihsmarkit.com/products/automotive-light-vehicle-engine-forecasts.html) and for medium and heavy powertrains (https://ihsmarkit.com/products/automotive-truck-commercial-vehicle-engine-forecasts.html).

[131] Increased from €2million-€3million under Euro 5 to €5million-6million under Euro 6d for a lead application. Costs for derivative applications were estimated at 12.5% (1/8th) of that.

[132] Average annual calibration for the whole industry is estimated at around €0.7 billion determined by both the unit costs and number of new and derivative applications.

[133] Discussion with CLOVE experts suggested that, even with no further changes to Euro 6, calibration costs for new hybrid models tend to be more demanding and costly that those for an ICE engine and that they would expect calibration costs to ensure compliance with Euro 6 be higher in the future. Given that the introduction of hybrid technologies is primarily driven by the need to achieve higher fuel efficiency and meet the CO_2 standards we have considered that these additional costs are mainly a result of other legislation and not the Euro 6. As such we have assumed that only a share (50%) of the calibration costs will continue in the future.

[134] One CLOVE expert estimated a total of €30million investment for a total of 10 testing cells for a large OEMs which is also largely in line with input provided from one large OEM (€10-100 million). This would suggest a cost for the 14 major OEMs (EU and non-EU) in the range of up to €420 million if all were to make similar investment. However, given the variation in size and the fact that some rely on the facilities of technical services (and pay on the basis of the services provided), total costs for OEMs would probably be significantly lower. However, it is not possible to provide a better estimate.

Table 5-17: Changes to the testing requirements between Euro 5 and Euro 6 RDE

Test type	Euro 5	Euro 6 pre-RDE	Euro 6 RDE
Type 1 (emissions)	NEDC	NEDC	WLTC vehicle TML[1] WLTC vehicle TMH[2] WLTC ATCT[3]
Type 6 (cold start)	NEDC -7°C (PI only)	NEDC (PI only)	NEDC (PI only)
RDE (On-road PEMS) **(Vehicle family for RDE may not match that for CO_2)**		RDE Monitoring (from April 2016) + correlation WLTC	RDE type approval + correlation WLTC
Notes:	[1] Test Mass Low (lightest vehicle in family) [2] Test Mass High (heaviest vehicle in family) [3] Alternative Temperature Correction Test at 14°C		

Input from the OEMs and discussions with technical services and type approval authorities suggests that it is very difficult to propose unit cost estimates as manufacturers may adopt different approaches in terms of the way the group models in model families while the legislation also identifies different criteria to group model depending on the specific test required. Information from two OEMs was provided on an annual basis (total costs) that we translated to cost per model family. Witnessing time effort and costs were also provided by one TAA. Furthermore, information provided by one OEM was that the overall level of effort and the associated costs for testing doubled between Euro 5 and Euro 6 pre-RDE and increased by a factor of 5 between Euro 5 and Euro 6d. This was validated by a TAA, a Technical service and a CLOVE consortium expert.[135] More detailed information is provided in Annex 6.

On the basis of the information available, we developed a cost estimate for certification and used information on the number of model families[136] to scale it up to the total costs for the period 2014-2020. The presented cost estimates capture the net increase in comparison to Euro 5.

Table 5-18: Estimated net increase to enforcement cost (type approval, ISC and CoP) from Euro 5 to Euro 6 (2014-2020)

	Euro 6 pre-RDE	Euro 6 RDE
Total number of model families certified per year (average for 2014-2020 period) (A)	870	
Number of years (B)	4	3
Average certification cost (type approval, CoP and ISC) per model family (C)	€34k-€69k	€172k-€351k
Net increase from Euro 5 (thousand €s) (D)	€0-€34k	€138k-€286k
Total net increase to certification costs (2014-2020) (€ million) (E=A*B*D)	**0-118**	**360-747**
Witnessing costs per model family (F)	6-8k	15k-20k
Net increase in witnessing costs from Euro 5 (G)	3-4k	12k-16k
Total net increase to witnessing costs (2014-2020) (€ million) (H= A*B*G))	**10-14**	**31-42**
Total net increase to enforcement costs (2014-2020) (€ million) (E+H)	**10-128**	**391-799**
Total for Euro 6 (€ million)	**401-927**	

[135] The proposed cost ranges that were presented during the AGVES meeting in November 26th 2020 were also considered appropriate by one automotive association.

[136] For this estimate, we used the analysis of the number of engine applications presented earlier. Following discussions with CLOVE consortium experts it was considered as more appropriate to use the number of lead and derivative applications as an indication of the total number of model families. Derivative applications group together individual vehicle models with other common features that are expected to rely on the same tests. Using the number of lead applications only would most probably underestimate the level of certification effort (it would group too many vehicle models together assuming only one certification) while using the number of individual type approval certificates granted would overestimate the costs since the

Source: Own analysis based on input from two OEMs as part of the targeted stakeholder consultation, discussion with TAA and TS and experts from the CLOVE consortium; Data number of model families based on own analysis of IHS Markit database

Administrative costs

Separate input on the reporting costs associated with the certification process was not generally available[137]. Only one OEM provided input on the time and associated costs on an annual basis suggesting an average cost per emissions type approval at around €40k. Given the absence of additional input to cross-check this information, this estimate should be treated only as indicative. In our own calculations we have used a much broader range (±50%) of €20k-€60k per TA to capture this uncertainty[138]. In terms of the level of change from Euro 5, we followed the input provided in the case of the overall certification effort – namely that the overall effort doubled in the case of Euro 6 pre-RDE and up to 5 times in the case of Euro 6d RDE in comparison to Euro 5. We note that in the responses to the targeted consultation, respondents suggested an increase of administrative costs of up to 50%. Thus, while it is not possible to verify, our estimate most probably represents a high-end estimate of the administrative costs faced by manufacturers.

In order to estimate the total costs for the whole sector we used the data on the total number of emission type approvals granted as presented in section 3.4. Furthermore, as already indicated in section 3.4, there has been a notable increase in the number of TAs granted after 2018 which is partly linked to the Euro 6 requirements and the RDE testing procedure. As these are often re-certifications of existing models it is expected that the level of effort may be more limited. As such, for these additional costs we have assumed a 50% share of the administrative costs estimated for a Euro 6 Type approval.

On the basis of the above assumptions we estimate net costs for the whole period €247 million-€793 million. Given the limited number of inputs on the admin costs we not that there is significant uncertainty which is partly covered by the wide range of upper and lower cost estimates in the calculations. Further to that, we note that while there has been a significant increase in the costs in comparison to Euro 5, it is still a small share of the total costs.

Table 5-19: Net increase in reporting costs between Euro 6 and Euro 5

	Euro 6b/c (2014-2017)	Euro 6d-Temp /Euro 6d (2018-2020)
Total reporting costs per TA (A)	8k-24k	20k-60k
Net increase from Euro 5 (B)	4k-12k	16k-52k
Years (C)	4	3
Average number of emission type approvals granted (year) (D)	2,493	
Net increase due to higher reporting costs (€ millions) (E=B*C*D)	**40-120**	**120-390**
Net increase in number of type approvals since 2018 (F)	-	3,650
Net increase in costs for additional TA (G=0.5* B)	-	8k-26k[139]
Net increase in costs due to increase in type approvals (€ millions) (H=C*F*G)	-	88-285
Total net cost increase per period (€ millions) (I=E+H)	**40-120**	**207-674[140]**
Net increase costs for period 2014-2020 (million)	**247-793**	

Source: Own elaboration based on data from one OEM on administrative costs for Euro 6 and input from OEMs as part of the stakeholder consultation, CLOVE consortium and TAA on the net impact of Euro 6 on total effort. Data

[137] We discussed this point further with one type approval authority and technical services which indicated that is difficult to separate the different parts of the certification in such level of detail to be able to identify the time spent on reporting/information provision.

[138] The proposed estimates presented during the AGVES meeting in November 26th 2020 were also considered appropriate by one automotive association.

[139] 50% of estimated increase of costs of €16k-€52k

[140] Net increase

on total number of type approvals based on input from 9 TAA authorities and extrapolated to the total using a factor of 0.65.

Fees to type approval authorities

Input on the fees charged by TAAs (not including the costs to cover witnessing) was provided by 6 of out of 9 TAAs[141] that responded to the targeted data request sent from the Commission. Their input suggests that the fees charged by TAA authorities are very small – in a range from €0-€2,000 per type approval depending on the TAA (€ weighted average of €0.7 k). Furthermore, the information they provided does not point to a systematic increase to the fees charged across all TAAs. Some reported an increase of up to 50% between Euro 6 pre-RDE and Euro 6 RDE but other reported a decrease. This is also because not all authorities charge fees that directly reflect the costs for the type approval process. Two TAAs (ES, RO) indicated that they do not charge any fees charged for type approval.

Put together, in terms of the fees charged by TAA there is no indication that these have systematically increased as a result of the introduction of the Euro 6. However, due to the increase in the number of emission type approvals reported (see also section 3.4) there was a small increase to the total costs associated with these fees. Our estimate is summarised in Table 5-20 below. As can be seen, this is a very small total net cost increase. Thus, even if these costs are underestimated by a factor of 10, they only represent a very small share of the total regulatory costs.

Table 5-20: Net increase in fees to type approval authorities (total fees for Type approval, ISC and CoP) and reporting costs between Euro 6 and Euro 5 – Figures used in the cost calculations

	Euro 6
Fees per TA (A) (€k)	0.5-0.9
Net increase from Euro 5 (B)	0
Number of TA per year (C)	2493
Years (D) (2014-2020)	7
Net increase due to increase in fees (€ millions) (E=B*C*D)	**0**
Net increase in number of type approvals since 2018 (F)	3,650
Number of years (2018-2020) (G)	3
Net increase in costs due to increase in type approvals (€ millions) (H=A*F*G)	**6-10**
Total net cost increase per period (€ millions) (I=E+H)	**6-10**

Source: Own elaboration based on data from 6 TAAs on the evolution of type approval fees over time. Data on total number of type approvals based on input from 9 TAA authorities and extrapolated to the total using a factor of 0.65

Regulatory costs of Euro VI

Hardware costs

Table 5-21 below presents the information on costs of technologies typically introduced in Euro VI vehicles to ensure compliance with the Euro VI requirements. The proposed values in the range of €1,798-4,200 cover the aftertreatment system and improvements to the fuel system and are based on data from the literature (ICCT, 2016b), discussions within the consortium and input from two OEMs. The broad range to the cost estimate provided reflects the fact that available cost figures from literature and the CLOVE consortium focused mainly on the aftertreatment systems used (thus seen as being lower cost estimates) while input from OEMs also captured engine material and other equipment[142] [143].

The hardware costs estimates are also comparable with the costs in the Euro VI IA support study estimation of cost per vehicle in the range of €2,539 and €4,009 (€2,817 to €4,419 in 2020 values).

[141] Input provided by LU, DE, SE, IE, ES, RO.

[142] One OEM reported costs per vehicle of €10,350. However, these referred to the total costs (not the incremental) and they also included aspects such a vehicle adoption. Asked for clarification, they indicated that the aftertreatment system costs were in the range of €2,000-€3,500 per vehicle (within the range we have considered, allowing for extra costs for additional hardware and packaging).

[143] Following the presentation in the AGVES meeting on 26/11 another large EU OEM commented that the proposed range is very much in line with the costs per vehicle they have experienced for the different HDVs they produce.

For the total period 2013-2020 that Euro VI has been in force we estimate total costs in the range of €4.1 billion - €9.5 billion.

Table 5-21: Summary of costs per vehicle for hardware costs to meet Euro VI standard

	Euro V to Euro VI
Assumed technology package (in bold new equipment added)	Improved fuel system, DOC, **DPF, closed-loop SCR systems, ASC,** Urea Kit, **OBD sensors**
Net cost range per vehicle (€s)	€1,798-4,200
Number of vehicles sold (2013-2020) (million)	2.27
Total cost for period 2014-2020 (€ billion)	**4.1-9.5**

Source: Own elaboration on the basis of input from targeted stakeholder consultation on Euro 6/VI evaluation input from experts within CLOVE consortium and literature (ICCT (2016b)*;* (Miller & Braun, 2020)*); Data on Euro 6 vehicle sales based on SIBYL model*

R&D costs

As in the case of Euro 6, estimating the costs of R&D (including calibrations and investment in relevant equipment) was less certain. Estimates of the R&D costs for the development or upgrade of new engine systems (engines and aftertreatment) were provided by three OEMs that participated in the study, two among the total of seven large OEMs with over 7% share of the market each[144] and one much smaller with less than 1%. They reported that total R&D investment (including equipment/tooling) was around €2.2 billion for the two large OEMs and around €0.6 billion for the smaller one.

The input provided suggests that the R&D activity was considered relevant for both the Euro VI and the US EPA 10 standards[145]. As such, for the purposes of our calculations we assumed that only part[146] of the reported R&D costs are directly linked to Euro VI, namely €1.1 billion for the large OEMs and around €0.3 billion for smaller one[147]. Furthermore, the two large OEMs are in the high end of the of the market and, as confirmed by one of them, it is reasonable to assume that their estimates represent the high-end cost estimate. To reflect this variation we considered a low end of the range at €0.55 billion per OEM (50% of the high-end costs).

On the basis of the above, the R&D costs incurred during the period 2013-2020 are estimated at around €5.0 billion-10.7 billion (see Table 5-22).

Table 5-22: Total R&D investment for Euro VI by major OEM (values in EUR million) for 2013-2020 period

	Number of OEMs	Average total R&D and facilities cost (2013-2020)	Total for sector for period 2013-2020 (€ billion)
Large OEMs	7	0.55-1.1	3.85-7.70
Small OEMs	10	0.15-0.30	1.5-3.0
Total			**5.35-10.7**

Source: Own analysis based on input from three OEMs in the context of the targeted stakeholder consultation on Euro 6/VI evaluation

The calculated total R&D costs are comparable to the total hardware costs incurred for the same period. On a per vehicle basis they represent a cost of €1,900-€3,800 per HDV vehicle

[144] Data from ACEA on HDV sales suggest that there are 7 large OEMs (MAN, SCANIA, DAIMLER Trucks, DAF, VOLVA Trucks, IVECO/FIAT, Renault) active in the HDV market (i.e. developing engines that need to be type approved under Euro VI), each of them with shares in the range of 7-22% of the total. Brought together they represented 92% of the total sales in 2019. The remaining share in the case of trucks is shared among small mainly non-EU manufacturers (e.g. Mitsubishi, ISUZU, FORD) In the case of the buses segment there is also a number of manufacturers that only produce vehicle bodies (e.g. Van Hool, VdL, EBusco, BYD, HIGER, TEMSA) that use the engine systems from the main OEMs. Such manufacturers do not incur R&D costs directly related to Euro VI. For our calculations we have assumed a total of 10 small HDV manufacturers. However, even this number may be an overestimate.

[145] US EPA standards are structured and tested quite differently to EU standards so direct comparisons are not possible, but in practice a similar level of technology is considered necessary to meet either standard, even if application and calibration approaches differ

[146] In the absence of specific information we assumed a 50% split of the costs. Given the similar nature of the requirements this was considered reasonable. It was also informally verified during the discussion with one OEM that provided data.

[147] A similar assumption was not made for the Euro 6 R&D costs that were directly linked to Euro 6 according to the input provided by the OEM.

sold over the period 2013-2020[148]. A high cost per vehicle in comparison to the respective costs for LDVs is to be expected given the much smaller volume of vehicles sold in the HDV market. At the same time, this estimate is 8-12 times higher than the estimated R&D cost per vehicle proposed in a recent analysis made by ICCT on the R&D costs for HDVs based on R&D costs data from the US (ICCT, 2016b). R&D costs in the range of $250-300/vehicle (ca €230-270 per vehicle) were considered assuming that both DPF and SCR technologies are introduced in new vehicles. On the basis of the number of Euro VI HDVs sold during the period 2013-2020 (ca. 2.7 million) this would represent a total R&D cost of around €0.7 billion.

As an additional way to corroborate the input from OEMs, the study team used information from the IHS Markit Database to develop an estimate of the calibration specific costs associated with new and derivative engines applications introduced since 2013[149]. Based on an analysis of available data, a total of 63 lead and 490 derivative applications (total of 553 engine families) were identified that were introduced in the period 2013-2020 and are Euro VI compliant. Furthermore, on the basis of discussions with experts in the CLOVE consortium on the cost per calibration[150] the total calibration costs for the period 2013-2020 were estimated as around €0.33 billion with a net increase in the total costs in comparison with Euro V of around €0.1 billion. Thus, assuming that calibration costs represent around 50% of the total R&D costs (similar to the assumption made for Euro 6), the total R&D costs can be estimated at around €0.6-€0.7 billion, similar to the low-cost estimate based on the ICCT study.

As such, there are grounds to question the R&D cost estimate on the basis of the OEM data, even once we have only assumed that 50% is related. To be in line with the estimates from ICCT and our own analysis of calibration costs would require that only 5-10% of the reported R&D expenditure is related to Euro VI. However, we discussed the estimates provided with one of the OEMs who considered that the estimates are indeed reflective of the costs incurred while also confirming that they probably represent an upper estimate of costs incurred and that other OEMs would probably have lower costs. Furthermore, the fact that similar total cost estimates were provided by two of the seven large OEMs strengthen the validity of these estimates. At this stage, for the purposes of further calculations on the benefit-cost ratio we have adopted a more conservative approach, i.e. used the higher cost estimate.

Enforcement costs

The introduction of Euro VI has led to some changes to the testing requirements and certification procedures (including Type approval, ISC and CoP) that were not applicable under Euro V. These were detailed in Section 3.3, and include additional tests (cold-start WHTC and NTE engine tests, PEMS vehicle tests) as well as changing to the use of WHSC and WHTC engine tests (from ESC and ELR), and changes to OBD requirements. As such, the impact of Euro VI is associated with net increase in the certification costs together with an increase in the time spent from TAA for the witnessing of these tests.

Input provided by two OEMs on the level of Euro VI certification costs suggests that these were in the range of €280,000 and €680,000[151] [152]per engine family. They did not provide additional input on the level of change of the costs in comparison to Euro V but, discussion with CLOVE consortium members pointed to an increase of these costs in the range of 20%-60% (€28,000-84,000). This is also in line with the assessment on the level of effort needed by one major TAA and one large Technical service that referred to a range of 40%-60%. In the case of the witnessing costs, input from one OEM and the discussions with one major TAA led to the conclusion that witnessing costs for Euro VI are in the range of €8-15k/engine family.

Similar to the calculations for Euro 6, we used the total number of engine families identified earlier (553 in total) to estimate the total level of certification effort across the industry. Based on data on engine production from the IHS database we identified a total of 553 engine calibrations. We note this is still not an accurate description of the total level of certification activity for Euro VI vehicles, but it is more appropriate than the number of Type approvals given that test results can be used for a range of engine families. Table 5-23 summarises the cost estimates for the certification and witnessing costs.

[148] We note that R&D costs and not directly related to the sales volume of an OEM and these are more closely linked to the number of engine families and vehicle variants. However, we have calculated R&D costs per vehicle in order to be able to compare with other sources in the literature.

[149] The analysis identified new "lead" applications (i.e. based on a new engine and aftertreatment system) and derivative applications (i.e. using the same engine but with different transmission or vehicle type). It was assumed that lead applications required a full calibration while derivatives required a small share of the effort. Based on

[150] Based on discussions with experts within CLOVE, calibration costs increased from €1.8 million under Euro VI to €3.5 million Euro VI for a lead engine application. Costs for derivative applications were estimated at around €230k.

[151] Two large OEMs provided data on annual certification costs and number of engine families suggesting total certification costs in the range of €580k-680k per engine family. A small OEM provided a very broad estimate of the total costs with a median of €275 k per engine family.

[152] Following the presentation in the AGVES meeting (26/11/2020), one additional EU OEM supported the figures provided commenting that the proposed range is realistic.

Table 5-23: Estimated increase in enforcement cost per type approval used for the cost calculations related to Euro VI

Type of cost	Euro VI
Total number of engine families (period 2013-2020) (A)	553
Total costs per certification (B)	€280 k-680 k
Net increase from Euro V (C)	€93 k – € 227 k
Total additional net costs for Euro VI certification (period 2013-2020) (€ million) (D=A*C)	**51-126**
Total costs per witnessing (E)	€8k-15 k
Net increase from Euro V (F)	€2.7 k – € 5 k
Total additional net costs for witnessing (period 2013-2020) (€ million) (G=F*A)	**1.5-2.8**
Total enforcement costs (D+G) (€ million)	**52.5-128.8**

Administrative costs

Our estimates on the total administrative costs associated with Euro VI is presented in Table 5-24 below. As in the case of Euro 6, there was no detailed input on the reporting costs associated with the certification process. Input from one OEM on the annual costs for reporting suggested costs per TA at around €35k while a second OEM suggested costs in the range of €10k-100k (median of €55k) We used these two data points to define the range. Both OEMs also referred to an increase to the reporting costs of up to 50% linked to the more demanding certification procedures (as discussed in Section 3.3), an estimate that was also supported in the discussion with a major TAA. In order to estimate the total costs for the whole sector we used the number of emission type approvals granted. Note that in contrast to the approach adopted in the case of Euro 6, we have not considered the increase in the number of certifications observed since 2018[153].

On the basis of the above, we have estimated the net costs for the whole period €26 million-€41 million. Given the limited number of inputs to the admin costs there is significant uncertainty which is partly covered by the wide range of upper and lower cost estimates in the calculations. Further to that, we note that while the costs increase does represent a significant increase in the costs in comparison to Euro 5, it is still a small share of the total costs.

Table 5-24: Net increase in reporting costs between Euro VI and Euro V

Type of cost	Euro VI
Total costs per certification (A)	€35k-€55k
Net increase from Euro V (B)	€17.5k – €27.5 k
Number of years (C)	8
Total number of TA (average for period 2013-2020) (D)	181
Total net increase of administrative costs (period 2013-2020) (€ million) (B*C*D)	**26-41**

Source: Own elaboration based on data from two OEM on administrative costs for Euro VI. Data on number of type approvals based on input from 9 TAA authorities

Fees to type approval authorities

As in the case of Euro 6, input on the fees charged by TAAs (not including the costs to cover witnessing) was provided by TAAs[154] that responded to the targeted data request sent from the Commission authorities. The input from four authorities that have granted Euro VI certificated (DE, BE, IE, ES) suggest the average fee charged per type approval remained very small (in the range of €0-€460) and did not change with the introduction of Euro V. This was also confirmed in the discussion with another large TAA that also indicated fees within the same range and that there was no change in the fees. On the basis of the above, we estimate that the total fees during the period were approximately €0.3 million (median value),

[153] As already commented in Section 3.4 the increase in the number of Euro VI emission type approvals is driven by the need for CO_2 certification. CO_2 certification falls under Regulation (EU) 2017/2400 that is implementing Euro VI Regulation (595/2009), but for the purposes of our analysis the resulting increase on certification and is not directly related to the pollutant emission requirements.

[154] Input provided by LU, DE, SE, IE, ES, RO.

but with no net increase to the total fees linked to Euro VI (i.e. the costs are the same as under the business as usual scenario).

Total costs of Euro 6 and Euro VI for the sector

Table 5-25 below summarises the cost estimates for the period 2013-2020 for both Euro 6 and Euro VI on the basis of the analysis presented above. These are total non-discounted figures per cost category. The discounted figures are presented in the following section where we also consider the future costs up to 2050.

Table 5-25: Estimated total regulatory costs associated with Euro 6 (2014-2020) and Euro VI standards (2013-2020) (€ billions – non-discounted figures)

	Euro 6			Euro VI	Total
	CI	PI	Total		
Compliance cost	17.2-46.7	3.3-7.2	20.4-53.9	9.4-20.2	29.9-74.1
Hardware cost	15.3-40	1.9-3.2	17.3-43.3	4.1-9.5	21.3-52.8
R&D costs	1.8-6.7	1.3-4	3.2-10.6	5.4-10.7	8.5-21.3
Enforcement			0.4-0.9	0.05-0.13	0.5-1.1
Fees			0.006-0.01	0-0	0.006-0.01
Administrative costs			0.3-0.8	0-0	0.3-0.8
Total	**17.2-46.7**	**3.3-7.2**	**21.1-55.6**	**9.5-20.4**	**30.6-76**

Source: Own elaboration

Total costs over the period up to 2050

To assess the cost effectiveness of the measures, an estimate of the regulatory costs up to 2050 is needed. This will be used to compare them with the monetized benefits associated with the emission reductions achieved as a result of the introduction of Euro 6 and Euro VI vehicles.

As such, we have examined which of the regulatory costs are expected to continue after 2020 (see Table 5-26). They are based on the assumption that there will be no further changes to the Euro 6/VI standards and the implementing legislation, namely that both the emission limits of the regulated pollutants and the testing procedures will remain the same.

Table 5-26: Assumptions concerning the expected evolution of future costs

Cost category	Expected evolution of costs after 2020
Hardware costs	Will continue as vehicles will need to be fitted with the relevant technologies. However, over time costs to decrease on the basis of learning effect. We have assumed a strong learning effect with gradual reduction to 75% of the initial value over a 6 year period of the basis of the widespread adoption of the specific technologies
Research and development and calibration (R&D) costs	No new R&D costs expected in the absence of changes to Euro 6 limits and testing procedures. Costs for calibration for new models to continue but at a lower level on the basis of a learning effect (assumed reaching 50% of current level of calibration costs over time)
Facilities/equipment costs	No new/additional investment in testing facilities/equipment expected.
Enforcement costs	Costs for the Type approval, ISC and Conformity of Production (CoP) to continue at largely the same level as under Euro 6d after 2020
Administrative costs	Reporting costs related to the Type approval, ISC and Conformity of Production (CoP) to continue at largely the same level as under Euro 6d after 2020
Type approval fees	No changes assumed

Source: Own elaboration

On the basis of the above assumptions, we have developed an estimate the total costs for the period 2050 for each of the vehicle categories (PI-LDVs, CI-LDVs and HDVs)

The Tables included in the following pages (Table 5-27,Table 5-28 and Table 5-29) presents the discounted net costs under the moderate[155], low and high cost scenarios. We can make the following observations:

- Total net regulatory costs associated with Euro 6 (i.e. in comparison to Euro 5 baseline) up to now (period 2014-2020) are estimated at €30 billion, while for the period up to 2050 at €133 billion (with a range between €80 billion and €186 billion).
- Total net costs for CI vehicles represents the major source of costs up to 2020 (81%) and in the future due to continuing higher hardware costs and the fact the CI vehicles will maintain a higher share of registration driven by the fact than vans are expected to be exclusively with CI internal combustion engines.
- On a per vehicle basis, the weighted average net costs per vehicle for the whole period 2014-2020 are estimated at €131/vehicle for PI vehicles and €600/vehicle for CI engines. Of course, this hides the fact that costs per vehicle have been significantly higher over the last few years since the introduction of Euro 6 RDE as already analysed in section 5.2.1.3.
- In general, hardware costs are the most important contributor to the total increase in Euro 6 costs (75% of the total for the period up to 2020; 90% for the period up to 2050). However, there is still a significant contribution of all other non-hardware costs. In the case of PI vehicles, the limited total hardware costs in the initial period up to Euro 6 RDE together with the increase in the increase in the TA activity in the period 2018-2020 meant that the non-hardware costs represented around 64% of the total additional costs incurred (within the range of 55%-67% of total depending on the cost scenario).
- In the case of Euro VI, net total costs in comparison to Euro V baseline for the period up to 2020 (2013-2020) are estimated at €12.9 billion and for the total period up to 2050 at €25.2 billion.
- The average net total cost per vehicle up to 2020 is estimated at €5,693 (range of €3,717-€7,961) of which non-hardware costs represent around 54% of the total. A significant part of this non-hardware cost is associated with the R&D expenditure for which we have noted that there indications that it may be an overestimate. Considering the whole period, the cost per vehicle is smaller (€2,421/vehicle) with non-hardware costs representing 40% of the total.

[155] The moderate scenario is based on central value between low and high estimates for each cost item with the exception of hardware/technology costs where we able to identify central estimates.

Table 5-27: Estimated net total costs to OEMs from Euro 6 and Euro VI (NPVs in billion Euros – 2010 values) (moderate scenario)

Detailed cost category (see definition in Table 5-14)	Euro 6 (cars and vans)						Euro VI (lorries and buses)	
	PI		CI		Total			
	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2013-2050
Hardware/technology costs	2.0	22.9	20.4	97.1	22.4	119.9	5.9	15.1
R&D/ packaging/ engineering/ calibration and equipment	2.5	3.4	3.6	4.8	6.1	8.2	6.9	9.7
Total compliance cost	**4.5**	**26.2**	**24.0**	**101.9**	**28.5**	**128.1**	**12.8**	**24.9**
Enforcement costs	**0.6**	**2.5**	**0.3**	**1.2**	**0.9**	**3.7**	**0.1**	**0.2**
Fees to TAAs	**0.003**	**0.003**	**0.002**	**0.002**	**0.0**	**0.0**	**0.000**	**0.000**
Total administrative cost	**0.4**	**1.2**	**0.2**	**0.6**	**0.618**	**1.829**	**0.03**	**0.09**
Total costs	**5.6**	**30.0**	**24.5**	**103.7**	**30.1**	**133.6**	**12.9**	**25.2**
Total vehicles[156]	**42,766,134**	**197,452,120**	**36,759,227**	**207,441,784**	**79,525,361**	**404,893,904**	**2,265,328**	**10,400,877**
Total cost/vehicle (€s)	*131*	*152*	*666*	*500*	*378*	*330*	*5,693*	*2,421*
Hardware cost/vehicle (€s)	*48*	*116*	*554*	*468*	*282*	*296*	*2,596*	*1,455*
non-Hardware costs (billion €s)	*3.6*	*7.1*	*4.1*	*6.6*	*7.7*	*13.7*	*7.0*	*10.1*
non-Hardware costs per vehicle (€)	*83*	*182*	*112*	*32*	*96*	*34*	*3,096*	*966*
Share of non-hardware costs in total	*64%*	*24%*	*17%*	*6%*	*25%*	*10%*	*54%*	*40%*

[156] Number of vehicles on the basis of the number of registrations at EU level for LDVs (PI and CI vehicles) and HDVs for the two periods provided in the SIBYL model.

Table 5-28: Estimated net total costs to OEMs from Euro 6 and Euro VI (NPVs in billion Euros – 2010 values) (low cost scenario)

Detailed cost category (see definition in Table 5-14)	Euro 6 (cars and vans)						Euro VI (lorries and buses)	
	PI		CI		Total			
	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2013-2050
Hardware/technology costs	1.53	15.26	11.28	58.24	12.8	73.5	3.53	9.07
R&D/ packaging/ engineering/ calibration and equipment	1.3	1.7	1.6	2.1	2.8	3.8	4.8	6.7
Total compliance cost	**2.8**	**16.9**	**12.8**	**60.3**	**15.6**	**77.3**	**8.4**	**15.8**
Enforcement costs	**0.4**	**1.6**	**0.2**	**0.8**	**0.6**	**2.4**	**0.0**	**0.1**
Fees to TAAs	**0.003**	**0.003**	**0.002**	**0.002**	**0.0**	**0.0**	**0.00**	**0.00**
Total administrative cost	**0.25**	**0.64**	**0.12**	**0.31**	**0.4**	**1.0**	**0.02**	**0.07**
Total costs	**3.4**	**19.2**	**13.1**	**61.4**	**16.6**	**80.6**	**8.4**	**16.0**
Total vehicles[157]	**42,766,134.0**	**197,452,120.0**	**36,759,227.0**	**207,441,784.0**	**79,525,361.0**	**404,893,904.0**	**2,265,328.1**	**10,400,877.0**
Total cost/vehicle[158] ***(€s)***	*80*	*97*	*357*	*296*	*2*	*199*	*3,717*	*1,536*
Hardware cost/vehicle (€s)	*36*	*77*	*307*	*281*	*161*	*182*	*1,556*	*872*
non-Hardware costs (billion €s)	*1.9*	*4.0*	*1.9*	*3.2*	*3.7*	*7.1*	*4.9*	*6.9*
non-Hardware costs per vehicle (€)	*44*	*102*	*51*	*15*	*47*	*18*	*2,161*	*665*
Share of non-hardware costs in total	*55%*	*21%*	*14%*	*5%*	*23%*	*9%*	*58%*	*43%*

[157] Number of vehicles on the basis of the number of registrations at EU level for LDVs (PI and CI vehicles) and HDVs for the two periods provided in the SIBYL model.
[158] Cost per vehicle has been calculated on the basis of the number of registrations at EU level for LDVs (PI and CI vehicles) and HDVs for the two periods provided in the SIBYL model.

Table 5-29: Estimated net total costs to OEMs from Euro 6 and Euro VI (NPVs in billion Euros – 2010 values) (high cost scenario)

Detailed cost category (see definition in Table 5-14)	Euro 6 (cars and vans)						Euro VI (lorries and buses)	
	PI		CI		Total			
	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2014-2050	costs up to 2020	costs for period 2013-2050
Hardware/technology costs	2.5	30.4	29.4	135.9	32.0	166.3	8.2	21.2
R&D/ packaging/ engineering/ calibration and equipment	3.8	5.0	5.7	7.6	9.4	12.6	9.7	13.4
Total compliance cost	6.3	35.5	35.1	143.4	41.4	178.9	17.9	34.6
Enforcement costs	0.87	3.39	0.41	1.60	1.28	5.00	0.11	0.34
Fees to TAAs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total administrative cost	0.58	1.84	0.28	0.87	0.86	2.71	0.04	0.11
Total costs	7.8	40.7	35.8	145.9	43.6	186.6	18.0	35.0
Total vehicles[159]	**42,766,134**	**197,452,120**	**36,759,227**	**207,441,784**	**79,525,361**	**404,893,904**	**2,265,328**	**10,400,877**
Total cost/vehicle[160] ***(€s)***	5.2	10.3	6.4	10.1	11.6	20.3	9.8	13.9
Hardware cost/vehicle (€s)	122.2	52.0	172.8	48.4	145.6	50.2	4,326.3	1,332.2
non-Hardware costs (billion €s)	*181*	*206*	*974*	*703*	*548*	*461*	*7,961*	*3,369*
non-Hardware costs per vehicle (€)	*59*	*154*	*801*	*655*	*402*	*411*	*3,635*	*2,036*
Share of non-hardware costs in total	*5.2*	*10.3*	*6.4*	*10.1*	*11.6*	*20.3*	*9.8*	*13.9*

[159] Number of vehicles on the basis of the number of registrations at EU level for LDVs (PI and CI vehicles) and HDVs for the two periods provided in the SIBYL model.
[160] Cost per vehicle has been calculated on the basis of the number of registrations at EU level for LDVs (PI and CI vehicles) and HDVs for the two periods provided in the SIBYL model.

5.2.1.3.2 *Costs to suppliers*

The Euro 6/VI standards can also have cost implications for suppliers of equipment. These can vary depending on their specific activity and type of equipment/component supplied. In general terms, they may include product development (R&D) costs to ensure that components and equipment supplied to OEMs are in compliance with the new requirements or, in the case of aftertreatment technologies, that the technologies used ensure that vehicles will be able to meet the new requirements. They also include costs for testing to ensure compliance and possible investment in new testing equipment. Furthermore, in the case of suppliers involved in the type approval of individual components, they will also incur costs for the type approval procedures.

Suppliers that contributed to the targeted stakeholder consultation when asked to indicate compliance costs pointed to the presence of one-off and ongoing costs associated with product development, testing and administrative costs. The costs reported varied greatly[161] but they were generally higher for larger suppliers (presentation of the input provided by automotive suppliers is included in Annex 6).

However, when considering the total cost to industry, it is generally expected costs to automotive should be largely – if not fully – reflected in the increased costs hardware/equipment paid by their clients (mainly the OEMs). This assumption is also supported by feedback provided by some suppliers and their representatives:

- When directly asked, a non-EU association representative of suppliers of emissions control technologies commented that it is safe to assume that costs of suppliers are passed to OEMs.
- Asked to comment on the costs to ensure compliance with Euro 6 standards, a large equipment supplier indicated that it is “very difficult to specify [the costs], mainly it is the OEMs who provide/calculate these costs including installation costs”.
- A supplier of powertrain technologies commented that the end price is covered by the OEM and, similarly, a supplier of evaporative control emission technologies also commented that the cost of the technologies are passed to OEMs.
- As such, we have not attempted to quantify the costs to suppliers in our analysis. They are generally considered to be captured in the form of the hardware costs for OEM analysed in the previous section.

5.2.1.4 *Costs to type approval authorities*

In the case of authorities, the introduction of Euro 6/VI has resulted in the following possible costs:

- One-off costs for investment in new facilities and equipment (if considered necessary) as well as preparatory action taken in the form of training, development of guidance documents or other system updates.
- On-going costs associated with the increased resources (human and other) required for the type approval process that resulted from the introduction of Euro 6/VI,

[161] Respondents indicated one-off costs ranging from less than 1 million to over 100 million for testing and product development and typically to less than 0.1 million for the administrative costs. In terms of ongoing costs, there were typically around 10% of the one-off costs.

including the time needed for witnessing of Type approval, ISC and Conformity of Production (CoP) tests and the review of the documentation of information provided by OEMs);

A detailed presentation of the input provided by TAAs on the costs is provided in Annex 6. For the purposes of our analysis of the total costs of the legislation we expect that most, if not all, the costs incurred by authorities should be expected to eventually pass to OEMs in the form of the additional costs for the witnessing or the fees paid for obtaining the type approval certification. This is particularly the case in terms of the ongoing costs that are linked to the testing/witnessing while one-off costs for activities like training may not be fully covered. Input from 9 TAAs as part of the data request suggested that the actual costs for the granting of the type approval certificates is covered by the fee paid only in some case[162].

All in all, we consider reasonable to assume that important part -even if not all - of the costs for TAAs associated with the implementation and enforcement of the Euro 6/IV Regulation are already covered by the OEM fees analysed earlier.

5.2.1.5 *Impact of costs on consumers*

As already indicated in Section 5.1.6.2.1 (EQ5), the general assumption is that the regulatory costs incurred should be expected to be passed to consumers, at least in the long term. This is on the basis of the structure of the automotive market, which is characterised as monopolistic competitive market with product differentiation but a high degree of competition among many firms (Mamakos, et al., 2013). This was also the assumption made in the IA SWDs for both Euro 6 and Euro VI. As indicated in our analysis in Section 5.1.6.2.1, it is difficult to identify evidence of the actual level of pass through based on past experience and to link it directly with the introduction of the standards. Pricing strategies and the fact that any increased costs may be recuperated through higher charges for additional vehicle features make it difficult to establish a direct connection between the costs and vehicle prices.

Assuming that a full pass through does indeed take place, then consumers should be affected through an increase in vehicle prices. Assessing the relative impact can be examined by comparing vehicle prices with the estimated net increase in cost per vehicle to establish what share of a vehicle price they represent. In our cost estimate we have used cost ranges to reflect the uncertainty and also the fact that vehicles in smaller size segments may not require all of the technologies identified in the typical package. As such, when comparing with relative vehicle prices it was also appropriate to refer to vehicles of similar size. Thus, for the comparison we compared the cost estimates presented earlier (Section 5.2.1.3.1.3 – table 5-25) against the weighted average[163] of prices of vehicles in the respective segments available via ICCT (2018 data). More specifically, we compared our low end cost estimates against the weighted average of prices of vehicles in the smaller size segments (mini/small), the moderate cost estimate against the average price of the

[162] Some TAAs indicated that they charge fees covering the full costs of the administrative aspects of the granting of a type approval (i.e. not the testing) while others that the fees charged is not linked with the administrative costs. Two authorities indicated that they do not charge any fees.

[163] Based on the respective shares of sales by vehicle segment and average price (including tax). Data are provided by ICCT in the EU Pocketbook (ICCT, 2019b)

medium size segments vehicles (lower medium/medium/off-road/multi-purpose) and the high end cost estimates with the higher cost segments (upper medium/sport/luxury).

As can be seen in Table 5-30, estimated costs per vehicle in most cases represent less than 2% of the average vehicle price. If we take the weighted average cost per vehicle[164] for the total period (2014-2020) these are less than 1.5% of the average vehicle price. Considering specific stages, pre-RDE Euro 6 CI vehicles had a cost of no more than 1.9% of the small segment vehicle price. In the case of PI engines the impacts were much lower as, typically, there was no need for new hardware to be installed. Focusing on the most recent stage (Euro 6d), we see that the estimated cost per vehicle for small segment market is significantly higher in the case of diesel vehicles (4.3% of the average price of a vehicle in the small vehicle segment). This is mainly driven by the higher hardware costs linked to the technologies to ensure compliance with Euro 6d. We note though that in this vehicle segment it is possible that not all technologies identified in our analysis need to be fitted. It is also the case that OEMs may spread the costs unevenly with a higher share going to more expensive models or models with more features which would mean that lower segment vehicles will not take the same share of the costs. Nonetheless, the analysis suggests a potentially more sizeable impact for this specific car segment[165].

Table 5-30: Analysis of relative regulatory costs of Euro 6 in comparison to average purchase passenger car prices per vehicle segment

	Cost & Vehicle segment	Total cost per vehicle*	Average vehicle price	Share of vehicle price
Total (weighted average of total period)	Low/small	€ 265	€ 17,209	1.5%
	Medium	€ 377	€ 31,933	1.2%
	High	€ 700	€ 68,082	1.0%
Euro 6 pre RDE – CI	Low/small	€ 323	€ 17,209	1.9%
	Medium	€ 622	€ 31,933	1.9%
	High	€ 922	€ 68,082	1.4%
Euro 6d – CI	Low/small	€ 745	€ 17,209	4.3%
	Medium	€ 1,303	€ 31,933	4.1%
	High	€ 1,861	€ 68,082	2.7%
Euro 6d – PI	Low/small	€ 200	€ 17,209	1.2%
	Medium	€ 300	€ 31,933	0.9%
	High	€ 399	€ 68,082	0.6%

Source: Own elaboration based on cost analysis and vehicles prices for passenger cars from ICCT (ICCT, 2019b). *; *Total cost per vehicle for individual stages is estimated based on a 1.15 increase to hardware costs that is the median value of the ratio of total to hardware costs when the long term ratio for period 2014-2050 is considered*

In the case of HDVs (Table 5-31), the estimated average costs per vehicle (lorries) are in the range of 4.2%-5.0 of an average lorry price per segment. For the typically more expensive buses, these additional costs should represent no more than 3.0% of the total

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[164] This is based on the estimated unit cost per vehicle for each vehicle stage (Euro 6 pre-RDE and Euro 6 post-RDE) weighted by the share of each category in the total number of vehicles sold for the period.

[165] In the case of vans, ICCT vehicle price data refer to two segments (car derived vans: average price of €21.8k ; non-car derived vans: average price of € 43.8k). Assuming that they fall into the low and medium categories in terms of the total costs the share of the purchase price should be also smaller than that indicated for passenger cars.

purchase price (see Table 5-31). We note that we do not have more accurate data on the HDV prices and, as such, the estimates should be considered as indicative.

Table 5-31: Analysis of relative regulatory costs of Euro VI in comparison to average purchase prices for Lorries and buses per price segment

	Cost segment	Total cost per vehicle	Average vehicle price*	Share of vehicle price
HDVs - Lorries	Low	€ 4,195	€ 100,000	4.2%
	Medium	€ 6,447	€ 130,000	5.0%
	High	€ 8,998	€ 200,000	4.5%
HDVs - Buses	Low	€ 4,195	€ 200,000	2.1%
	Medium	€ 6,447	€ 250,000	2.6%
	High	€ 8,998	€ 300,000	3.0%

Source: Own elaboration based on cost analysis ; Prices for medium segment lorry based on CO2 regulation IA study SWD(2018) 185 final (European Commission, 2018b)[166] ** Prices for buses are indicative based on information available to the study team.*

On the basis of the evidence available, we consider that there is no evidence to suggest that the impact of the regulatory costs associated with Euro 6/VI are not affordable for consumers. However, we note that input from the public consultation suggests that most stakeholders consider that there has been a tangible impact on vehicles prices. More specifically, when asked to indicate what was the impact on prices, between 80%-90% of respondents[167] considered that there was an increase in the vehicle prices in all categories (cars, vans, lorries, buses) with around 30% indicating a significant increase. There were no notable differences among the stakeholder groups. Nonetheless, when asked if they agree that EU legislation makes cars[168] unduly expensive the majority (85 out of 157) disagreed or strongly disagreed and only 41 agreed completely or somewhat. These were mainly industry representatives and citizens but in both cases they were no more than 30% of the specific group. All in all, we consider that the stakeholder responses appear to support the conclusion that the impact on vehicles prices and on consumers has not be significant or disproportionate.

5.2.1.6 *Are the costs affordable for industry?*

As already indicated, the assumption made based on the sector structure is that the regulatory costs will be passed to consumers. As such, any costs implications will only be in the short term for the period until manufacturers manage to recuperate these extra costs through increased prices.

Nonetheless, we note that even if such a pass through does not occur (partly or fully), our total cost estimate for the period 2013-2020 as a combined result of Euro 6 and Euro VI (total of €30.6 billion- €76.0 billion) represents no more than 2% of the total turnover of the

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[166] IMPACT ASSESSMENT - Proposal for a Regulation setting CO_2 emission performance standards for new heavy duty vehicles, SWD(2018) 185 final https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52018SC0185&from=EN

[167] 121 out of 137 for cars; 112 out of 130 for vans; 96 out of 109 for buses; 101 out of 113 for lorries.

[168] The question appears to refer to passenger cars. It is not clear if other vehicle categories were considered by stakeholders when answering the question.

motor vehicles sector in Europe for the same period (estimated at around €3.5 trillion-€4 trillion)[169].

As such, there is no strong evidence indicating that the associated costs are not affordable for the sector. Having said that, input from stakeholders in the context of the public consultation suggests that a sizeable minority (42 out of 118; including 25 industry representatives and 14 citizens; still less than 50% of respondents from the specific subgroups) considers that cost of compliance with the Euro 6/VI limits and the test procedures are not affordable. In contrast, 52 out of 118 stakeholders agreed that the associated costs are affordable with the majority of representatives of Member States and civil society representatives being supportive. Considering the costs associated with information obligations, 51 out of 103 respondents to the public consultation agreed that the costs are affordable and 27 (mainly industry representatives) that they are not. Again, a majority of Member States and civil society representatives considered the costs affordable. We also note that the regulatory costs represented a greater challenge to some manufacturers with small production volumes where costs cannot be spread across a higher number of vehicles sold[170] (including HDV manufacturers) and may only be able to recuperate these costs over a longer period.

5.2.1.7 *Are there any of the costs that are unjustified/unnecessary?*

The combination of the input from most stakeholders and the analysis of the costs presented suggests that administrative and testing costs have increased significantly as a result of the introduction of Euro 6/VI.

This is seen as a result of the increased complexity of the legislation and the multiple stages in the introduction of RDE with changes to requirements for cars and vans (e.g. the combination of the relevant tests including EVAP, ISC, OBD) coming very frequently. As proposed by one manufacturer, changes to testing provision sometimes come at short notice leading OEMS to revise or completely change type approval projects. As argued, this has often led to duplication of effort and an increase in the number of type approvals activity since 2017 linked to Euro 6d-Temp and Euro 6d with the associated higher costs.

Thus, it can be argued that some of these additional costs were unnecessary and could have been avoided if a more streamlined approach had been adopted, possibly over a longer period. However, this should be balanced against the benefits from the introduction of the RDE tests and the resulting reduction of emissions as a result of the RDE testing (as documented in EQ1).

The analysis of inputs from stakeholders did not point to other aspects that could be considered as unnecessary or unjustified.

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[169] According to Eurostat Structural Business Statistics data (SBS_NA_IND_R2) for the Manufacturer of motor vehicles (NACE 29.1) the total turnover of the sector increased from €600 billion in 2013 to €820 billion in 2018, the last year available. Assuming the same level per year for 2019-2020 we get a total of around €5 trillion (2013 values). However, this is total turnover of the sector (that includes revenues from the aftersales market and other services). Data on turnover from the main activity of the sector from the same sources is only available at MS level with some gaps (e.g. FR). Assuming a similar share of turnover from main activity to the total reported for all Member States it leads to a total of €3.5 trillion -€ 4 trillion for the period 2013-2020. We note that the above, does not include the turnover of suppliers of parts and equipment.

[170] We note that this should not be an issue for the small producers of luxury models with very high profit margins per vehicle (even if we were to assume no cost pass through). Moreover, small bus manufacturers in most cases purchase the bus chassis with the type approved engine systems from the larger HDV manufacturers. As such, they do not have to separately incur the important part of the regulatory costs associated with Euro VI analysed above.

5.2.1.8 *Conclusions*

Based on the analysis presented, the following initial conclusions can be made:

- The introduction of Euro 6 and Euro VI has led to significant additional total regulatory costs. The total costs have been estimated in the range of €30.6-76.0 billion over the period 2013-2020, €21.1billion-€55.6billion linked to the introduction of Euro 6 and €9.5billion-€20.4 billion linked to Euro VI.
- While sizeable, the total costs represent a very small share of the industry turnover, estimated to be no more than 2% of the total turnover of the sector.
- On a per vehicle basis, the weighted average for the whole period 2013-2020 was estimated in the range of €80-€181per vehicle for PI engines, €357-974 per vehicle for CI engines, and 3,717-€7,961 per vehicle for HDVs.
- The cost estimates are comparable to the cost per vehicle estimates provided in the two IA support studies (€265/vehicle for CI LDVs and range of €3,169 and €5,004 per vehicle for HDVs; no estimate for PI engines)[171]. We note that the IA studies for Euro 6 did not consider costs for additional technologies introduced as a result of the introduction of RDE testing or the increase in the non-hardware costs.
- Considering the specific cost drivers, hardware costs (i.e. costs of technology installed in the new vehicles) represent the most important part of these costs. The weighted average of the costs for the whole period were estimated in the range of €36-€59 per vehicle for PI engines and €307-€801 per vehicle for CI engines and 1,556-€3,635 per vehicle for HDVs. However, this cost increased over time for LDVs as a result of the introduction of Euro 6 RDE. Thus, the costs of hardware installed in the most recent Euro 6d vehicles is estimated at €402-€465 for PI and €751-€1,703 for CI vehicles.
- The analysis also points to sizeable R&D and testing costs. Overall, the estimated non-hardware costs per vehicle represent 23%-27% of total costs for LDVs and 54%-58% for HDVs. We note that the current estimates of the R&D costs for HDVs based on input from OEMs are considered as high and possibly overstating the actual costs associated with the Euro VI. As such, it is possible that the actual share of non-hardware costs was smaller, along the lines of the respective costs for LDVs. Even if the case of these possibly overstated R&D costs, the total R&D expenditure (€8.5b-€21.3 bn was a relatively small share of the total R&D expenditure of the motor vehicles sector (NACE 29.1), 3.4%-8.5% of the total of ca. €250 billion over the same period (Eurostat).
- As expected, total costs for compliance for diesel LDVs have been more significant up to now. However, Euro 6d requirements introduce additional costs for most PI vehicles. As a result, in the coming period, costs for compliance for PI (mainly petrol) vehicles should be expected to represent a higher share of the total costs for Euro 6 vehicles.
- Other cost elements related to enforcement, fees and administrative costs represent a smaller amount for both Euro 6 (4-5% of the total) and Euro VI (1%). The only exception are the costs for Euro 6 PI , since there was no need for new technologies in the initial stages, the overall share of the other costs elements was higher (19%)

[171] 2020 values.

- Input from equipment suppliers suggests that most of them incurred additional costs for new product development and testing of new equipment. Those that were involved in type approval activity also incurred relevant certification costs. However, it is largely the case that costs for suppliers are eventually covered by vehicle manufacturers, mainly through the cost of hardware fitted to vehicles.
- Type approval authorities also incurred certain one-off costs to authorities. They included investment in new facilities and equipment (in a few cases) as well as preparatory action taken in the form of training, development of guidance documents or other system updates. They also included the costs of some additional expert personnel to cover the increased time needed for witnessing the various tests and the increase demand for type approvals. However, their costs are also expected to be largely covered by vehicle manufacturers.
- Concerning the impact on consumers, it is generally expected that eventually any increase in regulatory costs will be passed through in the form of higher prices. In that respect, the analysis suggests that in most cases the estimated regulatory costs are in the range of 1%-3%. The exception is for small size Euro 6d-diesel vehicles where costs as high 6% of the average vehicle price vehicles can be expected. However, there is no evidence of such and increase to vehicle prices and it is expected that OEMs distribute these costs across all vehicle categories.
- The analysis so far suggests that the main area where unnecessary costs may have arisen concern the practical aspects (i.e. timetable) of the introduction of the requirement of the various testing requirements under Euro 6d-Temp and Euro 6d. This is reported to have led to duplication of effort among OEMs and extra regulatory costs that could have been avoided.

5.2.2. EQ9 To what extent has Euro 6/VI been cost-effective? Are the costs proportionate to the benefits attained? What are the factors influencing the proportionality of costs?

5.2.2.1 *Introduction*

In this section we compare the costs to authorities and industry of ensuring compliance presented in EQ8 with the associated benefits observed as a result of the achieved or expected emissions reduction and reduced environmental health impacts, as already outlined in the analysis in EQ5. The analysis covers the period between 2013/14-2020 but also considers the impacts up to 2050 that allows for the full benefits from the introduction of the Euro 6/VI standards to be taken into consideration and compared against the costs, a large part of which have already been incurred in the initial stages of the implementation of the standards (as already shown).

The analysis presented considers the views of stakeholders as to whether the costs are justified by the benefits supplemented by the analysis comparing the monetised benefits against the costs.

5.2.2.2 *Analysis of cost-effectiveness*

In order to assess the cost-effectiveness of the Euro 6/VI standards we have compared the monetised benefits from the achieved and expected total reduction of pollutant emissions (presented in EQ1) with the associated costs (already presented in EQ8).

The comparison is based on examining the Net Present Values (NPVs) (assumed base year is 2014 for LDVs and 2013 for HDVs), the benefit/cost ratio[172] and the abatement costs per tonne of NOx emissions avoided[173] for the period up to 2050[174]. We examined the overall cost-effectiveness of Euro 6 (in total, including RDE) in comparison to Euro 5 as well as in comparison to Euro 6 pre-RDE.

The monetised benefits have been calculated by multiplying the emission savings with the external damage costs per tonne of pollutant, for each of the pollutant covered, on the basis of the damage costs for air pollutants for transport identified in the 2019 Handbook of External costs of transport developed on behalf of the European Commission DG MOVE (CE Delft, 2019b). Benefits have been monetised for most regulated pollutants (NOx, NMVOC, PM) but, crucially, not in relation to PN which is linked to the use of GPF technology in some PI Euro 6 vehicles. It also does not cover CO, TH4 and CH4. As a result, the analysis underestimates some of the benefits associated with Euro 6/VI and, as a result, the associated cost-benefit ratios.

With this in mind we can make the following observations on the basis of the results presented in Table 5-32 concerning Euro 6:

- As can be seen, in the case of Euro 6, despite the high estimated costs there is a high NPV and a positive benefit to cost ratio[175] (2.0-4.7) when comparing to Euro 5 baseline. This is driven by the high benefits associated with the measures in the case of diesel vehicles (cost benefit ratio of 2.5-5.9).
- We also note that the cost-effectiveness of the last steps (i.e. Euro 6 RDE) is lower (2.5-4.7 for diesel vehicles; 1.6-3.1 in total). This is mainly a result of the higher costs associated with the last steps of the Euro 6 intervention (part of which are expected to continue in the future) as well with the significant emissions savings already achieved with the introduction of Euro 6 before RDE.
- The analysis suggests a negative cost effectiveness of the measures related to PI engines (negative NPV values and benefit/cost ratio of less than one). This is a reflection of the very small NOx emission savings associated with PI engines already presented in parallel with the high costs of compliance. However, due to absence of relevant emission factors, our analysis does not capture the impact on PN emissions as a result of the introduction of GPF (although the respective costs have been included in our cost estimates). As such, the monetised benefits linked to PI vehicles have been underestimated. On this point, an earlier ex-ante analysis of the cost-effectiveness of the introduction of GPF technologies to PI GDI vehicles (Mamakos, et al., 2013) concluded that the total costs (hardware costs and indirect costs) and the respective benefits (not accounting for the impact on non-regulated sub-23 nm particles) were expected to be of the same magnitude (overall net affect in the range of -€217/vehicle to €78/vehicle). It is not possible to verify this assessment and include the monetised benefits in our own analysis. However, we can reasonably expect that the total cost-effectiveness is higher than what is presented in Table

[172] Estimated based on the ratio of the present value of total monetised benefits in comparison to the present value of total costs for industry as presented in EQ8.

[173] Ratio of present value of costs to the total level of NOx emission reduction.

[174] The analysis includes all costs of compliance estimated as it has not been possible to disentangle the costs of focusing only on those aspects/technologies covering NOx emissions. On this basis this represent an underestimate of the benefit-cost ratio.

[175] Ratio of monetized benefits to associated costs

5-33, even though it may still be the case that the benefit to cost ratio will be lower than one.

Table 5-32: Analysis of cost-effectiveness of Euro 6 in comparison to the baseline scenarios (low, central and high cost scenarios)

	Euro 6 RDE to Euro 6 pre-RDE			Euro 6d (RDE) to Euro 5		
	Low	Central	High	Low	Central	High
	Total LDVs (cars and vans)					
NPV for 2014-2050 (€ Billion)	96.0	74.7	53.5	298.3	245.3	192.3
Benefit /Cost ratio	3.1	2.1	1.6	4.7	2.8	2.0
Abatement costs for NOx [€/ton]	2.5	3.7	4.9	1.8	2.9	4.1
	CI vehicles					
NPV for 2014-2050 (€ Billion)	105.8	93.2	80.5	303.5	261.3	219.0
Benefit/Cost ratio	4.7	3.3	2.5	5.9	3.5	2.5
Abatement costs for NOx [€/ton]	1.6	2.3	3.1	1.4	2.3	3.2
	PI vehicles (not including benefits from PN measures)					
NPV for 2014-2050 (€ Billion)	-9.8	-18.4	-27.0	-5.3	-16.0	-26.7
Benefit/Cost ratio	0.4	0.3	0.2	0.7	0.5	0.3
Abatement costs for NOx [€/ton]	-	-	-	-	-	-

The picture concerning the cost effectiveness of Euro VI is also positive (see Table 5-33). As can be seen, the NPV for the whole period up to 2050 is estimated in the range of €489.6-€508.7 billion with a high positive benefit to cost ratio under all scenarios (15.0-32.8).

Table 5-33: Analysis of cost-effectiveness of Euro VI in comparison to the baseline scenarios (low, central and high cost scenarios)

	Euro VI to Euro V (lorries and buses)		
	Low	Central	High
NPV for 2013-2050 (€ Billion)	508.7	499.5	489.6
Benefit /Cost ratio	32.8	20.8	15.0
Abatement costs for NOx [€/ton]	0.2	0.4	0.5

The positive cost-effectiveness of the implementation of Euro VI standards is also supported by a recent study that examined the introduction of Euro VI-equivalent standards in Argentina (Miller & Braun, 2020). It concluded that each $1 invested to comply with Euro VI-equivalent standards (from Euro V) should produce approximately $3.60 in monetized health benefits over the period 2021-2050 from the reduction of NOx and PM2.5 emissions. We should note though that that there are some differences since the analysis is based on lower technology costs ($1000-$1500 per vehicle; 3-5 times lower than our own assumption) and assumes a smaller share of non-hardware costs per vehicle (12.5% of the hardware costs) than has been our analysis on the basis of the inputs provided[176]. This is reflection of the fact that there is no need for investment in technology development. This points to possible broader impact of the standards beyond the EU boarders where other territories can benefit from technology developed in lower costs while still achieving significant emission reductions.

The overall conclusion of a positive cost-effectiveness of the standards is also supported by the input from most stakeholders including in the targeted consultation and the public consultation. When asked to compare the costs to in comparison to the benefits for society, the majority (18 out of 26 respondents)[177] considered that the costs were very low or quite low. In the case of Euro VI, 15 out of 19[178] also said the same[179]. (see Annex 9, Figure 10-17). Environmental NGOs, consumer groups, authorities and a member of the industry generally argued that that the benefits for society from the reduction of the emissions (and the associated health impacts) are so great, that the costs, even if relatively high, are very well justified. One EU consumer representative considered that "while the adoption of the Euro 6 emissions standards (especially again from Euro 6 d temp onwards) might have led to a slight price increase of new vehicles, the overall benefits for both consumers and society largely exceed the costs". They also pointed to the presence of several studies that have demonstrated the dramatic health impacts of poor air quality of which a large part can be attributed to road traffic.

Two NGOs also made reference to existing studies and data (including information from the EU's Handbook on External Costs of Transport (CE Delft, 2019b) which concluded that, in the EU alone, the external costs of air pollution from LDVs has been calculated at around €48 billion in 2019 and that between the Euro 5 and Euro 6 emissions standards the average external costs associated with air pollution of most CI cars and vans and some PI vehicles had decreased[180]. Similarly, for lorries and buses, the external costs were calculated at €18 billion with a substantial decrease between the Euro V and Euro VI emissions standards. They proposed that based on the projections for 2030 the estimated impact was a total reduction of health and non-health related costs of road traffic-related air pollution at around 71% in comparison to 2016. Concluding, it was argued that given the large external costs of air pollution from road transport, any reductions in the amount of pollution from vehicles can lead to significant reduction in the total external costs of air pollution to society and the costs associated with achieving these improvements are far outweighed by the benefits.

Along similar lines, one public authority noted that, from their perspective, Euro 6 entailed few additional costs but the gain in terms of air quality and public health will probably far outweigh possible additional costs; while an equipment supplier commented that the costs for the development of new technologies are insignificant compared to the achieved

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[176] In terms of benefits, the study used the emission factors for Euro V and Euro VI derived from the Handbook Emission Factors for Road Transport from HBEFA that was also used in our own analysis. (95% reduction for PM2.5 and 84%–89% reduction for NOX).

[177] Including two type approval authorities, four public authorities, two NGOs, one consumer representative, one fuel research organisation, four industry associations, one vehicle testing lab and three suppliers,

[178] Including two type approval authorities, four public authorities, one NGO, four industry associations, one fuel research organisation, one vehicle testing lab and two suppliers,

[179] One organisation indicated that the costs are very high in comparison to the benefits, but their comments and explanations suggests that this was, almost certainly, a mistake. [So you should remove this response from your analysis]

[180] One EU health NGO commented that the specific study actually underestimated the benefits from emission savings as it did not include relevant health impacts and the savings on healthcare costs.

benefits. Similarly, a fuel research organisation added that while there were significant investments needed to meet the requirements of the Regulations in the testing community, especially as a result of the adoption of the RDE, they pointed out that the costs associated with the negative health impact of air pollution are much higher than the investments made.

As expected, input provided from stakeholders was less positive when asked to compare the costs in relation to the benefit to their own organisation. Ten out of 27 respondents (including six from industry[181], three authorities and a research organisation) gave a negative assessment in terms of the costs of Euro 6 for their own organisation and 6 out of 19 (four from industry and two authorities) for Euro VI. One equipment supplier noted that Euro 6 developments (presumably in relation to Euro 6d-Temp and Euro 6d and the introduction of WLTP and RDE) required high effort with a short lead time but with no evident benefit. From the point of view of the organisation, it was commented Euro 5 was “easier” to cope with on a financial level, without any intermediate steps, and there were no huge technology steps from Euro 4 to Euro 5 (particularly on the gasoline/PI vehicles side)”.

Finally, in terms of the balance of benefits and cost to consumers (i.e. users of vehicles), our earlier analysis (section 5.2.1.5) pointed to an possible increase in the costs in a range of 1.0%-4.3% but in most cases less than 2.0% in the case of Euro 6 and no more than 5% for HDVs as a result of Euro VI. Given that various pricing strategies adopted by manufacturers this is also a cost increase that may not be directly visible to all consumers. Compared to that, the benefits arising from the reduced pollutant emissions are not directly visible to consumers and do not affect their purchase choices. This is a point made by a number of stakeholders when asked to indicate whether the costs to consumers are justified by the benefits. Nine out of 25 stakeholders that responded (including four OEMs, two suppliers, two type approval authorities and one research organisation) considered that the Euro 6 costs were not seen as justified[182]. The point made was that consumers do not really appreciate a direct benefit from pollutant emissions reduction and improvements in aftertreatment technologies in vehicles, at least in the same way that they do for fuel efficiency. As such, it should also be expected that consumers would not consider any higher prices of vehicles related to pollutant emissions regulation as justified.

In contrast, ten stakeholders (one EU NGO, one EU consumer association, three industry associations, two suppliers and three authorities) considered that costs are still justified by the benefits. Besides the health benefits, a European NGO pointed to the fact that Euro 6 (especially since the introduction of the RDE test) is significant when one also reflects on the important issue of the trust for consumers when it comes to vehicle purchase. This is linked to the impacts of the dieselgate scandal in that respect and thus the importance of a more rigorous – even if more expensive – testing regime. Further to that, we note that measures to internalise the cost of higher pollution in the form of higher taxes or in the form of restrictions for access to urban areas (i.e. low emission zones) can also change consumers perception of the importance of pollutant emissions performance and more directly affect purchase choices.

5.2.2.3 *Conclusions*

The analysis points to the overall high cost-effectiveness of the Euro 6 and Euro VI standards when assessed against the benefits from the reduced emissions.

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[181] 4 major OEMs

[182] In the case of Euro VI, only three out of 17, including two from industry, considered that the costs for their organisation are high in comparison to the benefits.

Despite the high regulatory costs, the associated benefits (in terms of emission savings and resulting monetised health impacts) are significant and lead to an overall positive NPV and benefit to cost ratio when considering the whole period up to 2050. This is a finding that is also supported by the large majority of stakeholders.

The main benefits come from the measures for diesel LDVs and for HDVs that have positive NPVs and high benefit to cost ratios. In the case of PI engines, the analysis of cost-effectiveness has not captured the main benefit coming from the reduction of PN and, as a result, leads to low benefit/cost ratio. Earlier studies suggested that the costs and benefits should be expected to be at largely the same level.

Questions on the extent that the costs are justified by the benefits are mainly raised by some industry stakeholders when comparing the costs with the benefits to individual organisations (namely for industry). Similarly, there are questions raised when comparing the costs against the benefits to consumers on the basis of the fact that most consumers tend not to consider performance in terms of pollutant emissions in their purchase decisions. However, besides the possible role in rebuilding trust after the dieselgate "scandal", measures adopted to internalise the cost of higher pollution in the form of taxes or low emission zones can also change consumers perception of the importance of pollutant emissions performance.

5.2.3. EQ10 Has Euro 6/VI achieved a simplification of vehicle emission standards in relation to EURO 5/V?

5.2.3.1 *Introduction*

In this section we examine the extent to which the Euro 6/VI standards have led to a simplification of emission standards in relation to Euro 5/V. More specifically we examine whether:

- The Euro 6/VI standards and the implementing legislation led to more or less complicated procedures for authorities and industry in comparison to the previous standards?
- The introduction of the standards and testing procedures in stages/steps (i.e. from Euro 6a to Euro 6d) contributed to the simplification (or not) of the legal framework.

The analysis presented is based on the findings of our own analysis combined with input from stakeholders to the consultation.

5.2.3.2 *Analysis*

The description of the Euro 6/VI standards in Section 3 including the various stages and multiple dates of introduction of different requirements already gives a strong indication that the Euro 6/VI legal framework is quite complicated and difficult to navigate:

- The legislation consists of a number of pieces of co-legislation and implementing (Commission) legislation, that are separate for light duty and heavy duty vehicles.
- Requirements have been introduced in multiple stages (e.g. 6b, 6c, 6d-TEMP, 6d in Euro 6, steps A to E in Euro VI) with additional sub-stages introducing new technical rules (e.g. OBD) or new enforcement mechanisms (e.g. ISC). For each main vehicle category there have been multiple combinations of requirements since 2018, often applicable in parallel.
- There are also different timetables for the entry into force depending on the type of vehicle (e.g. different dates for vans and cars under Euro 6).

- The legislation includes both lab-testing and on-road testing of vehicles and it is enforced via different enforcement mechanisms (Type-approval stage, Conformity of Production, In-Service Conformity, Market Surveillance).
- In total, the current text of the legislation is more than 900 pages long with multiple references to other pieces of legislation, including to relevant UNECE regulations.

A key determinant of this complexity is that Euro 6/VI legislation (as well as all previous Euro standards) has built on the previous text with new elements and requirements being added to existing requirements. The introduction of the on-road RDE testing was developed in 4 different pieces of legislation[183] and added to the already sizeable legislation. Such an add-on approach to the pre-existing requirements without changes to the structure of the legal framework would be expected to make the legislation more rather than less complex. At the same time, the dieselgate "scandal" created an urgent need for additional action at a fast pace, leading to a rather compressed timetable for the introduction of the RDE testing and other testing requirements allowing for limited lead time.

Put together, it is quite evident that Euro 6/VI have not led to simplification of the legislation. This is very much reflected in the input from stakeholders. The responses from stakeholders in the context of both the targeted consultation and the public consultation are quite unanimous in their negative assessment of the complexity of the legal framework and the role of Euro 6 standards in reducing complexity. Overall, according to the responses to the public consultation, 98 out of 128 respondents considered the Euro standards (both Euro 6 and Euro VI) as very complex or complex. This was a view that was shared among all categories.

Considering Euro 6 provisions in particular, stakeholders that responded to the targeted consultation identified a number of areas where they considered that had a negative impact (i.e. increased complexity) in comparison to the Euro 5/V standards (see also Annex 9, Figure 10-18). This included in relation to:

- Testing and type-approval procedures: 48 out of 50 respondents to the targeted consultation considered that it led to a negative change with 29 indicating significant negative impact).
- Reporting requirements (38 out of 42; 24 indicating significant negative impact)
- Conformity of production aspects (39 out of 44; 23 indicating significant negative impact)[184].

In the case of Euro VI, the assessment was, in relative terms, less negative as more respondents indicated a small increase in complexity in relation to:

- Testing and certification procedures (30 out of 33 respondents considered that it led to a negative change; 7 that it had a significant negative impact),
- Reporting requirements (27 out of 31; 5 indicating significant negative impact). [185]

The above were also confirmed in the input to the public consultation where more than half (68 out of 128 respondents) considered that emission test procedures for Euro 6/VI are

[183] RDE packages 1-4

[184] We note that the representative of OEMs (ACEA) and its 4 OEMs members did not respond to this question commenting that not all simplification is good and not all complexity is bad.

[185] Stakeholders were also asked to comment on the impact of the engine family concept but none of them provided a response (2 said that the did not know).

complex or very complex. This was a view shared by the majority of all stakeholder groups (industry, authorities, civil society and citizens) that contributed. There were also negative in terms of the actual number of tests (79 out of 128 considered them complex or very complex) with the exception of civil society representatives. In terms of the reporting requirements and compliance checks (e.g. Conformity of production), most respondents to the public consultation considered that these features are complex (63 out of 105 respondents in terms of the former; 65 out of 111 respondents for the latter). Only a small number across all stakeholder groups indicated that they are not complex (less than 10%), with the exception of civil society representatives where five out of 18 respondents considered that they are not complex.

Asked to identify specific drivers of the complexity the legal framework for each of the two standards, stakeholder pointed to the presence of multiple stages in the introduction of the standards as, by far, the most important parameter in both cases (see Table 5-34). Twenty-six out of 40 identified it as the most important drive of complexity for Euro 6 and 23 out of 52 in the case of Euro VI. This was also supported by respondents to the public consultation (including all relevant stakeholder groups) with 101 out of 128 respondents indicated that this aspect of the Euro 6/VI was complex or very complex. Other aspects identified by stakeholders as contributing to a lesser extent were more practical, including:

- The fact that there are references made to text contained in UN Regulations, instead of repeating the text inside the regulation
- The presence of borderline effects with the cut-off point of 2610 kg reference mass used for the testing of vehicles on the basis of Euro 6 (chassis dynamometer) or Euro VI (engine test) HDVs that is not in line with the existing vehicle classifications (e.g. N1, N2, N3) that are based on the Technical Permissible Maximum Laden Mass.
- The entry into force of the legislation in two stages (one for new types and then for new vehicles) was also considered as a problematic area among respondents to the targeted consultation although the views expressed among the participants to the public consultation was more balanced[186].
- The absence of an overview of the whole legislation in the main text, no index and not clear labelling of the various section that would make it easier to navigate through the document and identify relevant sections and provisions.

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[186] 56 out of 128 considered that the specific features of the standards were complex or very complex, 40 not complex and 32 only somewhat complex. Large share industry representatives considered that this aspect was not complex or somewhat (44 out of 61) while, in contrast, more than half of authorities, civil society representatives and citizens considered it as complex or very complex.

Table 5-34: Aspects of the legal framework that contribute to the complexity of the European emissions legislation for Euro 6/VI – Number and share of respondents identifying specific aspects as most important and weighted score (higher score indicates greater importance)[187]

	Euro 6			Euro VI		
	Number (out of 40)	%	Weighted score (9 maximum)	Number (out of 52)	%	Weighted score (9 maximum)
The presence of multiple stages in the introduction of the standards	26	65%	8.5	23	44%	8.3
References made to text contained in UN Regulations, instead of repeating the text inside the regulation	5	13%	6.2	5	10%	6.3
Borderline effects: 2610 kg separation between LDV and HDV	0	0%	5.0	1	2%	5.8
Introduction of new requirements gradually, first for new types and then for new vehicles	2	5%	5.3	6	12%	5.8
No overview of the legislation – No table of content of all relevant pieces of legislation	1	3%	5.2	1	2%	5.2
Test procedures (RDE, WLTP) are recorded in separate Annexes of the legislation	2	5%	5.0	1	2%	5.1
Type approval procedures for multi-stage vehicles	1	3%	5.2	3	6%	5.1
The emissions limits and the implementing legislation are part of different decision-making process[188]	0	0%	4.2	0	0%	4.3
Type approval extensions	0	0%	4.2	0	0%	4.2

Source: Targeted stakeholder consultation on Euro 6/VI evaluation

Elaborating further on the drivers of complexity, stakeholders pointed to a few key aspects:

- A range of them (including one public authority , an international association on road vehicle compliance, one technical service, one automotive supplier, three non-EU based OEMs, a local transport NGO) focused on the complexity brought by the introduction of the WLTP, RDE, ISC and the multiple stages. According to one OEM, since Euro 6c they have had to spend significant additional time (i.e. extra

[187] Stakeholders were asked to order the 9 specific aspects presented in terms of their importance.
[188] Regulation of Parliament and Council vs. Commission Regulations

manpower) to read, understand and process as part of their vehicle development process. According to the two other OEMs the multi-stage introduction of Euro 6 increased the complexity of the legal framework and led to confusion among non-EU manufacturers, especially while they also try to follow developments in other markets. In their view it had a negative impact on market access both inside the EU and with non-EU countries.

- The issue of the borderline effects with the separation of 2610 kg for LDVs and HDVs was not considered as the most important. However, one public authority suggested that this may have led to some OEMs aiming to have light lorries/buses type-approved as LDVs rather than HDV (due the less demanding requirements including in relation to CO2 regulations). Still, this is primarily an issue of the effectiveness of the provisions rather than of increased complexity of the legal framework. Having said that, there is also an inconsistency between the criterion used for determining the appropriate testing procedures and requirements for specific vehicle categories under Euro 6 or Euro VI (based on reference mass), and that of other legislation (e.g. Type approval legal framework, CO2 standards) that is based on the Technical Permissible Maximum Laden Mass (TPMLM) (see more information in EQ13, Section 5.4.2).
- One type approval authority considered that the introduction of a requirement for the verification of emissions strategies was one of the main drivers which has increased the complexity of the legislation. This was also a point reflected in the comments from a national authority.
- While indicating that the idea underlying the new RDE requirements is correct and justified, one technical service questioned whether the implementing legislation needs to go into as much detail and that it would be simpler to focus on monitoring the actual emission of vehicles on the roads more continuously. In that respect, this specific stakeholder seemed to suggest that a driver of the complexity is the overall logic of the legal framework that focuses on pre-market compliance and much less on market surveillance.
- Referring specifically to the tests for evaporative emissions, one automotive parts supplier commented that the requirement for pre-aging the canister prior to the evaporative diurnal test adds complexity to the procedures and that it could be simplified by a full useful life requirement and in-use testing.

In the case of Euro VI, the input provided mirrored some of the comments related to Euro 6. However, there were also clear indications that Euro VI standards are generally consider as less complex:

- One technical service noted that in general, Heavy duty vehicles legislation is less complex than the one for light duty vehicles.
- An EU environmental NGO repeated again the comments concerning the need for greater complexity of the testing (including PEMS testing), type-approval, and reporting requirements compared to the Euro V in order to ensure that buses and lorries placed on the EU market finally respect the emission limits on the road. Key to this was the introduction of PEMS testing. As suggested, the requirements under previous Euro standards, especially the testing requirements, were completely inadequate to ensure on road emissions compliance.
- From its side, one EU vehicle manufacturer noted that the introduction of multiple new requirements has increased the resources they need in order to ensure their understanding of the legislation.

- It should be noted that, while accepting that there has been increased complexity, a few stakeholders (including one public authority, one technical service, one vehicle testing supplier and two environmental NGOs) commented that this was justified – or at least acceptable – given the need to take additional measures (i.e. WLTP, RDE requirements and ISC) to ensure that vehicles are clean and improve from the previous standards that had been ineffective. Justifying the need for more complex requirements, one EU environmental NGO commented that under previous Euro standards, the testing and in-service conformity requirements were inadequate to ensure on road emissions compliance. An international transport research organisation added that the increased complexity of the RDE testing requirement is a direct consequence of the request by industry for limitations to the applicability of the provisions on real world conditions. As argued, a more uniform application of the rules could lead to a less complex framework. The input from EU vehicle manufacturers and one automotive association indicating that some complexity is actually positive – to the extent that it ensures that different conditions and needs are dealt with by relevant and specific provisions - could also be seen as supporting the conclusions on the drivers of the complexity.
- Finally, there was limited feedback from stakeholders that would suggest that the presence of two different pieces of legislation for LDVs (Euro 6) and HDVs (Euro VI) is problematic and adds to the complexity. 56 out of 126 respondents to the public consultation considered that the presence of a separate legislation does not add make the legal framework more complex while 36 more considered that it makes it slightly complex and 34 that it makes complex or very complex.
- However, there were differences among stakeholder groups. Most industry representatives (39 out of 60 considered that it is not at all complex while only 12 considered that it is complex or very complex). In comparison, authorities, civil society and citizens were less supportive with less than a third of respondents in these categories indicating that the legal framework is not complex. Further input was provided to the Inception IA[189] by a number of industry representatives (including from the fuel and energy industry, automotive sector representatives and individual vehicle and equipment manufacturers, transport operators representatives) as well as environmental NGOs (a national and a European one). Their comments pointed to what is also evident from the presentation of the two legal frameworks in Sections 2 and 3; the fact that these two categories of vehicles have very different markets and purposes of use, different requirements, testing regimes and measurement requirements and, in some respects, different parts of the broader industry affected by each of them. As such, while each of the two standards - and the implementing legislation - are considered complex, their existence in parallel is not seen as adding further to this complexity. Only a small number of stakeholders (one business from the mining sector, one representative of local authorities and a representative of vehicle dealers) provided comments to the inception IA supportive of the need to merge the two legislation but did not indicate what the underlying need and how the presence of two separate legislation adds to the complexity of the legal framework.

On the basis of the above, we conclude that the large majority of industry representatives do not see the presence of different legislation for LDVs and HDVs as a parameter of

[189] This was comment provided in response to the proposed policy option for simplification which included, among others, the idea of merging the legislation for HDVs and LDVs.

complexity, while input from other stakeholder groups suggests that a sizeable share of them considered that it does have a negative role.

5.2.3.3 *Conclusions*

All in all, it seems quite clear that the new legal framework for both Euro 6/VI is more complex than Euro 5/VI and has not led to any tangible simplification in the legal framework. In relative terms, Euro VI legislation is seen as less complex than Euro 6. Nonetheless, in both cases, the new testing framework is characterised by the presence of multiple, complex, more demanding tests and other requirements.

This complexity has mainly increased as a result of the new and more demanding testing requirements and the multiple phases of implementation (stages) with different dates for the introduction of various tests. These were largely introduced on an add-on basis without any changes to the structure of the legislation and with the increasing number of references to other pieces of legislation (UNECE) and without clear overview.

The identified complexity is also seen as contributing to the additional time and costs to implement the legislation, as has already been presented in Section 5.2.1.3 (EQ8). This is conclusion supported by most respondents to the public consultation. 88 out of 117 respondents agreed or strongly agreed that the complexity leads to significant additional costs with only a small number (13, mostly citizens) disagreeing. However, as indicated earlier, for some stakeholders this complexity is seen as, at least partly, justified in view of the need to ensure that vehicles are clean on the basis of more demanding and rigorous testing and in-service conformity requirements.

5.3. Relevance

5.3.1. EQ11 To what extent do the objectives of Euro 6/VI of ensuring that vehicles on EU roads are clean correspond to the current needs? Is there a demand/potential for cleaner vehicles on EU roads over their whole lifetime?

5.3.1.1 *Introduction*

This question examines the ongoing relevance of the Euro 6/VI standards. Namely, it examines the extent to which there are still air pollution and health problems across the EU associated with road transport that mean there is still need for Euro 6/VI standards to continue aiming to bring cleaner vehicles in the market.

The post-Euro 6/VI study (Part A) (CLOVE , 2020) concludes that that new fuels, engine and emission control technologies induced new emission species, which may not be currently regulated. For this, we also examine whether the scope of the standards (i.e. the pollutants covered) and provisions adopted for Euro 6/VI standards still correspond to current needs.

Results from the post-Euro 6/VI study (Part A) (CLOVE , 2020) also highlight the gap between the average age of the fleet and ISC/durability requirements of current Euro 6/VI standards. Based on this, we evaluate whether existing requirements of durability and monitoring still meet current needs.

In view of the new policy initiatives adopted by 2020 at EU level (e.g. European Green Deal (European Commission, 2019d)) and at local level (e.g. low emission areas), developments in the level of air quality and health and recent technological and market developments (e.g.

uptake of electric vehicles) it is important to assess the continued relevance of objectives set at the time of the adoption of the Euro 6/VI standards in light of these recent changes.

To answer these questions, the following sub-questions have been considered in detail:

- Are the objectives set at the time of the adoption of the standards still relevant today? Namely, is there still/ongoing need to:
- To take action in terms of reducing pollutants emitted by the road transport sector in order to improve air quality (and reduce associated health impacts)?
- Set harmonised rules on the construction of motor vehicles?
- Do the standards properly cover the relevant/important types of pollutant emissions from vehicles that currently pose a concern to air quality and human health? Are there types of pollutant emissions that pose important air quality and health impacts that are not covered?
- Are there any technological or policy developments that have introduced new needs or that make the use of vehicle emission standards more or less relevant, including:
- Policies promoting clean mobility and the adoption of alternative fuelled vehicles and electromobility;
- Technological developments related to pollutant emissions.

The analysis draws upon a combination of desk-based research and stakeholder inputs. The desk-based research is based on quantitative data to produce indicators and qualitative analysis from key literature in this area. This is complemented by inputs from national and local authorities, industry organisations and civil society and research organisations to the targeted stakeholder consultation (questionnaire and interviews) conducted for this study.

5.3.1.2 *Are the objectives set at the time of the adoption of Euro 6/VI emission standards still relevant today?*

The specific objectives at the time of adoption of Euro 6/VI were to (see Table 2-1):

- Improve air quality by reducing tailpipe and evaporative pollutants emissions of the road transport sector.
- Set harmonised rules on the construction of motor vehicles.
- Provide sufficient time to industry to prepare to meet more demanding emission limits.
- Ensure that limits are met in a cost-effective manner.
- Ensure that pollutant emission tests are robust and accurate.

For the evaluation of the relevance of the objectives above, we focus on whether there is still an ongoing need to:

- Take action in terms of reducing pollutants emitted by the road transport sector in order to improve air quality (and reduce associated health impacts).
- Set harmonised rules on the construction of motor vehicles.

5.3.1.2.1 *Need to take action in terms of reducing pollutants emitted by the road transport sector in order to improve air quality (and reduce associated health impacts)*

At the time of adoption of Euro 6/VI standards there were significant air quality problems throughout urban areas in the European Union. The thematic strategy on air pollution adopted in 2005 (European Commission, 2005b) concluded that further reductions in emissions from the transport sector were needed to improve air quality and that reducing vehicle emissions was part of the overall strategy.

Relevance of air pollution issues related to road transport

According to the World Health Organisation (WHO, 2016), air pollution still represents the biggest environmental risk to health. Exposure to air pollution at levels commonly present in Europe can cause or aggravate a number of diseases, including cardiovascular and respiratory diseases, heart attacks and arrhythmias, and cancer. According to the EEA (EEA, 2019a), in the EU-28 in 2016, PM concentrations were responsible for about 374,000 premature deaths per year, NO_2 for around 68,000 and O_3 for 14,000[190]. Recent research suggests strong associations of air pollution with health effects at low concentration levels, with no observable thresholds (HEI, 2020). These health impacts caused by air pollution lead to more than €20 billion per year in 'direct costs', plus €330 to €940 billion per year in 'indirect costs' (European Commission, 2020a).[191]

Urban areas are associated to activities that increase emissions of air pollutants such as traffic. In turn, the high population density leads to higher ambient concentrations of these pollutants and greater exposure to them. Air quality in European urban areas has improved over the last decades as a direct result of targeted policies and technological improvements. These include more stringent vehicle emission limits, low-emission zones and policy actions to promote cleaner modes (e.g. walking, cycling and public transport). The majority of respondents from all stakeholder groups to the public consultation (107 out of 156) stated that air quality in urban areas has increased over the past 10 years. However, a significant proportion of responses from citizens expressed a different view, with 21 out 55 responding that air quality in urban areas has decreased.

However, in 2017, a significant proportion of the urban population in the EU was still exposed to concentrations of certain air pollutants that were above the thresholds defined by the AQD 2008/50/EC. The percentages of people exposed to PM and O_3 were even higher if the more stringent World Health Organization (WHO) air quality guideline values (WHO, 2005) are considered. As part of the Green Deal, the Air Quality Directive thresholds may be reviewed in line with the new WHO guidelines. Table 5-35 presents evidence of the significant but still insufficient progress since 2007 with regards to population overexposed to air pollution. While the exposure to NO_2 above recommended levels (for both AQD and WHO) has clearly improved, exposure to PM and O_3 remains above the recommended levels for a significant share of the urban population in Europe, especially if WHO thresholds are considered.

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[190] Emissions of NMVOCs, NOx, CO, which are part of Euro 6/VI standards, contribute to the formation of ground-level (tropospheric) ozone

[191] Direct costs: Costs directly related to the health impact on the individual, e.g. fees for healthcare and medicine; lost income. Indirect costs: Costs caused by health impacts on the individual or population, which affect others or society, e.g. absence from work

Table 5-35: Percentage of urban population in the EU with air pollution levels exceeding Air Quality Directive limits or WHO guideline values in 2007 and 2017

	Exceedance levels in urban population based on EU AQ Directive (%)		Exceedance levels in urban population based on WHO guidelines (%)	
Pollutants	**2007**	**2017**	**2007**	**2017**
NO_2	20.7	6.5	20.7	6.5
Particles	30.4	17.2	85.8	44.4
$PM_{2.5}$	11.5	8.0	90.9	77.2
O_3	21.8	13.9	97.8	95.9

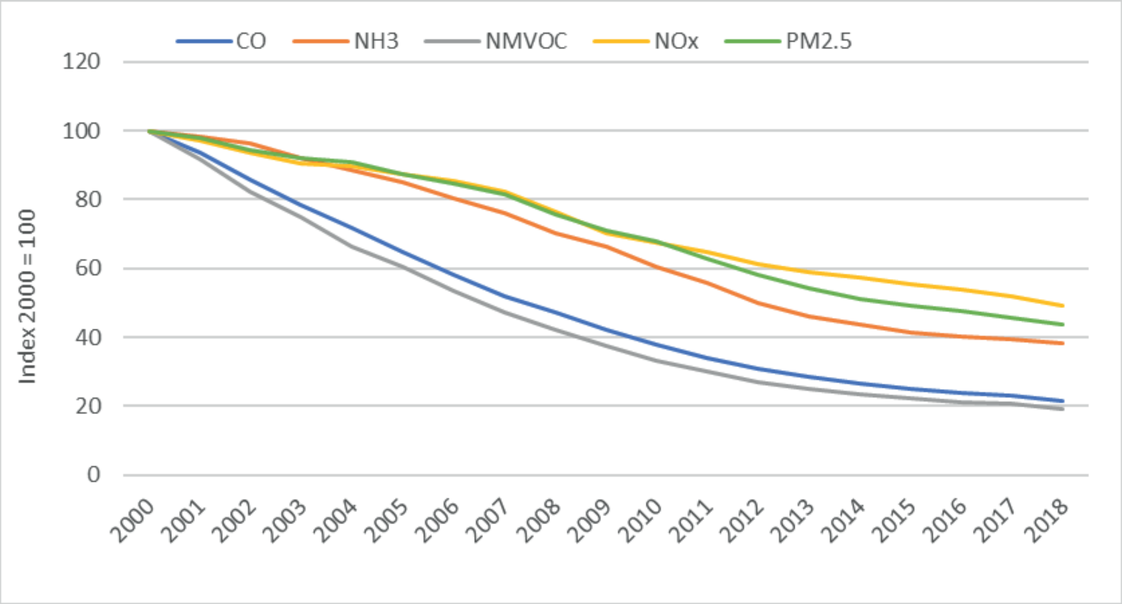
Source: European Environment Agency "Exceedance of air quality standards in urban areas" (July 3, 2019). Link

Road transport is still a major cause for air pollution in urban areas, particularly for NO_2. According to the EEA (EEA, 2019d), in 2017, the highest concentrations as well as 86% of all concentrations of NO_2 recorded above the annual limit value were observed at roadside stations, with much lower values observed at background stations far from traffic. These results are also consistent with other EEA data (EEA, 2019e) which indicates that road transport is the main emitting source of nitrogen oxides (NO_x), it represents 28% of total NO_x emissions in 2017 in the EU. In urban areas this proportion is higher. A JRC study in urban areas (JRC, 2019b) found that the contribution of transport to the overall NO_X emissions was on average of 47%, with minimum of 20% for Lisbon and maximum values of more than 70% (i.e. for Athens and Milan).

As for particles and $PM_{2.5}$, the effect of traffic is not so dominant (EEA, 2019a). Sources other than traffic are also relevant and the difference in PM concentrations between roadside stations and background stations is generally not significant.

The EEA report (EEA, 2019a) highlights that emissions from road transport of key pollutants have decreased significantly over the last two decades, but recent EEA data (EEA, 2019f) shows that reductions in pollution from road transport have slowed down since 2014 (see Figure 5-19).

Figure 5-19: Trends in emissions of air pollutants from road transport in the EU



Source: European Environmental Agency "Air pollutant emissions data viewer (Gothenburg Protocol, LRTAP Convention) 1990-2018" (January 2020). Link

Stakeholder consultation in the context of this evaluation indicates that there is a wide consensus among stakeholders that there are ongoing air pollution and health issues associated with road transport (see Annex 9, Figure 10-19a), with 44 out of 61 stakeholders that responded strongly agreeing with this statement and 12 partially agreeing. Only 5 stakeholders did not agree with this need. Those not agreeing or disagreeing are three EU vehicle manufacturers, an EU vehicle manufacturers' association and a fuel research institution. Similarly, almost all respondents to the public consultation (161 out of 165) supported the need for regulations on air pollutant emissions to ensure a high level of environmental and health protection.

When asked about the ongoing need for action to limit vehicle emissions of air pollutants (see Annex 9, Figure 10-19b), 42 out of 61 of stakeholders strongly agree on the relevance of this need and 15 out of 61 partially agree. Those who strongly agree are mostly civil society organisations and public authorities who point to ongoing health issues associated to road transport despite recent progress associated to policy measures adopted and the introduction of the RDE test (and PEMS-based test for HDVs) in particular. For example, an EU health NGO states that for health and environmental reasons, the vehicle emissions of air pollutants should be drastically reduced and highlights that reductions in pollution from road transport have slowed down since 2014. Industry representatives who partially agree with this need highlight the significant progress made by road transport in reducing air pollutant emissions acknowledged by the EEA report (EEA, 2019a) and point to evidence that the latest technology vehicles are addressing the issues on NOx and NO_2. Those partly or strongly disagreeing (5 out of 61) pose similar arguments.

Relevance of emission standards to reduce vehicle emissions

As indicated in section 5.1.2 (EQ1) there is limited doubt in terms of the positive role that the adoption and implementation of Euro 6/VI emission standards have played in terms of reducing vehicle emissions up to now. In their absence, only limited, if any, development in terms of the adoption of relevant pollution technologies should have been expected. The previous section also pointed to the ongoing need for action to tackle the air quality issues.

In this context, emission standards should be expected to continue to have an important role when it comes to achieving further emission reductions.

This was indeed the view of the majority of stakeholders that were asked about the need for emission standards to encourage a reduction in vehicle emissions (Annex 9, Figure 10-20a). The majority of respondents to the targeted consultation (50 out of 61) across all stakeholder groups strongly agreed with this need, while only 7 out of 61 partially or strongly disagreed. A similar level of support was provided in relation to the need for enforcement of emission standards (Annex 9, Figure 10-20b). In this case, 44 out of 61 stakeholders indicated they 'strongly agree' with this need and 9 out of 61 stated they 'partially agree' (mostly industry associations or vehicle manufacturers). Those who either 'partially disagree' (3 out of 61) or 'strongly disagree' (4 out of 61) belong to the industry group.

Respondents who strongly agree with the need to set and enforce emission standards argued that air pollution is an externality that is not captured in the economic incentives of neither vehicle producers, nor vehicle buyers. Therefore, they argued that there is an ongoing need for emission standards to force the adoption of new technologies there are no incentives for the development and deployment of emission control technologies.

Rather than questioning the relevance of the use of standards those who disagreed considered that the focus when it comes to further reduction should be elsewhere and that, in their view, there is no need for further (i.e. additional) action in terms of emission standards beyond Euro 6/VI. An EU vehicle manufacturers' association and its members argued that given recent progress made by Euro 6/VI new vehicles, the pending issue with air pollution from road transport is now linked to older vehicles. As a result, they argued that action is mostly needed to promote fleet renewal towards new Euro 6/VI vehicles and not as much on improving further the performance of new vehicles. In this sense, an EU vehicle manufacturer indicated that policy measures should focus on stock improvement, through scrapping schemes, and in-use compliance and through road-side checks to stop old and badly maintained vehicles. Another EU vehicle manufacturer noted that too strict regulations may increase cost of ownership and hamper fleet renewal. From a different perspective, an EU fuel suppliers' association also suggested that the focus should first be to understand the effect of the current fleet turnover on air quality and assess to what extent more stringent emissions standards would improve air quality in the next 10 years. Another EU fuel suppliers' association noted the role of fuel quality in complying with Euro standards and thus suggested that there is a need to take into account the role of the fuel itself.

Further to that, stakeholders within the car and fuel industry pointed to the need to address air quality and climate aspects in parallel. They referred to the inter-connected nature of the interventions, their impact on the uptake of cleaner vehicles and thus on pollutant emissions. At the same time, some industry stakeholders argued that stricter pollutant emissions targets could make achieving efficiency gains linked to the CO_2 target reductions more challenging (i.e. where emission control technologies would increase fuel consumption)[192]. In this sense, it was proposed that both the timing and the targets of the emission standards should be considered in conjunction with those laid out in the CO_2 standards for vehicles.

All in all, there is limited doubt of the overall relevance of the Euro 6/VI standards in terms of reducing pollutant emissions. Furthermore, the majority of stakeholders seem to agree that there is an ongoing need for action on the basis of emission standards reflecting the

[192] We note that, as already discussed in EQ3 this is not generally accepted and existing combinations of available technology allow to achieve both aspects in parallel.

ongoing air quality problems and the relevance of standards in forcing the adoption of new technologies in the absence of concrete financial incentives. Having said that, important part of the industry (including the automotive sector representatives) suggested that the relevance of any such further action is limited and that focusing on fleet renewal is more relevant and important. We consider that, while also relevant, this does not question the relevance of standards in view of the ongoing air quality issues already identified.

Relevance of emission standards to offset transport demand increases

The EEA report (EEA, 2019a) shows that air quality emissions from road transport have decreased significantly over the last two decades, although transported passenger and freight volumes have been gradually increasing. The report attributes this behaviour to the success of policies to reduce road transport emissions per travelled distance, including emission standards.

When asked about whether potential demand for transport could offset any emission reduction from improved vehicle technology, consulted stakeholders tend to agree this is a potential risk (Annex 9, Figure 10-21a). However, most of them (27 out of 57) stated they 'partially agree', while only 8 out of 57 'strongly agree'. A significant proportion (11 out of 57) indicated they 'neither agree nor disagree' and many (14 out of 57) do not know. 11 out of 57 responded they either 'partially disagree' (5 out of 57) or 'strongly disagree' (6 out of 57). A recurrent comment from consulted stakeholders was that they did not have sufficient information to provide a precise answer to this question.

At the same time, stakeholders mostly indicated (43 out of 58) that they 'strongly agree' that without relevant standards, vehicle emissions per km travelled would not decrease (see Annex 9, Figure 10-21b). Only 3 out of 58 were in disagreement with that statement. This suggests that while the overall balance between activity and future emission factors is uncertain, emission standards are generally seen as a requirement to offset potential demand increases.

In light of this evidence, the objective to take action in terms of emissions standards to reduce pollutants emitted by the road transport sector and improve air quality (and reduce associated health impacts) appears to remain very relevant. Air quality issues associated to road transport are clearly a persistent issue in European urban areas and emission standards are generally seen as a relevant mechanism to encourage a reduction in vehicle emissions that could offset potential demand increases. Stakeholders from the industry point to other needs in this area, including the need to promote the replacement of the fleet for new Euro 6/VI vehicles and the need to consider the timing and the targets of the emission standards in conjunction with CO_2 emission standards.

5.3.1.2.2 Need to set harmonised rules on the construction of motor vehicles

At the time of adoption of Euro 6/VI emission standards, it was considered necessary to continue the approach set in previous regulation (Euro 1-Euro 5 and Euro I to Euro V) setting and enforce standards in a harmonised way at EU level. This was considered necessary to prevent varying product standards emerging across Member States in an attempt to address the air quality and health impact of transport that could result in fragmentation of the internal market and imposition of unnecessary barriers to intra-Community trade and to allow to reap the economies of scale.

Since Euro 6/VI standards entered into force, there has not been any change in the operation of the EU internal market and the automotive sector in particular that could substantially affect the need for a harmonised approach in setting and enforcing vehicle standards.

Stakeholders were asked to compare the outcome of harmonised rules at EU level with a hypothetical situation where Member States would organise themselves to cooperate on the setting and enforcing of emission standards.[193] Stakeholders across all groups tend to agree that without harmonised rules at EU level, emission standards would be less strict (see Annex 9, Figure 10-30). A significant proportion (30 out of 73) either don't know or do not answer. From those who answered, 17 out of 43 indicated that strictness would be 'significantly lower' and 17 out of 43 responded strictness would be 'somewhat lower'. A minority (3 out of 43) considered that strictness would have been 'somewhat higher'. No significant bias is observed between different stakeholder groups. According to an international transport research organisation and two EU NGOs, the level of strictness would have been lower because Member States would have more incentives to reduce the cost of compliance for their home industry, which would drive a race to the bottom.

At the same time, consulted stakeholders mostly agree that rules set by Member States would have been less effective in reducing pollutant emissions (see Annex 9, Figure 10-30). In this case the proportion of stakeholders who believed that effectiveness would have been either 'significantly lower' (21 out of 44) or 'somewhat lower' (18 out of 44) is higher compared to the previous question. None of the respondents believed that effectiveness would have been higher.

Responses from stakeholders also confirm the need for harmonised rules to take advantage of economies of scale from both the industry and public authorities. A majority of stakeholders who responded (24 out of 44) indicated that without harmonised EU rules, costs for the industry would have been 'significantly higher', while 11 out of 73 stated that costs would have been 'somewhat higher' (see Annex 9, Figure 10-31). Those responding that costs would have been higher are clearly a majority within the industry (16 out of 29, compared to 3 out of 29 responding that costs would have been lower). For example, an automotive parts supplier stated that a harmonized approach allows for efficiency of development and certainty for product planning, while rules led by Member States individually would have led to a patchwork of initiatives, requiring industry to manage their technologies and fleets accordingly.

Figure 10-31 in Annex 9 shows that a similar result was obtained for costs to national authorities. 18 out of 42 respondents indicated that without EU harmonised rules costs for public authorities would have been 'significantly higher' and 12 out of 42 stated costs would have been 'somewhat higher'. Only two public authorities consider that costs would have been either 'somewhat lower' or 'significantly lower'.

This evidence suggests that the need for a harmonised approach at EU level to prevent a fragmentation of the internal market and to allow to reap the economies of scale is still relevant. There has not been any change in the automotive sector since the adoption of the standards that could have led to a change in the direction of this need. In addition, evidence from the EU added value question confirms that stakeholders tend to agree on that harmonised standards at EU level are more effective and more efficient for both the industry and public authorities.

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[193] While this is mainly aiming to capture the added value of action at EU level it also provides relevant input on the need for harmonised action

5.3.1.3 *Are there any environmental, technological or policy developments that have introduced new needs or that make the use of standards more or less relevant?*

5.3.1.3.1 Policy developments at EU level

In 2016, the Communication 'A European Strategy for Low-Emission Mobility' (European Commission, 2016b) stated that "air pollutant emissions from transport will need to be firmly on the path towards zero by mid-century". Moreover, the strategy sets a short-term ambition to "reduce emissions of air pollutants from transport that are harmful to health and the environment significantly without delay".

Subsequently, in 2019, the 'zero pollution' package of the European Green Deal (European Commission, 2019d) confirmed "the zero-pollution ambition for a toxic-free environment" and identifies the need to "revise existing air quality standards (covered by the AQD) to align them more closely with the World Health Organization recommendations" and "strengthen provisions on monitoring, modelling and air quality plans to help local authorities achieve cleaner air".

The Green Deal package to accelerate the shift to sustainable and smart mobility states that "transport should become drastically less polluting though a combination of measures dealing with emissions, urban congestion, and improved public transport". The package explicitly mentions that "the Commission will propose more stringent air pollutant emissions standards for combustion-engine vehicles".

Input from an automotive parts suppliers' association from the US in the context of the inception impact assessment consultation indicates that there is still improvement needed to meet the targets of the Green Deal due to constant increases in fleet and distance travelled.

Following the European Green Deal, the Commission recently adopted the 2030 Climate target plan (European Commission, 2020b), which highlights the synergies between climate mitigation and air quality benefits. The communication states that "achieving 55% greenhouse gas emissions reductions could contribute to further decrease air pollution, reaching a total reduction of 60% by 2030 compared to 2015".

In the Sustainable and Smart Mobility Strategy (European Commission, 2020d) adopted on 9 December 2020, the Commission describes various milestones towards achieving the objectives of a sustainable, smart and resilient mobility, including that by 2050 nearly all cars, vans, buses as well as new heavy-duty vehicles will be zero-emission.

5.3.1.3.2 Policy developments at local level

Another relevant policy development has been the widespread adoption of Low Emission Zones (LEZs) in Europe. The 2011 White Paper proposed a framework for urban road user charging and access restriction zones, including EU Guidelines on LEZs. Today, more than 250 European cities have a LEZ. There is clear evidence that Low-Emission Zones can reduce air pollution from no discernible effect to a reduction of 32%, with the most determinant factor being the design of the LEZ (Transport&Environment, 2019). A large proportion of existing LEZs use the Euro standards as a basic criterion for granting access or determining the charge to be applied. In line with the zero-pollution ambition, some cities (e.g. Amsterdam, Brussels, London, Paris) have already set course towards different forms of Zero Emission Zones (ZEZs).

The widespread adoption of LEZs at local level has confirmed the usefulness of emission standards for labelling purposes in access regulations. The ambition to introduce more restrictive access regulations in cities leading to the application of ZEZs confirms the need to update emission standards sequentially in line with a zero-pollution target.

5.3.1.3.3 Technological and market developments

The most relevant technological and market development since the adoption of the Euro 6/VI emission standards is the uptake of electric vehicles and other alternative fuelled vehicles. As defined in the Directive 2014/94/EU, 'alternative fuels' means fuels or power sources which serve, at least partly, as a substitute for fossil oil sources in the energy supply to transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector. This includes electricity, hydrogen, biofuels, synthetic and paraffinic fuels, natural gas, including biomethane, in gaseous form (compressed natural gas (CNG)) and liquefied form (liquefied natural gas (LNG)), and liquefied petroleum gas (LPG). Some of these, including electricity and hydrogen, generate no tailpipe pollutant emissions and, hence, significantly contribute towards the zero-pollution target. The uptake of electric vehicles and other clean vehicles has already been actively encouraged at EU level through a number of policy initiatives, including the Alternative Fuels Infrastructure Directive 2014/94/EU, the Clean Vehicles Directive 2019/1161/EU and the CO_2 emissions standards for new light- and heavy-duty vehicles (Regulation (EU) 2019/631 and Regulation (EU) 2019/1242).

From the new cars sold in 2019 in the EU, 2.1% were battery electric vehicles (BEV) and 1.2% were plug-in hybrid electric vehicles (PHEV) (European Alternative Fuels Observatory, 2020). The support measures introduced by various countries to stimulate car demand amid the COVID-19 pandemic disadvantaged conventionally-powered vehicles and have already caused a significant uptake of alternatively fuelled vehicles in 2020. According to data reported by ACEA, in the third quarter of 2020, almost one in 10 passenger cars sold in the EU was an electrically-chargeable vehicle (BEV and PHEV) (ACEA, 2020d).

This is in contrast to a share in 2014 of BEV of only 0.3% a share of PHEV of 0.3% (European Alternative Fuels Observatory, 2020). This shows a significant increase in electrically-chargeable vehicles sales since the adoption of the Euro 6/VI emission standards.

The uptake is slightly lower in light commercial vehicles. According to EAFO data, 1.3% of light commercial vehicles sold in 2019 in the EU were BEV but this share was only 0.6% in 2014.

Following the European Green Deal, the Commission in September 2020 adopted the 2030 Climate target plan (European Commission, 2020b), which states that the Commission will "revisit and strengthen the CO_2 standards for cars and vans for 2030" and will assess "at what point in time internal combustion engines in cars should stop coming to the market".

Furthermore, in the Impact assessment (European Commission, 2020c) linked to the Climate target plan, it is estimated that the share in the total fleet of cars equipped with an ICE (including pure diesel or gasoline ICE, gaseous ICE, hybrid vehicles and plug-in hybrid electric vehicles) will be around 86-89% by 2030 in the considered policy scenarios, but a rapid increase of low and zero emission vehicles is expected post 2030 thanks to fleet renewal. By 2050, almost all cars (between 88-99% of the vehicle stock) need to be low or zero emission in order for the climate neutrality target to be attainable. This means that the share of cars equipped with an ICE would fall to between 5 and 25% in the considered policy scenarios. For vans, the modelled scenarios estimate a share of vehicles with ICE of around 95% in 2030 and between 5 and 25% in 2050.

In the case of heavy-duty vehicles (long-haul lorries of over 16 t and buses), the Climate target plan foresees that “clean hydrogen will be crucial for decarbonising heavy-duty transport”. However, market entry costs are still high for the supply of fuel cell vehicles and hydrogen fuel and further changes to the policy framework (including as part of the review of the AFI Directive) to support the deployment of hydrogen fuel infrastructure may be needed (Hydrogen Europe, 2020). Furthermore, while electric buses are widely deployed in many European cities, electric lorries are still mostly in the development and testing phase, with commercial solutions expected in the coming years (Earl, et al., 2018). Full battery electric lorries could be suitable solutions for local and regional deliveries, while catenary solutions are also being developed for long-haul operations (Transport&Environment, 2020a).

Overall, to meet the carbon reduction targets for HDV, low and zero-carbon vehicles, including electric and hydrogen powered lorries and buses, will be needed, but their uptake is expected to be slower compared to passenger cars and vans. Policy scenarios of the Climate Plan Target Impact Assessment forecast only a marginal share of zero emission vehicles and a 16% of hybrid vehicles in 2030. In the long-run, a significant uptake of hydrogen and electric vehicles is expected in order to attain the climate goals. Still, the policy scenarios of the Impact Assessment estimate that the share of vehicles with ICE (conventional diesel, diesel hybrid and ICE gaseous) will represent around 55-63% of the fleet in 2050. In December 2020 Europe’s truck manufacturers under the umbrella of ACEA have stated that by 2040 all new trucks sold need to be fossil free in order to reach carbon-neutrality by 2050 (ACEA, 2020e).

The high level of uptake of non-ICE vehicles (mainly passenger cars) raises the question as to whether the need to introduce cleaner ICE vehicles through more stringent emission standards is still relevant in a context where an increasing share of the fleet has no tailpipe pollutant emissions. However, as described above, even in the case of accelerated uptake of zero emission vehicles (i.e. battery-electric or fuel cell vehicles), vehicles with ICE will continue to have a role, either in the form of pure ICE vehicles or in the case of hybrid, plug-in hybrids and range-extended electric vehicles supported by an ICE. As such, there will still be a need to ensure that the ICE engines of such vehicles are also clean and do not jeopardise the progress towards zero-emission from vehicles. Further to that, in the case of HDV even more time will be needed for a transition towards zero emission vehicles with a significant share of such vehicles still relying on ICE powertrains. As such, the need to introduce cleaner ICE vehicles will very much remain.

We should also note that the costs of producing battery electric vehicles and hydrogen fuel cell vehicles is currently significantly higher than that for comparable ICEs. Vehicle manufacturers struggle to recoup those costs through pricing alone, which means that some of these vehicles, especially the non-premium ones, are not profitable (McKinsey, 2019). In the case of electric vehicles, developments in battery chemistry[194] and expansion of production capacity in manufacturing plants are cutting costs (IEA, 2019). On the demand side, consumer preferences are changing and policies adopted to promote the uptake of zero and low emission vehicles (e.g. subsidies, preferable taxes, procurement policies) may eventually lead to lower total ownership costs for alternative fuelled vehicles in comparison to ICE vehicles. Based on outputs from Ricardo analysis using our SULTAN model, the total cost of ownership of EVs in 2020 is still higher than that of petrol and diesel passenger cars

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[194] It is worth noting that the cost of batteries for electric vehicles (EVs) is falling markedly and it is expected to continue to drop in the coming years (IEA, 2020)

(11% and 12% higher, respectively, on average). However, in 2030, the total cost of ownership of EVs is expected to become slightly lower compared to ICEs.

From their side, stakeholders tended to agree on the relevance of the need to continue to pursue less pollutant technologies for ICE. 59 stakeholders (out of 64 responding to this question) indicated that cleaning ICEs is either ‘very relevant’ or ‘somewhat relevant’ to protect the environment and reduce air pollution (Annex 9, Figure 10-22a). Similarly, 58 stakeholders (out of 63 responses) found that the need for cleaner ICEs was also relevant to minimise impacts on human health from vehicle emissions (see Annex 9, Figure 10-22b). In both cases, only 2 stakeholders from the industry considered that the emergence of electric vehicles makes the need for cleaner ICEs ‘somewhat irrelevant’ or ‘very irrelevant’.

All in all, despite the expected increase in the uptake of zero-emission vehicles in the coming years (as reflected in recently adopted Climate Target Plan), a significant proportion of the EU fleet is still expected to rely on ICE technology, including ICE vehicles using biofuels and vehicles where the ICE engine has a supporting role (i.e. mild hybrids), especially for HDVs. As such, at least in short to medium term, there will still be a need to further improve the performance of ICE vehicles to ensure that emissions of air pollutants from transport are not harmful to health and the environment. This could be both by setting more stringent limits as well as by adopting measures to ensure compliance with applicable limits over the vehicles’ life for existing and new vehicles.

5.3.1.4 *Do the standards properly cover all relevant/important types of pollutant emissions from vehicles that pose a concern to air quality and human health? Are there important types of pollutant emissions that are not covered?*

Euro 6/VI standards cover nitrogen oxides (NO_x), carbon monoxide (CO), total hydrocarbons (THC), non-methane hydrocarbons (NMHC), particulate matter (PM), and particulate number above 23 nanometres ($sPN_{>23nm}$) emissions. Ammonia (NH_3) and methane (CH_4) concentration is regulated for Euro VI engines only. Additionally, sulphur dioxide (SO_2), benzene, polycyclic aromatic hydrocarbon (PAH) and Lead (Pb) emissions are regulated indirectly through fuel quality requirements.

However, there are indications that the current coverage is no longer sufficient and do not cover all relevant and important type of pollutants. There are new emission species that are not regulated today that are expected to become a concern as new engines, exhaust aftertreatment technologies, fuels and additives are introduced. The analysis is the context post-Euro 6/VI study (Part A) (CLOVE , 2020) identified a number of emission species (NMOG, NO_2, NH_3, N_2O, CH_4 and formaldehyde) where the introduction of limits was considered appropriate. More specifically:

- Methane is of concern especially when using methane as fuel (natural gas, biomethane, synthetic methane). Currently, 0.51% of the EU car fleet is powered with compressed natural gas (CNG), however it is expected that natural gas vehicles will have a role in the decarbonisation agenda, especially if blended with biomethane. ACEA expects that by 2030, the g-mobility[195] market could be 10 times higher than today (ACEA, 2020a).

- It has also been shown that higher ethanol content in fuel blends also leads to higher aldehyde (including formaldehyde, and acetaldehyde) emissions (Manzetti & Andersen, 2015) that are linked with respiratory diseases and carcinogenic and they also lead to the formation of ground-level ozone. As gasoline with higher ethanol content (E10) seems to be gaining some traction (ICCT, 2019c), this could be expected to become an important issue in the future.[196] As per conclusions from the post-Euro 6/VI study (Part A) (CLOVE , 2020), oxygenated hydrocarbons included within non-methane organic gases (NMOG), and including formaldehyde are not adequately quantified under NMHC limitations.
- In addition, emission control systems introduced since the adoption of Euro 6/VI standards continue to induce NO_2 and generate N_2O and NH_3 emissions. Aftertreatment systems to reduce NO_x have increased the NO_2 to NO_x ratio of vehicle exhaust (ICCT, 2019c). However, this effect seems to have been mitigated in the later stages of Euro 6/VI, as the SCR systems preferentially digest NO_2, and the remaining NO_x tends to be dominated by NO.
- As described in section 5.1.6.2.3, several studies have also found that NH_3 emissions increase based on the technology used to comply with Euro 6/VI, at least for earlier versions. Exhaust and urea-based SCR systems or lean-NO_x traps for NO_x, used in CI engines, generate NH_3 (ICCT, 2019c). However, the use of ammonia slip catalysts (ASC) has been increased in more recent Euro 6d CI vehicles to mitigate this. As a by-product, N_2O may be produced by the oxidation of NH_3 "slip" from SCR across ammonia oxidation catalysts. Regarding PI vehicles, particularly high NH_3 and N_2O emissions have been observed on PI engines equipped with three-way catalysts (CLOVE, 2020).
- In relation to the non-tailpipe emissions, the post-Euro 6/VI study (Part A) (CLOVE , 2020) concluded that, despite expected improvements in the testing requirements for evaporative emissions, the ongoing de-dieselisation of the fleet and the increasing share of PI engines will have possible implications to the level of evaporative emissions that may require further action. In addition, the analysis of by the CLOVE consortium (CLOVE , 2020) identifies a number of issues in terms of the ongoing relevance of the existing provisions and recommended a revision of current testing procedures and limits for evaporative emissions:
- Increases in the frequency of high ambient temperatures over 35˚C (linked to climate change) may mean that current provisions that do not require for testing in high temperatures are no longer appropriate to ensure that high level of evaporative emissions are avoided. In comparison, both the standards in the US and China make provision for such hot temperature testing.

[195] Mobility applications based on natural gas, biomethane or synthetic methane

[196] So far E10 petrol has been introduced in a few countries in Europe (e.g. France, Germany and Belgium). While some countries such as the UK are proposing to introduce E10 as an additional grade of petrol in the next years (Department for Transport, 2020), some stakeholders express some concerns about land use impacts, the real CO_2 benefit of bioethanol (Transport&Environment, 2020b) and about vehicle compatibility issues (ACEA, 2018). These concerns in combination with a higher uptake of EV may limit the introduction of higher bioethanol blends

- Higher ambient temperatures over a longer period of time can also lead to higher running loses during vehicles operation. Currently, there are no provision in the legislation covering this aspect.
- A possible increase in ethanol content of fuels could also lead to increase contribution of PI vehicles to evaporative emissions. Ethanol has been found to increase the evaporative VOC emissions from vehicles due to increased permeation of fuel tank lining, its negative effect on the effectiveness of the carbon canister, increased vapour pressure and co-mingling of fuel.
- Regarding particulate emissions, the analysis by CLOVE in Part A study (CLOVE , 2020) also recommends controlling sub-23 nm and brake wear particle emissions with new measurement methods.

Table 5-36: Pollutant sources that may be insufficiently regulated under current Euro 6/VI standards

Pollutant source/formation	Measurement/regulation	Health and environment impacts
Primary NO2 The use of aftertreatment systems under Euro 6/VI standards could cause an increase in the NO_2 to NO_x ratio of vehicle exhaust. However, this effect seems to have been mitigated in the later stages of Euro 6/VI as the SCR systems preferentially digest NO2, and the remaining NOx tends to be dominated by NO	The standard sets limits on total NO_x emissions, but does not include a separate limit for direct NO_2 emission Current international emissions standards outside of Europe that regulate NO_2 in HDVs can be found in the US	NO_2 is the most toxic component of NO_x. An increase in primary NO_2 emissions can lead to higher direct exposure to this pollutant in the proximity of transited roads. In addition, the increase in the NO2-to-NOx ratio of diesel vehicles has led to higher ground-level ozone concentrations in several air quality measurement stations monitoring pollution from traffic in the EU (ICCT, 2019c)
Ammonia (NH_3) Emission from the urea-based SCR systems or lean-NOx traps for NO_x control from diesel engines, and from TWC equipped cars and vehicles. However, the use of ASC has been increased in more recent Euro 6d diesel vehicles to mitigate this for diesel vehicles. Reductions in NO_x emissions because of more stringent limits has left ammonia as the main fixed nitrogen species emitted by modern gasoline engines (ICCT, 2019c)	NH_3 limit of 10 ppm applies only to Euro VI heavy-duty diesel and gas engines. No NH_3 emission standards apply to cars or other PI TWC equipped applications in the EU, even though their NH_3 emissions can be several hundred ppm	These ammonia emissions can be a threat to urban air quality, given ammonia's significant role in the formation of secondary particles; emitted ammonia readily reacts in the atmosphere to form secondary particles, such as ammonium nitrate and ammonium sulphate, increasing $PM_{2.5}$ levels
Formaldehyde (HCHO) Formaldehyde emissions are the result of the incomplete burning of the alcohol content of the fuel. Therefore, they increase with high ethanol content in the fuel. Gasoline with higher ethanol content (E10) seems to be gaining traction (ICCT, 2019c)	Formaldehyde from mobile sources is not directly limited in the EU. The test protocols required to accurately measure aldehydes (including formaldehydes) and other oxygenated VOCs are available as they have already been developed in the context of UNECE's Global Technical Regulations. Formaldehyde from vehicle emissions is regulated in the US.	Formaldehyde is one of the compounds harmful to human health (e.g. carcinogenic) and to environment (ground-level ozone). Formaldehyde is harmful already at low concentrations, and thus THC/NMOG limit is not regarded sufficient for limiting formaldehyde

Pollutant source/formation	Measurement/regulation	Health and environment impacts
Non-methane organic gases (NMOG) Non-methane organic gases are similar to NMHC, however NMOG includes oxygenated compounds	Oxygenated hydrocarbons, including alcohols and aldehydes, are not adequately quantified under non-methane hydrocarbons (NMHC) limitations. NMOG is regulated in the US as a component of NMOG + NO_x standards	The substances included in NMOG, particularly aldehydes and alcohols, are a tropospheric ozone precursor. Exposure to ozone levels is still clearly exceeding recommended values (see Table 5-35)
Nanoparticle emissions Volatile, semi-volatile, and solid particles smaller than 23 nm from vehicle exhaust	Current PN limits only take into account solid particles larger than approximately 23 nm (only non-volatile particles).	Detrimental health effects, not only through direct exposure, but also because of their role in the formation of secondary aerosols and $PM_{2.5}$
Brake wear particles Brake wear, in particular, has been recognized as the leading source of non-exhaust particles, contributing up to 21% of all particles emissions related to traffic (Grigoratos & Martini, 2015)	A measurement procedure for brake wear particle emission is under discussion in UNECE's PMP (ICCT, 2019c)	Same as ultrafine particulate emissions, where particle number is the considered metric, plus the release of semi-volatile organics from brake pads. Substantial PM emissions of particle-filter equipped vehicles are dominated by coarse materials (>1µm). Metallic components, particularly within the fine particle fraction, are very likely to exert adverse health effects (Grigoratos & Martini, 2015)
Evaporative emissions Evaporative VOC emissions from vehicles account for an increasing proportion of total vehicle emissions, from 21% in 2007 to 32% in 2017 (EEA, 2020b). This is due to improvements in tailpipe NMVOC but also to increasing share of PI engines. Increases in ethanol content and high temperature episodes due to climate change could further increase evaporative emissions (CLOVE , 2020)	Evaporative VOC emissions are regulated for LDVs with PI engines that run on gasoline or have bi-fuel capabilities. Type 4 testing includes evaporative emissions test provisions. Diurnal hot and cold soak tests under the WLTP provisions only test for evaporative emissions while parked. Refueling emissions are controlled using Stage II systems installed on pumps at fuel dispensing stations. The evaporative emission standards in the United States include tests and limits to account for running losses and refueling emissions.	These volatile hydrocarbons contribute to ozone and PM2.5, as they easily convert into secondary organic aerosols. Many non-methane hydrocarbons (NMHCs) are toxic, including benzene, 1.3-butadiene, formaldehyde, acetaldehyde and poly-cyclic aromatic hydrocarbons (PAH)

Recent studies and stakeholder input as part of this evaluation are in line with our findings mentioned above. A recent report by the ICCT (ICCT, 2019c) points to a number of pollutant sources (ultrafine particles, ammonia, methane and nitrous oxide, aldehydes and other volatile organic compounds, tire and brake particles) that are not covered under the current Euro 6 standards. The majority of respondents from all stakeholder groups to the public consultation (102 out of 152) also agreed that current emission limits do not cover all relevant pollutants. The level of agreement slightly drops when stakeholders are asked about whether currently unregulated pollutants are emerging from road transport, but still a majority of respondents from all stakeholder groups agreed (65 out of 116). However, a significant proportion of respondents from the industry expressed a different view in this case, with 19 out 52 in disagreement and 16 out of 52 neither agreeing nor disagreeing.

When respondents to the public consultation answered that the current list of regulated pollutants is insufficient, they were further asked which air pollutants should be added to the Euro standards. The inclusion of ultra-fine particles and brake emissions received the highest level of support among all groups of stakeholders (55 out of 61). Most stakeholders among all groups (50 out of 61) agreed that NH3 and tyre and road-wear emissions should also be added to the list. The regulation of N2O and NO2 emissions received lower support from all stakeholder groups, with less than 40 out of 61 stakeholders in favour. The regulation of NMOG received the lowest level of support, with only around 20 out of 61 stakeholders agreeing to include it. The majority of respondents to the public consultation from all stakeholder groups (65 out of 116) supported this conclusion. However, a significant proportion of respondents from the industry expressed a different view, with 19 out 52 in disagreement and 16 out of 52 neither agreeing nor disagreeing.

Put together, results from the effectiveness analysis and the relevant literature together with input from most stakeholders confirm that aftertreatment systems introduced under Euro 6/VI standards, trends in the use of fuels and new measurement methodologies available introduce the need to limit pollutant species that are currently not regulated. Some of these (e.g. NO_2, NMOG and formaldehyde) are currently aggregated in wider pollutant categories and need to be separated for a more precise emission control. Others (e.g. NH_3, ultrafine particles, brake wear particles, evaporative emissions) need new measurement methods.

5.3.1.5 *Are there any developments that have introduced a need for action to appropriately monitor the emissions performance of vehicles over their complete lifetime?*

The analysis presented earlier in Section 5.1.4.2 (EQ3) describes the role of the durability requirements on the effectiveness of the standards and their limitations when considered against the increasing lifetime of vehicles. In addition to that, advancements in emission control technologies point to new questions and challenges to the current provisions. The new systems developed to reduce emissions are more complex and the functionality of the whole emission control system is becoming increasingly intertwined with engine operation and the accompanied calibrations. This increases the need for a more complete demonstration of their durability (CLOVE, 2020).

In that respect, recent developments in the field of on-board monitoring (OBM) in all regions (i.e. EU with OBFCM, US with REAL, China with Remote OBD) already demonstrate the significant possible benefits of the use of more advanced OBD/OBM on vehicle emission monitoring (CLOVE, 2020). Data collected from an OBM system can be used by the regulatory agencies for improving in-use compliance. California and China have already adopted OBM regulations requiring heavy-duty vehicle (HDV) OBD systems to collect and store emissions data from the vehicle’s sensors (ICCT, 2019c).

As such, these technology developments point to the possible need for more comprehensive monitoring provisions that will be better placed to capture the increasing complexity of the emission control systems and help monitor their effective operation over the vehicles normal life.

Responses to the public consultation tend to support these conclusions, but there are some divergent views, especially from the industry side. Around half of respondents from all stakeholder groups (72 out of 124) agreed that real-world emissions are not adequately monitored over the entire lifetime of a vehicle in Euro 6/VI, while 42 out of 124 disagreed. Those who disagreed mostly belong the industry group. Within the industry, 29 out of 59 respondents were in the opinion that emissions are adequately monitored. In addition, when asked about OBD, 40 out of 69 respondents from the industry agreed that OBD ensures that new vehicles are compliant with the pollutant limits over their entire lifetime.

However, the majority of stakeholders within Member States, civil society and citizens stated that OBD does not ensure compliance over the entire lifetime.

5.3.1.6 *Conclusions*

Our analysis of the ongoing relevance of the objectives and provisions of the Euro 6/VI standards points to the following conclusions:

- The objective to take action in terms of emissions standards to reduce pollutants emitted by the road transport sector and improve air quality (and reduce associated health impacts) appears to remain very relevant. Air quality issues associated to road transport are clearly a persistent issue in European urban areas and recent research suggests strong association of air pollution with health effects even at low concentration levels, with no observable thresholds. Current standards contribute insufficiently to the necessary decrease in pollutant emission emerging from road transport.
- Emission standards are generally seen by stakeholders as a relevant mechanism to encourage a reduction in vehicle emissions that could offset potential demand increases.
- Air pollution is an externality that is not captured in the economic incentives of neither vehicle producers, nor vehicle buyers. Because of this market failure, without standards forcing the adoption of new technologies there are simply no incentives for the development and deployment of emission control technologies.
- The European Green Deal introduces a “zero-pollution ambition” and states that “transport should become drastically less polluting“. This creates a need for “more stringent air pollutant emissions standards for combustion-engine vehicles”. The increased climate ambition of the 2030 Climate Target Plan is expected to facilitate the decrease of pollution levels from road transport with a higher uptake of zero emission vehicles.
- The emergence of electric vehicles and other traction options with zero tailpipe emissions does not alter the need of vehicle emission standards, because ICEs (either in the form of pure ICE vehicles or in hybrid forms) are still expected to represent a significant part of the fleet, at least for the coming decades, and especially for HGVs.
- Aftertreatment systems introduced under Euro 6/VI standards and trends in the use of fuels increasingly induce pollutant species that are not covered under current Euro 6/VI standards. These recent changes and trends question the relevance of the current scope of pollutants. In particular:
- NH_3 emissions, which are not regulated for LDV, increase with the technology (urea-based SCR systems or lean-NO_x traps) used to comply with Euro 6 (and Euro VI) and have a significant role in the formation of secondary particles, increasing $PM_{2.5}$. This effect has been mitigated in more recent Euro 6d diesel vehicles with the increased use of ammonia slip catalysts. However, particularly high NH_3 emissions have been observed on gasoline cars equipped with three-way catalysts.
- Aftertreatment systems to comply with Euro 6/VI standards could cause an increase in the NO_2 to NO_x ratio of vehicle exhaust, with NO_2 being the most toxic component of NO_x. However, this effect seems to have been mitigated in the later stages of Euro 6/VI.

- Formaldehyde (HCHO) emissions may increase with the potential increase of ethanol content in gasoline blends. Formaldehyde is harmful for human health already at low concentrations and thus THC/NMOG limit is not regarded sufficient for limiting formaldehyde.
- New measurement methodologies are being developed to control nanoparticles (smaller than 23 nm) and brake wear particles. Once readily available, these developments would question the relevance of excluding these components from current Euro 6/VI standards.
- The improvements in tailpipe emissions control mean that evaporative emissions represent an increasing share of VOC emitted from LDVs and HDVs. The existing requirements, while expected to bring certain improvements, do not appear to be sufficient to capture the expected increase in VOC as a result of the increasing frequency of high temperatures and the increase in ethanol content.
- The analysis suggests that increasingly complex emission control technologies require a more complete demonstration of durability. New technologies in the field of on-board monitoring introduce the need for a more comprehensive monitoring approach.

5.4. Coherence

5.4.1. EQ12 To what extent Euro 6 / VI features work together sufficiently well? Are there any inconsistencies, overlaps or gaps?

The assessment of internal coherence examines the extent to which there are any inconsistencies, overlaps or gaps within the Euro 6 and Euro VI legal frameworks. We also examine if the Euro 6/VI regulations are coherent with each other. We have based our assessment on input from stakeholders, evidence from the analysis on the effectiveness of the standards by the CLOVE consortium (i.e. Part A study (CLOVE, 2020)) and logical analysis to assess the existence and importance of those inconsistencies, overlaps or gaps.

5.4.1.1 *To what extent do the Euro 6 / VI features work together sufficiently well? Are there any important inconsistencies, overlaps or gaps?*

5.4.1.1.1 Overall stakeholder assessment of coherence

As part of the targeted stakeholder consultation on the Euro 6/VI evaluation, stakeholders were asked if, overall, vehicle manufactures are provided with a coherent policy and legal framework to reduce vehicle emissions[197]. The great majority of stakeholders, 38 out of 47, responded positively to this question (Annex 9, Figure 10-23).

Among the nine stakeholders that responded negatively, eight where industry stakeholders. Asked to elaborate, three stakeholders (an international automotive parts suppliers' association, an EU vehicle manufacturer and a fuel research organisation) focused on the complexity of legal framework, notably the multiple processes and procedures over many

[197] Please note that this question was not exclusively about *internal* coherence, but related to all coherence aspects, including *external* coherence (the subject of the next evaluation question, section 5.4.2)

legal instruments, which make interpretation difficult. However, they did not point to specific inconsistencies or overlaps that jeopardise its effectiveness. As noted by an EU automotive parts suppliers' association, the fact that emissions from vehicles are being reduced suggests that the framework is coherent enough allow this to happen. From its side, an EU local transport NGO the current framework has allowed for loopholes, leading to less ambitious emission reduction goals. Other stakeholders (including two national authorities, a fuel research organisation and an international vehicle testing association) considered that the framework is generally coherent, even though that there is still room for improvement.

All in all, the majority of stakeholders considered that the standards provide a generally coherent legal framework and the few negative comments did not point to significant and problematic inconsistencies.

5.4.1.1.2 Internal coherence issues on Euro 6

This section considers in more detail the internal coherence of the Euro 6 standards. Asked to comment on this issue, a large share of stakeholders (24 out of 35), mainly from industry (16 out of 19), suggested that there are important inconsistencies in relation to the emission limits and requirements (Annex 9, Figure 10-24). Furthermore, industry stakeholders were also the ones that pointed to consistency issues with the testing procedures (17 out of 20; in total, 23 out of 34).

At the same time, most stakeholders stated that the identified inconsistencies did not have an impact on their own costs (16 out of 24) (Annex 9, Figure 10-25). Among those that did indicate that there are costs to their organisation, only a few of them provided specific information on the type of costs incurred. Furthermore, some of them indicated that these costs were not incurred by the organisations themselves but by the society at large or consumers. The following sections summarise the key areas where coherence issues were identified.

5.4.1.1.3 Testing

A number of relatively minor issues related to specific provision of the testing procedures outlined in the Euro 6 regulations were identified by the 15 stakeholders that commented on the coherence of the testing provisions. Inputs from one authority, two associations, two academic organisations, and several individual companies pointed to some inconsistencies in terms of the testing requirements or specifications. While some of these issues could have arguably increased costs for stakeholders, most of them do not appear to represent important inconsistencies, overlaps or gaps.

Text box 5-3: Stakeholder input on the presence coherence issues associated with the testing procedures

An EU automotive parts suppliers' association and one supplier indicated that RDE error margin and no error margin on type 1 test was a necessary inconsistency but needs to be eliminated. Another EU automotive parts suppliers' association indicated issues with the RDE evaluation factor OVC-HEV vs. rest and the durability requirement in TA vs. ISC.

A non-EU vehicle manufacturer noted that while new ISC requires 100% testing for the families with more than 5,000 annual sales, Type 5 test requirement is not necessary for such families, creating an inconsistency. This was a point also made by another non-EU vehicle manufacturer. These two non-EU vehicle manufacturers also added that low temperature requirements for Type1 and RDE are redundant: while multiple requirements are understandable for normal temperature, either one seems enough for low temperature.

A testing equipment supplier indicated several issues related to specifications for instrumentation. These included NH3 measurements (related to analyser types, e.g., QCL; and also sampling/analyser temperature differences) and differences in the CVS / PM sampling requirements between LD, HD and NRMM.

An EU vehicle manufacturer indicated an issue with the use of WLTP in the LCV segment above 2,610 kg. As suggested, this leads to costs related to additional measurements including road load determination.

An automotive parts supplier said that the PEMS' error margins are not clearly defined and a non-EU vehicle manufacturer indicated that the definition of RDE conformity factors provides room for interpretations and is a confusing element in the certification process.

A type approval authority argued that the main elements of LDV regulation have been improved with the introduction of RDE/WLTP and ensured consistent provisions concerning defeat devices.

5.4.1.1.4 Differences in provision for vans and passenger cars

An EU automotive parts suppliers' association and a national authority pointed to the different ways that passenger cars and vans are treated by the regulations in terms of conformity factors[198] and deadlines for compliance with specific testing procedures[199]. According to this authority, this brings environmental costs to society, as vans are allowed to pollute more than comparable passenger cars.

5.4.1.1.5 No PN limits for port fuel injection engines

Several stakeholders (an EU automotive parts suppliers' association, a fuel research organisation, an automotive parts supplier and a vehicle testing supplier) pointed to the absence of PN particulate limit for port fuel injection (PFI) petrol engines – this is in contrast to GDI engines. These stakeholders considered that this was inconsistent, but they did not suggest that it represented a significant problem or limitation.

Finally, other comments of stakeholders referred to issues or limitations of the Euro 6 standards (at least from their perspective) which cannot be considered as evidence of inconsistencies of the standards. These are presented in the text box below.

Text box 5-4: Stakeholder input on issues or limitations of the Euro 6 standards

- Fuel/technology neutrality of limits: Several stakeholders indicated that by setting different requirements for CI and PI vehicles (CI engines have a higher limit for NOx than PI engines; these limits are 0.08 and 0.06 g/km, respectively) the regulations are not fuel or technology neutral. This could indeed be perceived as an internal coherence issue that ultimately can have detrimental effects in achieving lower levels of air pollution. Still, it should also be noted that different approaches might have been followed for different fuels and technologies to take into account the practicality can cost-effectiveness of imposing certain limits for certain fuels. A majority of respondents, from all stakeholder groups, to the public consultation (89 out of 128) also noted that the differences in emissions limits based on fuel and technology are at least somewhat complex. Still, 24 out of 61

[198] As noted in the implementation section (section 3), Class I N1 vehicles (those with a reference mass of 1,305 kg or less) have the same limits as M vehicles (passenger cars). N1 vehicles with higher reference masses (Class II and III) and N2 vehicles have higher limits.

[199] The timeline for compliance with the different testing procedures is the same for Class I N1 vehicles as it for M vehicles. For the heavier N1 vehicles (Class II and III) and N2 vehicles, the timelines are more extended allowing for an extra 6-18 months (depending on the specific test in question) for the new testing procedures to be used.

industry stakeholders disagreed with the majority, and indicated that these features are not complex at all.

- Unclear terminology: A testing equipment supplier focused on the wording of the Regulations and what they see as unclear legal text and definitions, which leaves room for misinterpretations.
- Differences between Euro 6 stages: An EU consumer organisation argued that the main inconsistency of the Euro 6 regulations is that it applies to both vehicles type-approved before and after the entry into force of new tests (RDE and WLTC). This leads to the first generation of Euro 6 vehicles (Euro 6b/c) having much higher polluting emissions than the latest ones. As this organisation notes the Euro 6 category could thus be misleading and difficult to understand because it covers such as broad range of vehicles and performances. This not only has the consequence of some older vehicles having higher emissions, but also some vehicles (especially diesel ones) losing value faster than otherwise would be expected.
- Absence of forum for manufacturers to resolve issues: Finally, while not referring to specific issues, an EU vehicle manufacturer considered that the main issue is the absence of appropriate mechanisms to raise, discuss and address many relatively minor issues. The result is that it leads to different interpretations of the provisions of the Regulations and these can take many years to resolve. Ultimately, the existence of many small coherence issues results in considerable costs and time spent dealing with them.

5.4.1.1.6 Internal coherence issues identified on Euro VI

Regarding the internal coherence of the Euro VI standards, only a minority of stakeholders indicated consistency issues with the emission limits and requirements (9 out of 20) and with testing procedures and requirements (7 out of 18) (Annex 9, Figure 10-26). On the other hand, a majority of industry stakeholders identified inconsistencies with the emission limits (six out of seven) and with testing (five out of six).

Furthermore, when asked if any identified inconsistencies in Euro VI led to costs to their organisations, only 4 out of 20 stakeholders responded positively (Annex 9, Figure 10-27). Three of those stakeholders were from industry. No stakeholders provided details on which costs they incurred.

5.4.1.1.7 Testing

As in the case of Euro 6, stakeholders pointed to a few issues of incoherence in relation to testing (see text box below). However, there was no evidence provided that would suggests that there are particularly problematic.

Text box 5-5: Stakeholder input on coherence issues associated with the testing procedures for Euro VI

- A technical service indicated an issue with Euro VI Step E. During engine homologation on the engine dyno, there is never a check-sum being equal to a vehicle's check-sum, because the engine's test bed data-set has many disabled vehicle functions for making the engine run at all on the test bed. Thus, a general definition about which parts of the dataset a check-sum is built is required in order to avoid manufacturer specific solution. Furthermore, PEMS CF cold and CF warm weighing does not follow the same approach as in WHTC cold/warm weighing. The PEMS CF cold considers just and only the cold portion of the test while WHTC cold considers cold and warm parts.

- A testing equipment supplier indicated several issues related to specifications for instrumentation. These included NH3 measurements (related to analyser types, e.g., QCL; and also sampling/analyser temperature differences) and differences in the CVS / PM sampling requirements between LD, HD and NRMM.
- An automotive parts supplier indicated that, “although not directly comparable, Type VI test limits / cycle are not consistent any more with the requirement of WLTP / RDE”. This stakeholder noted there are no impacts on costs resulting from this.

An EU automotive parts suppliers’ association also pointed to the fact that units for the limits for ammonia (NH_3) are in “ppm (average)”, while all other limits are in “mg/kWh”. However, while this presents an inconsistency, it was not seen as leading to any important problems.

Other input from stakeholders referred to issues or limitations of the Euro VI standards (at least from their perspective) which cannot be considered as evidence of inconsistencies of the standards. These are presented in the text box below.

Text box 5-6: Stakeholder input on issues or limitations of the Euro VI standards

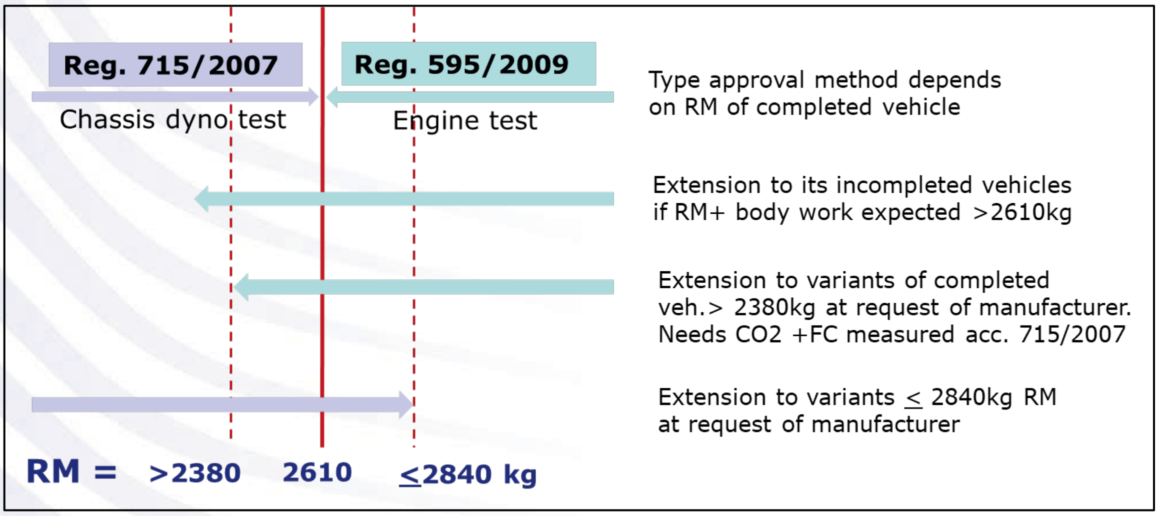
- Fuel/technology neutrality: Like with Euro 6, several supplier stakeholders argued for fuel and technology neutrality in Euro VI. Two of these stakeholders (an EU automotive parts suppliers’ association and an automotive parts supplier) specifically pointed out that differences in WHTC and WHSC are applicable to different fuels.
- Unclear terminology: A testing equipment supplier focused on the wording of the Regulations and what they see as unclear legal text and definitions leaving room for misinterpretations.
- Methane: An automotive parts supplier commented that the methane (CH4) limit for natural gas engines should be replace with a GHG limit for the overall vehicle. This is because the current limits force the engine to be tuned in such a way that the methane limit is achieved at the expense of higher CO2 emissions.
- Other issues: An EU vehicle testing suppliers’ association argued that measuring particulate matter in numbers (PN), instead of using plate values for diesel vehicles, would “drastically strengthen the fight against fraud”. This is because the suppression of the determination of plated values during the homologation process handicaps the controls and weakens their severity.

5.4.1.1.8 Incoherence between Euro 6 and Euro VI

In general, there were not inconsistencies identified between Euro 6 and Euro VI that were considered problematic. While there are differences in terms of the limits and the testing requirements, these are generally considered to be appropriate in view of the very different nature of light duty and heavy duty vehicles.

One area of overlap between the Euro 6 and Euro VI regulations that was identified relates to testing regime that the vehicles that have a reference mass (RM) in the “borderline” between the two different regulations are subject to. More specifically, this could happen for a vehicle with a RM between >2380 kg and ≤2840 kg (see Figure 5-20). As shown in the picture, there are vehicles with a RM under 2,610kg that can be approved under Euro VI, and some vehicles with a mass over 2,610kg that can be approved under Euro 6. Still, there are practical reasons for this overlap that explains why such exceptions exist. For example, a manufacturer might produce a family of HDVs which has some variants that are lighter and thus would fall under Euro 6; these exceptions allow for all the vehicles in that family to be approved under Euro VI instead of having to split them between Euro 6 and Euro VI. As such, the existence of these exceptions adds flexibility to the TA framework and cannot be considered to be an inconsistency.

Figure 5-20: Schematic picture of allocation rules of vehicle or engine tests according to Regulations (EC) 715/2007 (LDV on chassis dyno) and 595/2009 (heavy-duty engine on engine test bed)



Note: RM refers to the "reference mass" of the vehicle. Source: (Hausberger and Rexeis, 2018) as presented in (CLOVE , 2020)

In terms of stakeholder input, when asked to refer to any coherence issues between the Euro 6 and Euro VI regulations, a vehicle testing supplier pointed to the fact while Euro VI has limits for ammonia (NH_3), Euro 6 does not. Euro VI impose such limits is because the selective catalytic reduction (SCR) systems used in diesel HDVs can lead to sizeable NH_3 emissions (if poorly calibrated or malfunctioning). However, while there are also concerns about the level of NH_3 emissions in LDVs, linked to the use of SCR in diesel vehicles, there is currently no such limit in place (CLOVE, 2020b). Having said that, there is no indication that this does lead to possible problems or costs.

Finally, results from the public consultation show a split between stakeholders on whether having a separate regulatory framework for cars/vans and lorries/buses brings any complexity to the Euro standards. While a majority of stakeholders from Member States, civil society and citizens (49 out of 66) indicated that such a separate regulatory framework is at least somewhat complex, a majority of industry stakeholders (39 out 60) said that it was not complex at all.

5.4.1.2 *Conclusions*

Despite the complexity of the legal framework, the analysis concluded that the features of the Euro 6 and Euro VI standards work together sufficiently well. This was a conclusion supported by most stakeholders: 38 out of 48 stakeholders (including 15 out of 23 industry stakeholders) indicated that industry was provided with a coherent framework to work with.

Nonetheless, certain inconsistencies were identified on testing, the lack of fuel and technology neutrality, and differences in applicability for cars and vans.

- On testing, a few stakeholders pointed out aspects (e.g. on instrumentation and error margins) in the testing procedures that they considered to be internal coherence issues within the testing procedures outlined in the Euro standards. However, no stakeholders provided evidence to suggest that any of these issues represented important inconsistencies or gaps.
- On the lack of fuel and technology neutrality, there are different requirements for CI and PI vehicles, and between different technologies available for each fuel. For example, PFI petrol engines have no limits for their PN emissions, in contrast to GDI engines (which have the same PN limit - $6x10^{11}$ #/km – as diesel engines). In Euro 6, CI vehicles also have higher limits for NOx that PI vehicles. While there might be practical reasons for the lack of neutrality in some specific instances, the fact is that could be indeed considered an internal coherence issue.
- On the difference in the applicability for cars and vans, passenger cars and vans are treated by the regulations in terms of conformity factors[200] and the different deadlines for entry into force of specific testing procedures. There is no obvious justification for these differences and, while it has provided a more step-wise approach, this has made the framework more complicated while allowing vans to pollute more than comparable passenger cars.

5.4.2. EQ13 To what extent is Euro 6/VI consistent with other legislation pieces (such as CO_2 standards, air quality legislation, fuel legislation, roadworthiness framework, etc.) applying on the same stakeholders and with similar objectives? Are there any inconsistencies, overlaps or gaps?

The aim of this question is to identify the extent to which the Regulations are coherent with other EU interventions. Thus, we examined the objectives and provisions of Euro standards in relation to the objectives and provision of relevant pieces of legislation including:

- Vehicle CO_2 standards.
- Ambient Air Quality Directive and the National Emission Ceilings Directive.
- Vehicle roadworthiness/PTI/RSI legislation.

Furthermore, we compared the Euro 6/VI regulations with broader EU objectives such as mobility and transport policy, climate change and environmental policy, employment policy, taxation policy, and industrial policy.

This analysis was based both on desk research, including relevant studies analysing other EU interventions (impact assessments, fitness checks and evaluations) and on field research, using the input from stakeholders on the questions that focused on external coherence.

[200] Class I N1 vehicles (those with a reference mass of 1,305 kg or less) have the same limits as M vehicles (passenger cars). N1 vehicles with higher reference masses (Class II and III) and N2 vehicles have higher limits.

5.4.2.1.1 Ambient Air Quality Directive and the NEC Directive

At the general level, the objectives of the AQD (2008/50/EC) and the NECD (2016/2284/EU) are largely aligned as both are intended to improve air quality across the EU by setting limits concerning specific pollutants. By aiming to provide for a high level of environmental protection in the European Union and improving air quality by reducing tailpipe and evaporative pollutants emissions of the road transport sector, the Euro 6/VI standards should contribute to the achievement of both Directives. The NECD also has the objective to contribute to the progress towards the EU's long-term objective of achieving levels of air quality in line with the air quality guidelines published by the World Health Organisation. This objective is aligned with the Euro standards' general objective of providing for a high level of environmental protection in the EU. In terms of stakeholder assessment of the issue, a majority of stakeholders across all stakeholder groups indicated consistency issues with AQD/NECD (27 out of 39). These results are shown in Annex 9, Figure 10-28.

However, there also important areas where the objectives and approach adopted do not appear to be fully in line:

- The AQD and NECD cover a relatively large number of species selected because of their potential to cause harmful effects on human health and the environment as a whole. For example, Annex X of the AQD covers the measurement of ozone precursor substances and lists 31 compounds (including formaldehyde) and the 4th Daughter Directive of the AQD gives a list of polycyclic aromatic hydrocarbons (PAHs) and metals. The organic compounds are referred to generically in the Directives as "volatile organic compounds", VOCs. Inorganic species in the two directives include NO2 and SO2. In comparison, the Euro 6/VI standards specify different compounds or groups of compounds. They cover THCs, which are nearly, but not quite, the same as VOCs, NOx which is the sum of the harmful NO2 and the much less harmful NO, and PM rather than the more specific fractions particles and PM2.5 used in AQ measurements. Thus, the Euro 6/VI standards are only indirectly linked and contributing to meeting the respective AQD limits. Having said that, many of the species in the AQD are present in such low concentrations in vehicle exhausts that it is reasonable that they are not regulated pollutants under Euro 6/VI. For some others practicality or cost/benefit considerations have, to date, meant they are not measured.
- A type approval authority and an EU environmental NGO, noted that when the Euro 5/6 standards were set up there was no consideration of the air quality problems that the standards should help overcome. Instead, limits were set based upon best available technology, reflecting the objective that Euro standards are met in a cost-effective manner taking into account the implications on competitiveness. The NGO thus noted the lack of alignment between the interventions. An automotive parts supplier added that such an alignment would allow better "cause and effect" studies and increase consumer awareness and concern.
- An EU vehicle manufacturers' association and three of its members (in a coordinate response) and an EU fuel suppliers' association also considered that the AQD and the Euro standards are not aligned. For these stakeholders, for some AQD targets to be achieved a very large turnover of the fleet (much larger than as historically occurred) would be needed, conflicting with the goal of bringing into compliance non-compliance areas "as soon as possible" as envisioned in the AQD.

On the practical side, the 2019 fitness check of the AQD noted that challenges in implementation and enforcement of the Euro standards have had negative consequences for air quality (European Commission, 2019a). However, the study also noted that changes introduced since 2015 (see section 3 on implementation) regarding TA (including RDE) led to tighter EU oversight that should help the Euro standards further support the AQD goals. This was supported by one national authority, who noted that if RDE was introduce earlier, inner city air pollution could have been tackled timely and effectively sooner; another national authority noted that differences between testing and real emissions jeopardise their air quality goals. According to an EU environmental NGO and an EU health NGO, these challenges were one of the reasons for the slow improvement in air quality over the previous years across the EU.

5.4.2.1.2 Coherence with vehicle CO_2 standards

Cars and vans CO_2 emissions targets have been in place since 2009 (Regulation (EC) 443/2009 for cars) or 2011 (Regulation (EU) 510/2011 for vans). Regulation 2019/631 has replaced those Regulations and sets new targets for the period after 2020 (2025 and 2030) for both cars and vans. In the case of HDVs, the first set of standards was introduced in 2019 (Regulation (EU) 2019/1242).

There are no direct overlaps between the objectives of the Euro emission standards and CO_2 emission standards as they are aimed at reducing emissions from different components. A large share of stakeholders (19 out of 43) did not identify any coherence issues; still, the majority of industry stakeholders (12 out of 22) did find coherence issues with the CO_2 standards. These results are shown in Annex 9, Figure 10-28.

At the practical level, some of the technologies used to meet the Euro standards may increase fuel consumption, suggesting a possible trade-off. As already discussed in EQ3 (section 5.1.4) some stakeholders point to the possible negative impact on fuel efficiency from the use of specific technologies intended to reduce NOx emission (e.g. pre-warming of SCR to ensure effective operation in the case of cold-start or the use of EGR). However, such negative impacts can be effectively addressed through the combination of technologies. As such it is mainly a question of choice and possible cost implications for OEMs and not of technical feasibility.

From the consumer perspective, a few stakeholders (a national consumer organisation and an automotive parts supplier) considered that the two sets of legislation may give contradicting signals to consumers in terms of which vehicles are preferred in terms of emissions and their environmental impact. Consumers may be given the information that diesel (CI) cars emit less CO_2 than a comparable petrol (PI) car, while at the same time, that this same diesel (CI) car emits more NOx. From this perspective, it is suggested that an integrated approach would help provide a more consistent message to consumers. However, it should be noted that while messaging to consumers might be important consideration it is not the objective of the Euro standards that aim to ensure that all vehicles meet the requirement. Other tools, such as vehicle labelling, are more relevant to determine the required information that is made available to consumers.

Some stakeholders also commented that there seems to be limited coordination between the two policy areas. An EU vehicle manufacturers' association and three of its members pointed out that discussions around the CO_2 and the Euro standards are usually kept separate while an automotive parts supplier considered that the duplication of legislative acts aimed at different sets of emissions adds to the costs that the industry has to incur. However, we note that in both recent impact assessment support studies on CO_2 Regulation for LDVs and HDVs the implications on pollutant emissions were also considered[201]. At the same time, given the very different focus and nature of the interventions (the CO_2 standards focus on average emissions across the fleet while Euro 6/VI on maximum level of pollutant emissions from each vehicle), the use of different legislative acts is clearly justified.

Another potential inconsistency between the Euro standards and the CO_2 standards relates to the specific criterion considered to decide the testing procedure. The is due to the fact that issue happens because while the testing procedures for type approval are defined on the basis of the reference mass (RM), the categorisation of the N1 and N2 vehicles (as defined by Directive 2007/46/EC and used to define the emission limits in Euro 6) is based on the Technical Permissible Maximum Laden Mass (TPMLM), with N1 not exceeding 3,500 kg. However, a vehicle with a RM of up to 2,610 kg (thus approved under Euro 6) can have a TPMLM below 3,500 kg (thus making it a N1 vehicle) and up to around 7,000 kg, making it a N2 vehicle. The practical implication of this is that there are N1 or N2 vehicles that can be subjected to either LDV or HDV certification procedures, and the same is true for some N2 vehicles (CLOVE, 2020b). This in itself is in an inconsistency of the Euro standards with Directive 2007/46/EC. Furthermore, in relation to the CO_2 standards, it is possible for two N2 vehicles with the same TPMLM need to be tested for CO_2 under different testing procedures, depending on whether they are identified as light duty or heavy duty vehicles on the basis of their reference mass. Despite the obvious inconsistency, there was no indication that this has been particularly problematic for industry, including the fact that it only affects a relatively small share of vehicles[202].

All in all, certain inconsistencies with the CO_2 standards have been pointed at, but there is no indication that these have been particularly problematic. There are concerns raised by industry of possible trade-offs arising in achieving the objective of CO_2-reductio and reduction of pollutant emissions but there are technology options available that allow both requirements to be met without such trade-offs. Some stakeholders also consider that separate frameworks limiting different types of emissions lead to inefficiencies but the difference in the approach seem to be largely justified on the basis of the different overall approach of the two pieces of legislation. Finally, the use of different masses (RM or TPMLM) to define the testing regime that a vehicle is subjected to also leads to certain inconsistencies when it comes to the testing regimes of N1 and N2 vehicles for their CO_2 emissions.

5.4.2.1.3 Vehicle roadworthiness legislation

The vehicle roadworthiness Directive has the general objective to contribute to the reduction of the emissions of GHG and air pollutants from road transport through measures aiming at detecting more effectively and removing from circulation vehicles which are over-polluting because of technical defects. In this respect, it is vital to appreciate the differences between the two legislations. The roadworthiness emissions testing is primarily focussed on trying to ensure that key emissions control systems are present and operating correctly and that

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[201] The same stakeholders commented that in the recent revision of the CO2 standards, the CO2 targets were “set in stone with economic and technical feasibility assessed based on the existing emission standards” with no consideration to the possibility that new emission standards might change the technologies being deployed and that these eventual new technologies might have impacts on CO2 emissions. In that respect, we note that this is reasonable in the absence of specific proposal for new pollutant emission standards.

[202] In 2016, and according to data from ACEA (as reported by (TU Graz, 2018)) for vehicles sold in the EU-28 with a RM over 2,380kg (over 400,000 vehicles): 2.8% of these vehicles were N2 (or M2, the equivalent categorisation for buses) certified under Euro 6; 8.0% of N1 (or M2) vehicles were certified under Euro VI.

vehicles in circulation are not over-polluting due to any technical defects. As all vehicles are tested in an unloaded state, this testing is not a substitute for a loaded chassis dynamometer test with full vehicle emissions analysis. For CI vehicles, which includes nearly all heavy-duty vehicle engines, the emissions test is only a free acceleration smoke (FAS) test. This could detect a DPF fault (or the DPF's absence) but, for example, is not designed to check the correct operation of a vehicle's SCR system. (However, some SCR faults would create an OBD fault code and could be picked up using this detection method.) Exactly the same arguments apply to roadside inspections. Therefore, whist roadworthiness emissions testing (used at both PTI and RSI) is intended to tackle air pollution by reducing the emission of pollutants from road vehicles, the very limited nature of the tests used, mean that vehicles that do not comply with Euro 6/VI emissions standards manage to pass them.

Taking this into account, it can be said that the two pieces of legislation have not been designed in a way to support each other. In that respect, a large number of stakeholders that responded to the targeted consultation (15 out of 27 stakeholders; including seven authorities, five industry representatives and three civil society representatives; see Annex 9, Figure 10-28) considered that there are inconsistencies between the vehicle roadworthiness legislation. The comments provided pointed to missed opportunities in terms of ensuring a more consistent approach in ensuring clean vehicles on the road as the two sets of legislation do not operate in a complementary and coherent way so that to achieve the best possible result. An international vehicle testing association commented that the Euro standards "forgot" to consider the role of PTI in assessing compliance with emission limits, a view also shared by a type-approval authority and a national authority. Other stakeholders (a fuel research organisation, two national authorities and an EU transport NGO[203]) also agreed that PTI could and should be more directly correlated to the type approved emissions.

At the same time, the Euro 6 OBD requirements also appear not to be fully consistent with the PTI testing requirements. As noted, emission tests during PTI can be done by checking the OBD. Some stakeholders (an international transport research organisation, an international vehicle testing association, an EU local transport NGO[204] and a type-approval authority) argued that the current OBD requirements, set out on the Euro standards, do not allow for an effective PTI test on emissions. This is because OBD systems have limited capacity and are ineffective in detecting and diagnosing degradation, failure or tampering of emission control systems. As more and more PTI across the EU relies on OBDs, this could create a problem in the effective enforcement of emission limits. Thus, according to the international vehicle testing association, lack of clear guidance on the PTI legislation on how OBD can be used can lead to different interpretations by the different PTIs across the EU.

5.4.2.1.4 Broader EU policy objectives

As part of the targeted stakeholder consultation conducted for this study, stakeholders were also asked to comment on whether they have identified inconsistencies with a broader set of EU policies including:

- Mobility/transport policies
- Climate change adaptation/mitigation and environmental policies

[203] On a position paper submitted to the AGVES group.

[204] On a position paper submitted to the AGVES group.

- Taxation policies to promote sustainable development
- Industrial policies
- Employment policies

In general, the majority of stakeholders (more than half) did not identify inconsistencies in any of these areas. Nonetheless, an important number of stakeholders indicated issues related to climate change and environmental policy (16 out of 36 and 13 out of 36, respectively) (Annex 9, Figure 10-29) and a smaller number in relation to taxation (11 out of 36) and mobility and transport policy (eight out of 36). A very small number identified inconsistencies in terms of employment (five) and industrial policy (three).

In terms of the interaction of Euro standards with climate change and environmental policy the comments were varied and related to the lack of a single approach to pollutants and GHG emissions and the lack of progress in reducing pollutants. On the former issue, a national consumer organisation indicated that the fact that pollutants and GHG emissions are treated separately means that there are inconsistencies between the EU climate change and environmental policies. On the issue of the lack of progress, an international transport research organisation noted that a significant proportion of the EU's population is still subjected to air pollutants in excess of EU standards, with road transport still being an important source of that air pollution. As such, more stringent standards are probably needed to ensure coherence with the overall EU environmental goals. Finally, an EU environmental NGO considered that Euro 6/VI in part undermine the objectives of EU environmental legislation, e.g. to protect habitats and biodiversity; no further details were provided on why this NGO made this observation.

In relation to the EU mobility and transport policy, the focus of comments was on the implications of the use of Euro standards as the basis for implementing other mobility and transport policies and the issue arising from the existing variation between type approval and real world emissions. One national authority pointed out that vehicles are still being sold that, due the difference between the type approval and real world emission are, in practice, not in line with the Euro limits. As suggested, this leads to conflicts with the overall mobility goals of Member States and the associated policies applies. Further elaborating on this point an EU local transport NGO[205] noted that the use of the Euro standards as the basis for restrictions at the local level is hindered by the fact that real emissions are higher that during type approval. As argued, this has led some local authorities to consider outright bans of CI and/or PI vehicles in urban areas. From a different perspective, the coordinated response by an EU vehicle manufacturers' association and three of its members considered that the fact that many local/city and regional authorities are imposing local restrictions leads to a fragmentation of the EU internal market, arguably in contrast to the objective of ensuring harmonisation on the basis of the Euro standards. Two non-EU vehicle manufacturers also argued for the need for greater coordination between the Euro standards and fleet renewal policies that would allow for faster replacement of vehicles and thus the realisation of the emission reduction goals. Finally, an automotive parts supplier stressed that all new emission regulations should carefully consider the impact on access to affordable transport and its relation to the "just transition" elements of the European Green Deal.

In terms of the interaction with taxation policy, the comments did not point to actual inconsistencies with the EU standards but rather on the possible need for greater and consistent use of the Euro standards. An EU automotive parts suppliers' association

[205] On a position paper submitted to the AGVES group.

indicated that it would be desirable to achieve European wide environmental and taxation policy to avoid local or national measures (e.g. traffic bans, low pollution zones) and to have similar tax incentives or tax disadvantages across Member States to avoid that old, dirty vehicles are sold to Eastern Europe. It would be preferable to have common incentives, linked to the Euro standards, this stakeholder added. Another EU automotive parts suppliers' association and an EU vehicle manufacturers' association agreed that taxation is applied inconsistently across the EU for different types of vehicles, with the EU vehicle manufacturers' association noting that unified tax incentives or disadvantages and unified environmental policies would help vehicle manufacturers to focus their efforts. Finally, a technical service argued that tax privileges for certain fuel types may be questionable.

On the possible interaction with industrial policy, among the three stakeholders that indicated inconsistencies the only comment came from an EU environmental NGO. They noted that the weak test requirements for Euro 6a/b/c were one of the reasons why systematic cheating in the car industry was not uncovered in the EU. For the NGO this negatively impacted the reputation and competitiveness of European industries. While the introduction of RDE helped the competitiveness of the industry, the fact that the requirements are less stringent than in other regions like the USA, undermines the technological leadership of the EU industry.

Finally, while a few organisations generally indicated inconsistencies with the EU employment policies (five out of 31 respondents), there were no specific comments provided pointing to specific issues.

In summary, stakeholders largely agree that the Euro standards are coherent with other EU policies, including policies on mobility and transport, environment and climate change adaptation, taxation, industrial, and employment. While some stakeholders pointed out some specific areas for improvement these mostly do not appear to be inconsistencies, but rather features that these stakeholders would like to see included in the Euro standards.

5.4.2.2 *Conclusions*

- This evaluation question analysed the external coherence of the Euro emission standards with other EU interventions. The interventions under analysis were the CO_2 emission standards, the air quality directives, and the vehicle roadworthiness legislation. An analysis was also done against a broader set of EU policy areas (mobility and transport policy, climate change and environmental policy, employment policy, taxation policy, and industrial policy).
- Overall, some coherence issues were identified with all EU interventions under consideration although there were no indications of significant problems arising. In particular:
- In relation to the vehicle CO_2 standards, we identified an inconsistency related to the use of different masses (RM or TPMLM) to define the testing regime that a vehicle is subjected to. Some N2 vehicles with the same TPMLM could be subjected to different testing regimes for their CO_2 emissions, depending on their RM.
- In relation to the AQ/NEC Directives, the coherence issues identified result from the fact that different pollutants are covered by the different interventions (NO_2 in the AQD but NOx in Euro 6/VI, particles and $PM_{2.5}$ in the AQD but PM in the Euro 6/VI standards). There are however practical reasons for such differences , including the fact that for some species covered AQD/NECD are present in such low concentrations in vehicle exhausts that it is reasonable that they are not regulated pollutants under the Euro standards. Stakeholders also considered that the

interventions should have been developed and implemented with greater consideration of each other to support their effectiveness.

- Finally, regarding the vehicle roadworthiness legislation there are potential coherence issues associated with the fact that both sets of legislation where developed independently and have not been designed to complement each other. PTI and RSI based testing has not been designed so that can help in ensuring ongoing compliance with emission limits. Also, OBD checks under Euro 6 cannot effectively help when it comes to identify malfunctions and to support the PTI & RSI emissions tests. As more sensors are added to vehicles for emissions control, and checked as part of the vehicles' OBD system, it is likely that OBD checks become more able to support the type approval emissions standards.

5.5. EU added-value

5.5.1. EQ14 What is the added value of Euro 6/VI compared to what could have been be achieved at merely national level? Do the needs and challenges addressed by Euro 6/VI correspond to the needs of an EU internal market? Do the needs and challenges addressed by Euro 6/VI continue to require harmonisation action at EU level?

5.5.1.1 *Introduction*

The assessment of EU added value examines the benefit of developing legislation at EU level (to be applied by all Member States), compared to individual action by Member States through the development of their own comparable legislation (i.e. emission limits and testing procedures), or through other combined international efforts, like those of the United Nations Economic Commission for Europe (UNECE).

The analysis focused on the following aspects:

- How do the results and impacts of Euro 6/VI (in terms of effectiveness in achieving the objectives and efficiency) compare with what would have been achieved by action taken at national level only?
- Is there continued EU added value of requiring harmonisation at EU level? Could certain elements be added or dropped?
- How do the results and impacts of Euro 6/VI compare with what would have been achieved by action taken at international level only (i.e. on the basis of the UNECE)?

The analysis has been mainly qualitative, using inputs from stakeholders and logical analysis.

5.5.1.2 *What would have happened on the basis of action taken at national or regional level only?*

In a scenario where there would be no EU action to deal with vehicle-related pollution, Member States should generally be expected to take action to limit the impact on health from road transport. This could include setting emission limits at national level, introducing measures to promote vehicles that fulfil stricter emission limit values and establishing relevant procedures and requirements to ensure compliance. At regional/local level, measures such as bans on certain types of vehicle entering cities or creation of low emission zones would also be expected to become more widespread. At the same time, it is possible that like-minded countries would aim to harmonise vehicle emission standards, either at a lower or higher level than the current limits.

Such a scenario could have an impact on the capacity to meet the objectives of reducing pollutant emissions and reducing health impact while ensuring harmonisation as well. The costs to industry and public authorities would also be negatively impacted.

5.5.1.2.1 Impacts on effectiveness in reducing vehicle-related emissions

With no harmonisation of measures across the EU, Member States would work either alone or in groups of like-minded countries to introduce their own limits or to use other measures (e.g. taxation) to reduce vehicle-related pollution (see next paragraph). Such fragmented approach is unlikely to have produced the same level of results in achieving EU-wide reductions in pollutants. Having said that, it is possible that some MS (especially smaller ones) would just adopt the standards created by the larger MS[206]. Nonetheless, it is unlikely that the same level of harmonisation and strictness of standards across the EU would be achieved. Input from stakeholders appears to support this assessment (see Annex 9, Figure 10-30). A large majority of respondents to the targeted stakeholder consultation indicated that the strictness of emission limits would be somewhat or significantly lower (i.e. higher) (34 out of 43 that answered the question). Only three stakeholders (one technical service, an EU vehicle testing association and a type approval authority) considered that the strictness of emission limits would be somewhat higher but did not provide any justification to back this up. In the case of the type approval authority, this response might be an indication that they believe that, in their Member State, the strictness of emissions limits would by higher, but does not necessarily mean that the same would happen EU-wide. For the other two stakeholders (one technical service and an EU vehicle testing association) it should be noted that none of their peers agreed with their assessment.

Furthermore, stakeholders also considered that effectiveness in bringing cleaner vehicles to the market and reducing emissions of pollutants would also be somewhat or significantly lower (38 out of 43 and 39 out of 44, respectively). Two national authorities indicated their belief that ultimately some MS would agree on a standard, but that would be less ambitious than what is achieved under EU law. Furthermore, one of these national authorities noted that RDE testing is such an example where that has happened, with the ambitious proposal leading to ambitions thresholds and procedures that eventually became EU law. Additionally, an international vehicle testing association indicated that emission limits without EU coordination “would lead to chaos”, indicating clear support for EU intervention.

Differences in the current level of taxation of passenger cars and freight vehicles across Member States provides an indication of the potential variation in the way that MS might follow if there is no EU action in regulating vehicle-related emissions. A 2019 study commissioned by the European Commission took stock of the different taxes and fees that are imposed on road vehicles across the EU (CE Delft et al., 2019). Table 5-37 below, shows the revenue, in purchasing power parity (PPP) terms, for road passenger vehicles and road freight vehicles across the EU27, on a €/1000 passenger-km (pkm; for passenger vehicles) or €/1000 tonne-km (tkm; for freight vehicles) basis. These results include all taxes

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[206] This is a situation that has happened in the USA, where the state of California has its own set of environmental standards, and other states decide do adopt the California standards instead of the federal (national level) standards (Shama, 2019).

and charges applied to road vehicles. As can be seen in the table, the willingness of a Member State to tax road transport varies considerably. For passenger transport, taxes and charges vary from as low as €24/1000 pkm (Luxembourg) to almost €100/1000 pkm (Netherlands), a four-fold difference. The same is true for freight transport, which vary from a low €6/1000 tkm (Luxembourg) to as high as €27/1000 tkm (Croatia). While these results cannot indicate with certainty that MS that tax the road sector more heavily would be more willing to impose stricter emissions standards, the different levels of taxation might be a proxy of that willingness.

Table 5-37: Average taxes and charges in each Member State for passenger and freight road transport

Member State	€/1000 pax-km	€/1000 ton-km	Member State	€/1000 pax-km	€/1000 ton-km
AT	62.73	15.98	**IT**	61.07	20.75
BE	50.12	17.65	**LV**	36.86	13.30
BG	50.06	18.28	**LT**	33.86	15.58
HR	81.52	26.95	**LU**	24.28	5.76
CY	46.83	18.36	**MT**	71.47	21.71
CZ	40.04	26.61	**NL**	99.40	13.56
DK	78.73	16.03	**PL**	34.43	11.38
EE	37.04	11.09	**PT**	77.44	17.61
FI	59.78	11.74	**RO**	43.29	22.21
FR	43.26	14.41	**SK**	46.17	15.42
DE	44.89	15.87	**SI**	49.18	21.99
EL	56.38	22.14	**ES**	49.92	9.60
HU	35.36	18.68	**SE**	40.18	14.49
IE	61.65	11.60	**Average**	**52.44**	**16.62**

Notes: Pkm=passenger-km (passenger vehicles); tkm=tonne-km (freight vehicles). Values are in PPP.

Source: (CE Delft et al., 2019)

Furthermore, a study by the European Parliament (Gieseke & Gerbrandy, 2017), analysed specific cases where Member States were against the adoption of more stringent standards or testing procedures. As reported in that study, several Member States[207] opposed on a number of occasions a Commission proposal for more ambitious conformity factors for NOx limits, leading to the overall adoption of less stringent standards with less environmental benefits. On testing, some Member States[208] prevented the formation of a qualified majority that would approve the quicker adoption of RDE tests, ultimately delaying the adoption by up to six years. This represents a strong indication that some Member States would be unwilling to adopt stricter emission standards in the absence of the EU intervention.

[207] AT, BU, CZ, ES, FR, HU, IT, PL, SK, RO, UK
[208] ES, FR, HU, IT, SK, RO.

5.5.1.2.2 Impact on costs for authorities and industry

While likely reducing the effectiveness of reducing vehicle-related emissions, lack of EU intervention would most probably also increase the costs for stakeholders, as it is unlikely that uncoordinated action at national level (or coordinated across like-minded countries) would be as efficient as EU level action. With no harmonisation and no level playing field, there would be an increase in costs for the industry, as it would need to adapt to many different national measures or, perhaps, adopt the stricter standard, especially if that standard was imposed by a large Member State where a large portion of vehicles in the EU are sold[209]. Furthermore, while the type approval would remain regulated at EU level (Regulation 2018/858), that process would become more bureaucratic as there would be a need to prove compliance across different Member States. Given the large capital investments that the industry requires to develop their vehicles and adapt to standards, this would have had the potential to significantly increase the industry's costs. This also raises the possibility of certain manufacturers abandoning certain EU markets where compliance with standards would be too costly. This point was mentioned by an EU vehicle manufacturer during the field research portion of this study. This manufacturer indicated in such a scenario they would probably try to match the most stringent standard and sell those vehicles across the EU. But, if that was not possible, they might not be able to sell vehicles in some Member States, this EU vehicle manufacturer added.

Stakeholders also largely agreed with this assessment on efficiency, with 30 out of 42 stakeholders indicating higher costs for authorities if there was no EU intervention, including 12 out of 17 authorities; eight stakeholders said that costs for authorities would remain the same (Annex 9, Figure 10-31). Only one of those eight stakeholders was a type approval/ national authority[210], a clear indication that a majority of authorities believe their costs would go up. Similarly, 138 out of 160 stakeholders that responded to the public consultation agreed that EU regulations on air pollutant emissions are more efficient that national regulations on air pollutant emissions with no important variation among the different groups.

In terms of costs for industry, 35 out of 44 indicated that they would expect higher regulatory costs, including 16 out of 21 industry stakeholders while four stakeholders indicated that costs for industry would stay the same. Only five stakeholders (three industry, one technical services and one civil society/R&D) indicated that cost for authorities would decrease, but no further explanations were provided. Given the expected fragmentation of the approach if EU level action was to stop, it is difficult to understand how costs to industry could decrease. One possible explanation for these answers could be that these stakeholders might expect that EU level action would eventually lead to intervention at international level, which might bring bigger economies of scale compared to EU level intervention – this possibility is discussed later in this evaluation question.

Such a situation would also increase regulatory uncertainty across the EU for the industry as OEMs will need to monitor development across multiple Member States. Besides the direct administrative costs, this can lead to delays for investment in new technologies (until the time that they can ensure that such an investment is justified on the basis of the presence of sufficient demand). A fuel research organisation noted that different

[209] Again, something similar has happened in the USA, with some large manufacturers (BMW, Ford, Honda and Volkswagen) agreeing with the state that they would meet the California standards for all the vehicles they sold nationwide (Shama, 2019).

[210] The other seven stakeholders were four industry stakeholders, two technical services and one civil society/R&D organisation.

approaches among MS might lead to “a lot of different answers to the same issue”, as it has been the case of the implementation of the vehicle roadworthiness legislation.

Ultimately, this proliferation of standards, increases costs and regulatory uncertainty can have a negative impact on the competitiveness of the sector. This result was confirmed by the stakeholder input, where 23 out of 38 stakeholders (including 11 out of 20 industry stakeholders) agreed that lack of EU intervention in this field would lead to lower competitiveness of the sector. Nine stakeholders (five industry stakeholders, three authorities and technical services and two civil society/R&D organisations) indicated that the competitiveness of the sector would increase without EU intervention, but no details were provided on why these stakeholders gave these responses.

5.5.1.2.3 Conclusion

All in all, the analysis points to a clear added value from the action taken at EU level. While Member States would be expected to act to reduce emissions (although perhaps using other means – like taxation – besides emission standards), it is unlikely that a harmonised approach across the EU level would ensue. Instead, a fragmented approach where Member States acted alone or in groups of like-minded Member States would be more likely. This would have negative impacts both in terms of the effectiveness of the intervention, and the costs for stakeholders.

Action at Member State or regional level is also unlikely to result in the same level of stringency of emission standards. This would then negatively impact the effectiveness of bringing clean vehicles to the EU market and reducing pollutants. This assessment was supported by the large majority of stakeholders with 34 out of 43 stakeholders agreeing that standards would be less strict without EU intervention. Stakeholders also considered that effectiveness in bringing cleaner vehicles to the market (38 out of 43) and reducing emissions of pollutants (39 out of 44) would also be lower. Furthermore, even if that level of results were possible to be achieved, they would probably be achieved at a higher cost for industry and authorities, a conclusion also supported by stakeholder input, with 30 out of 42 stakeholders indicating higher costs for authorities and 35 out of 44 indicated higher regulatory costs for industry.

Put together, these factors lead to the conclusion that there is added value in EU action compared to action at the national level.

5.5.1.3 *Is there continued EU added value of requiring harmonisation at EU level? Could certain elements be added or dropped?*

To ensure the correct functioning of the internal market, Article 114 of the Treaty on the Functioning of the EU (TFEU) establishes the EU’s prerogative to act on setting standards related to environmental performance and the protection of health[211]. This is aimed at ensuring that common requirements are set across the EU (ensuring harmonisation), supporting the correct functioning of the internal market, the existence of a level playing field across the EU and minimising costs for the industry (as well as regulators).

Furthermore, given that pollutants emitted in one Member State can lead to pollution in another Member State, concerted action at EU level is required. The fact that the policy

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[211] More concretily, it establishes the authority of the European Parliament and Council to adopt measures that have as their object the establishment and functioning of the internal market, and that those measures will “take as a base a high level of protection” of “health, safety, environmental protection and consumer protection” (Article 95(3)) (European Union, 2007).

objectives cannot be achieved solely by Member State action, the cross-border nature of pollution and the need to avoid barriers to the internal market also suggest that the subsidiarity principle is respected by this EU intervention (European Commission, 2005a). No information on the literature was found regarding concerns with the subsidiarity of the intervention and this was also not raised by any stakeholder. This could be an indication that the Euro 6/VI regulations are generally considered as respecting the subsidiarity principle, in line with the assessment in the initial impact assessment studies. There is also no relevant input provided or other indication suggesting that the current scope of the Euro 6/VI should be reduced due to concerns related to the subsidiarity of the intervention.

As noted, given the cross-border nature of road transport and air pollution, EU intervention in this sector supports the correct functioning of the EU internal market. To assess whether stakeholders agreed that the EU intervention supported this correct functioning of the EU market, the field research asked what would be the impact of removing EU intervention in the level of harmonisation across the fleet (Annex 9, Figure 10-32). Out of 45 stakeholders, 39 agreed that without EU intervention harmonisation in terms of placing of vehicles in the EU market would have been lower. This is an indication that stakeholders support the view that EU intervention has added value in support the correct functioning of the internal market. While a majority of stakeholders supported this view, no more details or explanation where provided.

Concluding, given the cross-border nature of road transport and air pollution, there is justification and added value for EU intervention in this sector to ensure the correct functioning of the EU internal market, while respecting the principle of subsidiarity. No indication was found that the need to avoid fragmentation of the internal market addressed by Euro 6/VI no longer require a harmonised approach, supporting the view that there is EU added value in the intervention.

5.5.1.4 *How do the results and impacts of Euro 6/VI compare with what would have been achieved by action taken at international level, on the basis of the UNECE)?*

An alternative approach to action at EU level would be through action at international level i.e. via the UNECE's World Forum for Harmonization of Vehicle Regulations. UNECE aims to establish "global" harmonisation of certain technical regulations for vehicles[212], with mutual recognition of type approvals amongst signatories of the UNECE agreements, of which EU members compose the majority[213]. UNECE areas of action include vehicle safety, environment, energy efficiency, and anti-theft performance (UNECE, 2020). Under this mandate, UNECE establishes standards for vehicle components, aspects of crashworthiness and measurement of fuel consumption (e.g., WLTP was developed under the auspice of UNECE). Pollutants are also regulated by UNECE, with emission limits being set in its Regulation 49 (R49) for HDVs and in Regulation 83 (R83) for LDVs. These

[212] The application of these regulations is set out in three international agreements signed in 1958, 1997 and 1998.

[213] Most of the signatories to these agreements are EU countries, with Russia, South Africa, Japan, South Korea and Australia, being some of the non-EU countries that work to develop standards within UNECE in a total of around 50 signatories of the 1958 agreement (UNECE, 2020).

regulations are legally binding for its signatories, who have to transpose the UNECE provisions to their national legal framework[214].

In general, it can be argued that the EU has been the driving force behind UNECE adoption of more stringent environmental standards (Norman, 2018), which led to UNECE regulations R49 and R83 eventually aligning with Euro VI and Euro 6, respectively (Transport Research Laboratory, 2014). Those revisions[215] to the UNECE regulations led to the adoption of the same emission limits as in Euro 6/VI and the same testing procedures are also part of the UNECE regulations[216]. Given the large presence of EU Member States in the composition of the UNECE bodies (27 countries out of 51 signatories), the EU has enjoyed a strong position and has been able to strongly influence UNECE's regulatory agenda, particularly in its environmental aspects (Norman, 2018). This was also a point made by a technical service as part to the targeted stakeholder consultation on the Euro6/VI evaluation. This organisation noted that UNECE environmental regulations are generally driven by the EU.

Given the above, it is reasonable to expect that, in the absence of action at EU level via the Euro 6/VI, standards on pollutant emissions under the auspices of UNECE would develop with like-minded countries (e.g. some EU Member States and third countries) promoting more or less advanced requirements. However, the level of stringency of the limits for pollutants emissions adopted would most probably be the lowest common denominator necessary to ensure approval from the necessary number of UNECE members and they would take more time to adopt. As pointed by some stakeholders, UNECE regulations usually take longer to be developed than in the EU (as argued by a national authority, an EU vehicle testing suppliers' association and a vehicle testing supplier). This slow progress has been noted, for example, in the development of a "whole vehicle" type approval system and on several safety-related initiatives (European Commission, 2015).

This overall assessment was only partly supported by stakeholders that contributed to the targeted stakeholder consultation. More specifically:

- While a large majority considered the EU action would be more effective in bringing cleaner vehicles to the market (38 out of 43 respondents), an important minority number (18 out of 45 respondents), suggested that action at UNECE level could have similar, if not better, results (see also Annex 9, Figure 10-33).
- A majority of respondents (28 out of 44 respondents) indicated that intervention at international level would result in less strict standards but an important number (15 out of 44), mainly representing industry (11), still considered that they would be the same.
- In terms of the effectiveness in reducing pollution, 24 out of 46 respondents considered that effectiveness would be lower. However, again, an important minority (22) indicated that it would be the same or higher. As above, industry representatives where the majority (15) of those that argued that effectiveness would be the same or higher.

[214] In some cases countries ask for exceptions to certain elements. This is the case, e.g., of Japan, who has an exception on UNECE regulations related to the environment (Norman, 2018).

[215] These revisions of the UNECE regulations took place between 2013 and 2020.

[216] While a full comparison between the UNECE and the EU regulations was outside of the scope of this study, it should be noted that no stakeholders identified any areas in the UNECE regulations that should be covered by the EU regulations, or vice-versa.

- Most respondents (23 out of 42) considered that an UNECE route would not have a negative impact on the harmonisation in placing vehicles in the market. This was particularly the case among industry representatives – 17 out of 23 considered that it would be the same and a further three industry stakeholders said that it would be better.
- In terms of the impact on costs, a high number of respondents considered that the cost using the UNECE approach could be the same or lower. In the case of costs to authorities, 23 out of 44 stakeholders indicated that costs would stay the same, and a further 15 indicated that costs would be lower. Fourteen out of 17 authorities indicated that the costs for them would be the same or lower. Concerning the costs to industry, 28 out of 47 stakeholders indicated that costs for industry would be lower, and a further 13 indicated that costs would be the same. Amongst industry representatives, only two considered that their costs would increase
- Twenty-three out of 43 stakeholders indicated that they expect that the competitiveness of the EU automotive industry to stay the same, with only 13 out of 43 expecting it to decrease.

All in all, there appears to be an expectation by a number of stakeholders – particularly among industry - that a global approach would be more effective and efficient. This is not surprising given the global nature of the industry and the fact that, under the current situation, manufacturers have to ensure compliance with different requirements (both in terms of limits, testing requirements and administrative procedures) and face sizeable costs (as presented in Section 5.2). As such, a global approach based on common requirements accepted in all markets should, in theory, bring benefits, at least in terms of the costs for the industry.

To the extent that emission limits adopted would also be the same, this would also have positive impacts in terms of harmonisation and achievement of pollutant emissions, beyond what action only at EU level could achieve. However, the existing evidence also suggests that, at least to this point, agreeing on the same of level of ambition in terms of limits across the UNECE would be much more difficult to achieve and would require significant additional time. Compromises on the level of ambition would most probably be needed to reach an agreement on common global requirement. Furthermore, changes to the testing procedures (such as those introduced based on RDE) would require much more time to agree and to put in place (especially given the cost implications in terms of testing required). As pointed by a number of stakeholders, (including a national authority, a technical service and a fuel research organisation) it is difficult to see how ensuring global harmonisation would not bring a lower level of ambition compared to the Euro standards.

Concluding, the input from stakeholders shows that there is some scepticism – particularly among industry representatives – of the added value of action at EU level in comparison to the action under the auspices of the UNECE. This is a reflection of the strong role and influence that the EU has over the UNECE's regulatory agenda that could be seen as largely replicating the EU approach in terms of emission legislation at the international scale, albeit at a rather slower pace. Combined with an expectation of lower costs for industry than those associated with the Euro 6/VI standards (which would have to be confirmed in assessment of the costs and benefits of both interventions), an important share of industry representatives did not recognise a clear EU added value. However, it is difficult to see how such a harmonisation (assuming it can be achieved) will not also require compromise in terms of the level of ambition (and thus the impacts of the standards) and take place at a slower speed. Furthermore, while industry representatives rather unexpectedly suggest a global approach, most other stakeholders still consider that EU action has brought greater benefits in terms of reducing pollution.

5.5.1.5 *Conclusions*

The assessment of EU added value compared what could be achieved with intervention at national or international (i.e. UNECE) level compared to the EU action. This section also analysed the continuous need to address this issue of pollutants emission with harmonised intervention at EU level, taking into account the needs of the internal market.

Regarding action at national level:

- There is clear added value taken at EU level. While MS would be expected to act to reduce emissions (either alone or coordinated between groups of MS), it is not likely that a harmonised approach to reduce emissions would exist. This fragmented approach would reduce the effectiveness of the intervention, with a lower reduction of pollutants.
- At the same time, costs would increase for both industry and authorities, and the industry would face less regulatory certainty, which would impact its competitiveness. A majority in all groups of stakeholders agreed with these conclusions.

Regarding action at international level:

- If action where to happen at international level, it is expected that the process would be slower and less effective in terms of reducing vehicle-related emissions, as there would be a need to agree in a lower common denominator in terms of emissions. This shows the clear added value of the EU intervention. The majority of stakeholders agree with this view, indicating that EU action would be more effective in terms of reducing pollution.
- There is, however, scepticism among some stakeholders of the added value of action at EU level in comparison to the action at international level under UNECE. This is particularly the case of industry stakeholders, with some indicating a preference for a single "global" standard that could allow them to achieve greater economies of scale and ensure greater level of harmonisation.
- There is no cost-benefit assessment comparing the Euro standards to eventual UNECE standards, so it is not possible to ascertain that this assessment would materialise. However, notwithstanding the strong role of the EU in the UNECE, it is still reasonable to expect that such a process would be slower and less effective in terms of reducing vehicle-related emissions, as there would be a need to agree in a lower common denominator in terms of emissions.

Finally, in terms of the needs of the internal market:

- The cross-border nature or road transport and air pollution indicates a clear need for EU intervention. This allows for the correct functioning of the EU internal market, while respecting the principle of subsidiarity.
- As discussed, without such intervention, it is likely that a MS-based intervention would result in a fragmented approach to the problem, which would lead to a reduced effectiveness vis a vis the results presented in the analysis in the relevant section on effectiveness (section 5.1).
- This shows the EU intervention clearly addresses the need of the EU internal market, and there is added value in such an intervention.
- Furthermore, no evidence or other indication was found that the need to avoid fragmentation of the internal market in terms of setting emission standards no longer require a harmonised approach as addressed by Euro 6/VI.

6. Conclusions

This section presents the overall initial conclusions of the study. In each case, the main research findings on which the conclusions are based are summarised, which provides the link back to the evidence presented in the main body of the report.

6.1. Effectiveness

The analysis on effectiveness examined the extent to which the Euro 6/VI standards achieved their objectives, the role of the existing testing procedures and the factors that influenced their performance. We also considered the impacts of the standards in terms of vehicle prices, innovation and competitiveness of the automotive industry and their contributions to other legislation.

The Euro 6/VI standards have had an overall positive contribution towards making vehicles cleaner by leading to significant reductions in emissions of key regulated air pollutants, albeit with ongoing limitations.

- In the case of **Euro 6**, the available evidence points to reductions in the levels of NOx emissions from new Light Duty Vehicles (LDVs) both in the initial stages (Euro 6b/c) as well as since the adoption of more demanding Real-Driving Emissions (RDE) testing procedures (Euro 6d-Temp and Euro 6d). More specifically:
- The available data from the literature and emission factors, point to a 51% reduction in real world NOx emissions per vehicle for the initial version Euro 6 vehicles (Euro 6b/c) prior to the introduction of the RDE testing procedures. This is in comparison to 56% reduction in the emission limit values between Euro 5 and Euro 6. I Euro 6d-Temp and Euro 6d vehicles (i.e. vehicles after the introduction of RDE testing) achieved further levels of reduction, with real-world emission factors dropping by 92% compared to Euro 5.
- There are also similarly sizeable reductions of other pollutants on the basis of currently available emission factors. In relation to CO they reduced by 30% between Euro 5 and Euro 6d for compression ignition (CI) passenger cars and in the case of particles they reduced by 19% for CI passenger cars[217] and 10% for positive ignition (PI) passenger cars[218]. In addition, emissions of exhaust particles only have reduced by 86% for PI passenger cars. PI passenger cars also see large reductions in THC (62%) and NHMC (61%). All other regulated pollutants emission factors also reduced from Euro 5 to Euro 6d emissions.
- As such, we can conclude that Euro 6d-Temp and Euro 6d vehicles are significantly cleaner than Euro 5 vehicles.
- However, as they were only recently introduced in the market they still represent a small share of the total fleet (e.g. at the end of 2019, only 7.1% of the overall light-duty vehicle fleet in Germany complied with the Euro 6d-temp and 6d standards).

[217] Refers to all Internal combustion engines that can be fuelled by diesel fuel or biodiesel. It also refers to all types of hybrid diesel vehicles including plug-in hybrid.

[218] Refers to all Internal combustion engines that can be fuelled by gasoline fuel, gasoline fuel blended with oxygenates including methanol and/or ethanol, liquid petroleum gas or compressed natural gas. It also refers to all types of hybrid petrol vehicles including plug-in hybrid.

As a result, the net impact on total pollutant emissions – and on air quality - from Euro 6 vehicles has, so far, been relatively limited. Thus, a more sizeable reduction in emissions is expected in coming years with the gradual increase in the share of Euro 6 RDE vehicles (78.1% reduction of NOx in the 2021-2050 period).

An important part of the reduction in emissions is due to the improvements in testing procedures:

- The introduction of the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) played a positive role by introducing a more representative driving cycle.
- The main contributor was the introduction of the RDE testing during type approval that defined a broad range of boundary conditions that cover normal driving conditions and accounted for differences in level of emissions under a broad range of driving conditions, including different ambient temperatures and different altitudes and included cold-start emissions.
- Within the boundary conditions set, the available evidence from various studies shows that RDE testing has led to very significant reductions in real-world emissions of NOx, CO and PN and ensured that real world emissions are in line with the emission limits.
- In-service conformity (ISC) requirements and market surveillance have also helped ensure that, at least within the context set by the RDE boundary conditions, use of defeat devices that deactivate emissions control equipment in the real world are not applied. TAAs are now responsible for re-testing through in-service conformity checks instead of relying on technical reporting by manufacturers. In the latest changes to the testing provisions that only recently came into force (RDE 4th package), the Regulation further expands the effectiveness by including surveillance on in-use vehicle fleet by type approval authorities and other accredited independent laboratories. However, this only applies to vehicles up to 100,000000 km, which excludes an important part of the in-use fleet.

Having said that, problematic aspects of the Euro 6 standards that limit their effectiveness were also identified.

- The most important one concerns the absence of provisions in relation to driving conditions outside the RDE testing boundaries. The analysis shows that some level of emissions under real-world emissions still remains unaccounted for. RDE test boundaries exclude short trips, high mileage and high-altitude use, extensive stop-and-go driving during traffic jams, high or low accelerations and severe temperature conditions for LDVs. These operating conditions represent a small proportion of vehicle operations overall, but they include scenarios that are not that uncommon and that have been found to be associated with emission levels well above the limits. Furthermore, while the vehicle can be tested with a high payload, devices affecting the aerodynamics (including roof and rear mounted equipment and trailers, except for PEMS installation) are not included within RDE testing but can lead to higher level of emissions. As a result, while the RDE boundary conditions effectively capture the normal condition of use that still miss a part of total emissions produced by vehicles during untypical driving conditions. Defeat devices may still be possible to be used and not be identified outside the boundaries conditions set in the RDE test methodology. However, as the window outside the testing boundary conditions is smaller than in the past there is also reduced incentive in using them.

In the case of Euro VI for Heavy Duty Vehicles (HDVs), the analysis points to similar positive impacts in terms of the reductions in pollutant emissions from Euro VI buses and lorries.

- The available data from the literature and emission factors, point to a level of reduction in real-world NOx emission factors of around 72% between Euro V and Euro VI vehicles. This translated into actual savings in NOx emissions in 2020 for the whole vehicle fleet of around 52% in comparison to a Euro V baseline.
- There are also similarly sizeable reductions in the pollutant emissions from HDVs as reflected in the changes to the emission factors. In relation to particles, exhaust emission factors reduced 90% between Euro V and Euro VI while CO emission factors have also largely decreased by the same level. There were also significant reductions for THCs (around 23.45%), CH_4 (20.5%) and NMHC (283%). In contrast, NH_3 emissions increased by 45.7%.
- Overall, we conclude that Euro VI vehicles are significantly cleaner than Euro V vehicles. At the same time, as Euro VI vehicles already represent a significant share of the total fleet (17.3% at the end of 2018), the analysis of the impacts on total fleet-wide emissions also suggests overall sizeable reductions.

Having said that, the analysis also points to ongoing limitations of the existing testing procedures for Euro VI which mean that they can lead to misleading conclusions in terms of the actual level of emissions generated under normal conditions of use:

- The engine cycles (World Harmonized Transient Cycle (WHTC) and World Harmonized Stationary Cycle (WHSC)) coverage remains insufficient and the potential for optimisation of a vehicle's engine to the test remains. Similarly, the elimination of the "moving average window" results at less than 10% power from the PEMS test results can exclude significant real-world emissions generating scenarios from regulation. The applicable tests' boundaries exclude emissions measured at low loads, low speeds and during engine idling - i.e. the conditions that buses are mostly operating under in the real world. As such, the existing tests may not properly capture the emission levels in urban areas, or for the full range of HDV use, being more representative of medium-long haul trucks. Even with the recent changes to the power threshold from 20% to 10%, a significant proportion of pollutant emissions are not accounted for by the test procedures.
- In addition, the regulations allow for the deactivation of emissions under specific conditions to protect the engine or aftertreatment system from damage . Although the conditions limit the occasions on which such deactivation of emissions controls can occur, the allowance is also used to justify unnecessary deactivations.
- These limitations are compounded by the fact that tampering is still possible, allowing some vehicle operators to disable aftertreatment systems on heavy duty vehicles. Unlike LDV, no third-party verification is included in the legislation and ISC for HDV is undertaken by manufacturers. Hence, it is possible that manufacturers may not pay appropriate attention to the security of their systems and may, unintentionally, allow for tampering and hacking to occur. Further to that, existing on-board diagnostic (OBD) requirements do not appear to be robust enough to ensure that it is not possible to manipulate and to ensure detection of degradation or failure of emission control systems under all circumstances. This is because the OBD threshold is not set sufficiently low to ensure that all faults are detected. For HDVs, OBD limits for CO, NOx and PN are even higher than the Euro VI emission limits. Furthermore, it seems that the signals on which the OBD is based, can be

tampered with. This results in a lack of monitoring of missing or damaged particle filters, increasing the risk that diesel particulate filters (DPFs) and gasoline particulate filters (GPFs) are illegally removed for cost saving by the user.

- As in the case of Euro 6, durability provisions appear to be not effective when it comes to capturing vehicles' real-world emissions over their useful lifetimes. Current durability provisions under Euro VI currently cover around 60% of the average lifetime of heavy-duty vehicles (in terms of age and mileage) and this share could be further reduced in the future if trends for an increased lifetime continue.

The standards appear to have largely achieved the objective of ensuring the effective functioning of the Single market. Nonetheless, there are still limitations.

- It is generally recognised among stakeholders that both Euro 6/VI regulations have a positive role in terms of ensuring a harmonised approach in terms of access to the market for vehicle manufacturers.
- However, there are still outstanding distortions in the market due to discrepancies in testing procedures followed, variations in technical expertise and resources available to type approval authorities leaving room for different interpretation of the requirements.
- "Room for interpretation" is driven by inconsistent interpretation of the term "illegal defeat device", through different European TAAs, lack of clarity over the right to disable emission control devices to protect components , ongoing financial relationships between TAAs and manufacturers and the fact that the current type-approval procedure does not prevent manufacturers from requesting approval from a different Authority if its request has initially been rejected. This leads manufacturers to select the authority with the least stringent interpretation of existing rules. As a result, the market is not yet fully harmonised.

The initial Euro 6/VI Regulations provided sufficient lead time to the industry, but the subsequent introduction of new testing requirements has been more challenging:

- The notification timeframes provided by the EU standards (seven and four years for Euro 6 and Euro VI respectively) provided sufficient time for industry to develop the relevant technologies in advance of the legal compliance dates for the initial phases of the standards. The type of technology developments necessary to ensure compliance with the new emission limits typically require two-three years of lead time.
- The picture was different in the case of the introduction of the RDE testing regime. While also introduced in stages, it brought effective changes to the real performance of vehicles within a shorter period of time (2016-2019). However, from the point of view of the industry this meant that there was not sufficient lead time provided in view of the significant changes required, a point made by the majority of industry representatives (including OEMs and suppliers). It has been linked with substantial additional effort within a very short period of time. Nonetheless, given the seriousness of the situation with respect to the dieselgate scandal and the huge impact this had on consumer confidence in the automotive industry, it could be argued that the additional efforts required by the industry at short notice were proportionate to the nature and scale of the problem.
- The complexity of the legal framework appears to have a negative impact on its effectiveness:

- The current legal framework is particularly complex, characterised by a very large legal text with references to a large number of supporting legislation (including UNECE Regulations). It has been the result of a gradual evolutionary process with multiple additions and changes introduced without changes to the overall structure.
- Besides the implications to the costs of compliance (discussed below), this complexity makes both compliance with and enforcement of the legal framework challenging. It also provides room for different interpretations that can limit the effectiveness of the measures.
- Other factors that have had negative impacts on achieving the objectives of the Euro 6/VI standards include: an incomplete coverage of regulated pollutants, important ties between type-approval authorities and manufacturers, durability provisions, the uniform use of conformity factors, the presence of separate regulatory frameworks for cars and vans, the absence of separate regulatory frameworks for lorries/buses and the gradual phase-in of the standards. More specifically:
- Durability provisions currently only cover a proportion (approximately 50%) of the average lifetime of vehicles (in terms of age and mileage) and this share could be further reduced in the future if the trend for an increased lifetime is confirmed. Thus, the durability provisions appear to be not effective when it comes to capturing vehicles' real-world emissions over their useful lifetime.
- Introduced to account for potential measurement uncertainties and emissions in "worst case conditions", conformity factors used up to now (the 2.1 for Euro 6d-Temp and 1.43 for Euro 6d) may have allowed additional emissions that may not be fully justified by the PEMS (Portable Emissions Measurement System) measurement uncertainties. To the extent that such conformity factors continue in the future they can have a negative effect on the effectiveness of the standards.
- The presence of different implementation dates for vans may have a negative impact on the stringency of the standards for these vehicles, even though they are likely to be more polluting given the likely driving conditions in which they are used (lower speed, more urban driving and more stop-start than cars) and the additional power required in comparison to cars due to their loads.
- The current standard testing procedures for heavy-duty vehicles – including the NTE and PEMS tests – reflect medium and long distance truck operation better than urban delivery and bus applications. the latter are frequently operating under engine idling conditions, or at low speed / low engine load levels and consequently typically operate with at lower engine temperatures than the former. Thus, the current testing approach ignores a large proportion of the emissions from buses and urban delivery trucks because these operating conditions are not accounted for.

The evaluation also examined the impacts of the Euro 6/VI standards on the EU automotive market and EU industry's competitiveness, focusing on the impact on innovation, the capacity to compete in other markets and the impacts on profitability.

The available evidence suggests that the introduction of Euro 6/VI standards and new testing requirements have had a positive role in the development of innovation:

- Euro 6/IV standards have been relevant to foster the development and, even more so, the market uptake of aftertreatment control technologies in a number of areas. Technologies like Selective Catalytic Reduction (SCR), which was first used for many HDV from Euro V and a handful of high-end LDV at Euro 5, has seen further R&D activity leading to more effective and lower-cost and widespread adoption. In other cases, (e.g. Gasoline Particulate Filters for Gasoline Direct Injection engines), the introduction of PN limits is directly credited with bringing the specific technology to the market. In parallel, while not the only driver of such developments, improvements in engine design, in-cylinder control technologies and engine management systems can be linked with the Euro standards while also improving performance, fuel efficiency and reducing CO_2 emissions.

- In that respect, the adoption of RDE testing as part of Euro 6 was much more important to incentivise innovation in relation to most of the above technologies than the changes to the emission limit values. This is a common view of most stakeholders, and it is also evident by the evolution of the technologies fitted in the most recent Euro 6d-Temp and Euro 6d vehicles.
- Whether in reference to new or existing emission control technologies, the adoption of the standards was clearly relevant in terms of technology adoption by vehicle manufacturers. Voluntary adoption of emission control technologies, in the absence of these standards, was highly unlikely to have happened as technology is costly and the perceived value of improved pollutant emissions performance by customers is limited.
- There is limited evidence on the specific role that available support mechanisms (e.g. R&D funding) have played to support OEMs and suppliers in the development of innovation. The input available suggest relevant mechanisms have been in place (e.g. through Horizon 2020, investment support from the EIB at EU level together with national support scheme) and have been more utilised by industry (some more than others). However, this is a global trend and has not only affected EU manufacturers. Moreover, EU OEMs share of total world motor vehicle production remained similar between 2014 and 2019
- The impact on the international competitiveness of the sector is a result of the combined impact on profitability, innovative capacity and market access. Put together, we conclude that the impact of the implementation of the Euro 6/VI standards was positive but limited. Most probably they have not had a negative impact on competitiveness and that they may have even helped to ensure that they are in the forefront when it comes to the adoption of emission control technologies. More specifically: There is clear evidence that the standards led to an increase in production costs that has probably had a small negative impact on the profitability of the automotive sector as a whole (i.e. costs incurred to ensure compliance, enforcement/monitoring, administrative costs). However, as manufacturers are generally expected to pass costs to consumers, any such impact should be limited. Furthermore, given that the requirements (and the associated costs) apply to all vehicle manufacturers that place vehicles in the EU market, impacts on profit margins should not put EU OEMs at a disadvantage. Still, indirectly EU OEMs may be at a disadvantage as a result of the higher labour and other indirect costs when compared to competitors in lower cost countries. As such, the higher regulatory costs arising from Euro 6/VI legislation may have had a small and indirect negative effect on the profitability of some EU manufacturers.
- While this varies depending on the specific pollutant under consideration, the role the Euro 6/VI standards has mainly been towards that the adoption of existing technologies and ensuring that manufacturers do not fall behind third country competitors. It had less of a role in the adoption of new breakthrough technologies which could provide an early technological advantage vis a vis their competitors based in other regions.

- It is difficult to tell if there is a direct impact from the adoption of Euro 6/VI standards in terms of international market access and, if so, how significant it is. This depends on the stringency of the requirements vis a vis those in other markets – which is high when considering the combination of limit values and testing procedures – but also on the extent that EU based manufacturers rely on sales in the EU (still more than 75%) and the extent of local production of vehicles sold in other markets (generally high). Overall, we conclude that the Euro 6/VI standards have probably had a positive but limited role in terms in supporting access to other markets.
- Finally, the adoption of the standards is linked to a sizeable level of investment in R&D activity to support the adoption and further development of the technologies which may provide a competitive advantage. However, given that the EU standards are no longer to be in the forefront (at least in terms of the limits set), it is probably the case that their supportive role has been primarily to support the adoption of existing technologies and had less of a role in the adoption of new breakthrough technologies, hence not providing any early technological advantage.

The Euro 6/VI standards have a positive **contribution towards the objectives of other legislation** in some cases, and a negative contribution on others.

- The reduction in emissions achieved also contributed to reducing the level of key pollutants (CO, NOx, PM) regulated under the National Emissions Ceilings Directive (NECD, Directive 2001/81/EC) and, to a certain extent, towards the achievement of Member States' air quality targets under the Ambient Air Quality Directive (Directive 2008/50/EC).
- However, while the absolute level of emissions from transport reduced (as already indicated), the relative contribution of the road transport sector to overall pollution at EU-level remained the same due to a yearly increase in activity. The road transport sector has still contributed to around 40% of all NOx emissions, 12% of PM2.5 emissions, 19% of CO emissions, 1% of NH3 emissions and 10% of NMVOC emissions every year since 2014 (EEA, 2019c).
- According to our analysis based on COPERT model and EEA data, if the savings of Euro 6/VI are realised, we expect that Euro 6/VI would contribute to at least 49.6% savings on the total level of NOx emissions from all industries by 2050.A small increase in NH3 emissions from CI LDVs may be a possible side effect of the technologies used to limit NOx emissions, at a time when no NH_3 emission limit exists for LDVs in the Regulation. Recent studies point to the fact that NH_3 emissions are produced by LNT during regeneration and cold starts, and by SCR, both causing "ammonia slip" (ICCT, 2019c). The use of ammonia slip catalysts (ASC) has increased in more recent Euro 6d diesel vehicles (see Section 3.5.2) to mitigate this and emission factors suggest that the average level of emissions has remained stable since Euro 6 a/b/c, while remaining higher than Euro 5 vehicles. In turn, NH_3 emissions from PI LDVs have slightly reduced.
- We have found no evidence to suggest that that Euro 6/VI has led to an increase of CO_2 emissions. There is potential impact on CO_2 emissions from the choice of specific emission control technologies which increase the backpressure required for filtration or SCR units, but these are rather the result of technology choices by OEMs and it is not necessarily caused by Euro 6/VI as the technology to improve CO_2 emissions and NOx emissions exists.

Finally, we find no evidence of sizeable impact on employment as well as in the terms of increasing awareness of air pollution issues.

- There are no indications of a significant impact – positive or negative – on the levels of employment that can be directly associated with the introduction of Euro 6/VI. A positive impact on employment can be expected linked to the increased R&D activity by OEMs for the development of new or updated technologies and for suppliers specialising in pollution control technologies as a result of the increased demand for such technologies. In addition, there has also been a demand for additional human resources in the relevant regulatory/homologation departments in response to the more demanding testing and type approval procedures introduced, particularly following the adoption of RDE.
- Finally, Euro 6 standards appear to have had a limited contribution towards raising awareness of vehicle-related air pollution and influencing public attitudes. Whilst society seems to be more aware of air pollution issues and the role of vehicles in creating these issues, this is mainly the result of other events/trends (such as the dieselgate scandal, the growing use of Low Emission Zones (LEZs) in cities, fiscal taxes and benefits). There is still an indirect link with the Euro 6/VI standards as these are used to determine access to fiscal incentives or access to LEZs. Still, it is probably the case that consumers associate the adoption of these instruments – rather than the Euro 6 standard itself – with any impact on air pollution.

6.2. Efficiency

The analysis of the efficiency of the Euro 6/VI standards assessed the total regulatory costs of the legislation and compared them with the respective benefits to society arising from the reduction of pollutant emissions. It has been based on input from stakeholders combined with other relevant information collected over the duration of the study and the use of the internal expertise of the CLOVE consortium. In our quantification we considered the marginal costs incurred up to now but also the marginal costs expected to be incurred up to 2050 in comparison to a Euro 5/V baseline out to 2050, by which time all ICE light duty vehicles in the fleet are expected to be Euro 6d vehicles. Given the small number of responses provided by OEMs, the analysis of the costs presented is provisional.

The following points summarise the main findings of the analysis in relation to the key evaluation questions.

Sizeable impact on regulatory costs, with increase in all cost elements

- Overall, the introduction of Euro 6 and Euro VI has led to significant additional regulatory costs for industry. The total costs have been estimated in the range of €30.6-76.0 billion over the period 2013-2020, €21.1billion-€55.6billion linked to the introduction of Euro 6 and €9.5billion-€20.4 billion linked to Euro VI.
- While sizeable, the total costs represent a very small share of the industry turnover, estimated to be no more than 2% of the total turnover of the sector. Furthermore, it is generally expected that OEMs would eventually pass-through most of the costs to consumers.
- For the total period up to 2050, net compliance costs for Euro 6 are estimated in the range of €80.6 billion to €186.6 billion (discounted to 2013 base year with a social discount rate of 4%). The respective costs for Euro VI are estimated at €16.0 billion-€35.0 billion.
- The cost estimates are comparable to the cost per vehicle estimates provided in the two IA support studies (€265/vehicle for CI LDVs and range of €3,169 and €5,004

per vehicle for HDVs; no estimate for PI engines)[219]. We note that the IA studies for Euro 6 did not consider costs for additional technologies introduced as a result of the introduction of RDE testing or the increase in the non-hardware costs.

- Considering the specific cost drivers, hardware costs (i.e. costs of technology installed in the new vehicles) represent the most important part of these costs. The weighted average of the costs for the whole period were estimated in the range of €36-€59 per vehicle for PI engines and €307-€801 per vehicle for CI engines and 1,556-€3,635 per vehicle for HDVs. However, this cost increased over time for LDVs as a result of the introduction of Euro 6 RDE. Thus, the costs of hardware installed in the most recent Euro 6d vehicles is estimated at €402-€465 for PI and €751-€1,703 for CI vehicles.
- As expected, total costs for compliance for diesel LDVs have been more significant up to now. However, Euro 6d requirements introduce additional costs for most PI vehicles. As a result, in the coming period, costs for compliance for PI (mainly petrol) vehicles should be expected to represent a higher share of the total costs for Euro 6 vehicles.
- The analysis also points to sizeable R&D and testing costs. Overall, the estimated non-hardware costs per vehicle represent 23%-27% of total costs for LDVs and 54%-58% for HDVs. We note that the current estimates of the R&D costs for HDVs based on input from OEMs are considered as high and possibly overstating the actual costs associated with the Euro VI. As such, it is possible that the actual share of non-hardware costs was smaller, along the lines of the respective costs for LDVs. Even if the case of these possibly overstated R&D costs, the total R&D expenditure (€8.5b-€21.3 bn was a relatively small share of the total R&D expenditure of the motor vehicles sector (NACE 29.1), 3.4%-8.5% of the total of ca. €250 billion over the same period (Eurostat).
- Other cost elements related to enforcement, fees and administrative costs represent a smaller amount for both Euro 6 (4-5% of the total) and Euro VI (1%). The only exception are the costs for Euro 6 PI , since there was no need for new technologies in the initial stages, the overall share of the other costs elements was higher (19%).
- Input from equipment suppliers suggests that most of them incurred additional costs for new product development and testing of new equipment. Those that were involved in type approval activity also incurred relevant certification costs. However, it is largely the case that costs for suppliers are eventually covered by vehicle manufacturers, mainly through the cost of hardware fitted to vehicles.
- Type approval authorities also incurred certain one-off costs to authorities. They included investment in new facilities and equipment (in a few cases) as well as preparatory action taken in the form of training, development of guidance documents or other system updates. They also included the costs of some additional expert personnel to cover the increased time needed for witnessing the various tests and the increase demand for type approvals. However, their costs are also expected to be largely covered by vehicle manufacturers.
- Concerning the impact on consumers, it is generally expected that eventually any increase in regulatory costs will be passed through in the form of higher prices. In

[219] 2020 values.

that respect, the analysis suggests that in most cases the estimated regulatory costs are in the range of 1%-3%. The exception is for small size Euro 6d-diesel vehicles where costs as high 6% of the average vehicle price vehicles can be expected. However, there is no evidence of such and increase to vehicle prices and it is expected that OEMs distribute these costs across all vehicle categories.

- The analysis so far suggests that the main area where unnecessary costs may have arisen concern the practical aspects (i.e. timetable) of the introduction of the requirement of the various testing requirements under Euro 6d-Temp and Euro 6d. This is reported to have led to duplication of effort among OEMs and extra regulatory costs that could have been avoided.

Positive overall cost-effectiveness of the standards

- The analysis of the costs has been compared against the monetised benefits arising from the emission reductions. The comparison is based on examining the Net Present Values (NPVs) for both the costs and monetised benefits it has considered the whole period up to 2050 at which point all vehicles ICE vehicles are expected to be Euro 6d in order to properly capture the benefits arising from the standards.
- Considering the overall cost-effectiveness of the legislation, the analysis points to the overall high benefit to cost ratio for both Euro 6 and even more so for Euro VI standards when assessed against the expected monetised benefits to the society from the reduced emissions and resulting environmental and health impacts. This is a point that is supported by the large majority of stakeholders that consider that the costs are justified by the benefits achieved.
- The ratio of net monetised benefits for the period up to 2050 against the expected net costs (in PV values) is in the range of 2.0-4.7 for Euro 6 depending on the cost scenario assumed. Compared against Euro 6 pre-RDE the ratio is smaller (1.6-3.1) reflecting the higher costs for compliance with Euro 6-RDE.
- Focusing on the CI (diesel) LDVs only, the ratio is higher (2.5-5.9 against Euro 5 and 2.5-4.7 against Euro 6 pre-RDE). In the case of PI engines the small emission savings (mainly in relation to PM) lead to overall costs that are higher than the respective benefits (negative overall net present value). However, as the analysis does not capture the health and environmental benefits resulting from the adoption of PN limits for petrol GDI engines (while it does include the associated costs of the introduction of these technologies) it underestimates the benefit/cost ratio. An earlier analysis on the expected effectiveness of the specific measure (introduction of GPF) suggested that the costs per vehicle would be relatively similar to the benefits. As such, the inclusion of the impacts on PN should be expected to lead to a positive NPV and a benefit-to-cost ratio higher than one.
- In the case of Euro VI, the analysis also points to a clearly positive benefit/cost ratio (15.0-32.8).
- Considering that the current cost estimates are uncertain and, most probably, overestimate some of the regulatory costs, the above figures are also expected to be an underestimate of the actual benefit/cost ratio.

Need for simplification to reduce some of the costs

- While being overall cost-effective, the legislation did not bring a simplification to the legal framework. Rather on the contrary, the legal framework for both LDVs and HDVs has become more complicated. In relative terms, Euro VI legislation is less complex than Euro 6, notwithstanding the changes to some of the testing requirements moving from Euro VI-A to Euro VI-E. .

- The complexity of the legal framework has mainly increased as a result of the new and more demanding testing requirements and the multiple phases of implementation (stages) with different dates for the introduction of various tests. These have been largely introduced on an add-on basis without any changes to the structure of the legislation, with increasing number of references to other pieces of legislation (UNECE) and without clear overview. Such level of complexity has contributed to increased enforcement and administrative costs. However, while not desirable, such complexity could be seen as partly justified in view of the need to ensure that vehicles are clean on the basis of more demanding and rigorous testing and in-service conformity requirements.

6.3. Relevance

In general, the overall objectives to take action in terms of introducing more stringent emissions standards to reduce pollutants emitted by the road transport sector and improve air quality (and reduce associated health impacts) appears to remain very relevant. However, the analysis also suggests that certain non-regulated pollutants of concern today were not included in the past for various reasons.

Overall, on the basis of the analysis we conclude that:

- Air quality issues associated to road transport remain a persistent issue in European urban areas and recent research suggests strong associations of air pollution with health effects even at low concentration levels, with no observable thresholds.
- The European Green Deal introduces a “zero-pollution ambition” and states that “transport should become drastically less polluting“. The increased climate ambition of the 2030 Climate Target Plan is expected to facilitate the decrease of pollution levels from road transport with a higher uptake of zero emission vehicles. While the increased uptake of electric vehicles and other traction options with zero tailpipe emissions will contribute to the Green Deal ambition, this also creates a need for more stringent air pollutant emissions standards for combustion-engine vehicles. ICEs (as pure ICEs or in hybrid forms) will still represent a significant part of the fleet in the coming decades, especially for HGVs, and reducing their overall impact on air pollution will still be necessary.
- In that respect, emission standards are a relevant mechanism to encourage a reduction in vehicle emissions that could offset potential demand increases. Air pollution is an externality not captured in the economic incentives of vehicle producers or vehicle buyers. Due to this market failure, without standards forcing the adoption of new technologies there are simply no incentives for the development and deployment of emission control technologies, and it would not be possible to achieve significant reductions in emissions of air pollutants.

However, aftertreatment systems introduced under the Euro 6/VI standards and trends in the use of fuels increasingly induce pollutant species that are not specifically regulated under current Euro 6/VI standards while posing air quality and health issues. In particular:

- Ammonia (NH_3) emissions, which are not regulated for LDV, increase with the technology (urea-based SCR systems or lean-NO_x traps) used to comply with Euro 6 (and Euro VI) for diesel vehicles and have a significant role in the formation of secondary particles, increasing $PM_{2.5}$. This effect has been mitigated in more recent

Euro 6d CI vehicles with the increased use of ammonia slip catalysts. However, particularly high NH_3 emissions have been observed on PI cars equipped with three-way catalysts, which appears to be the main outstanding issue.

- Formaldehyde (HCHO) emissions may increase with the potential increase of ethanol content in gasoline blends. Formaldehyde is harmful for human health (e.g. carcinogenic) and to the environment (ground-level ozone) already at low concentrations and thus the THC/NMOG limit is not regarded as sufficient for limiting formaldehyde.
- The standard sets limits on total NO_x emissions (comprising NO and NO_2) but does not include a separate limit for directly emitted NO_2, which is the most toxic component of total NO_x emissions. Aftertreatment systems that are used to comply with the Euro 6/VI standards may lead to an increase in the share of NO_2 in total NO_x emissions. However, this effect seems to have been mitigated in the later stages of Euro 6/VI.
- In addition, new measurement methodologies are being developed to help monitor and control nanoparticles (smaller than 23 nm) and brake wear particles. Given their important health impacts, such developments would lead to questions on whether these components should be excluded from the emissions standards for light and heavy-duty vehicles.
- The improvements in tailpipe emissions control mean that evaporative emissions represent an increasing share of VOC emitted from LDVs and HDVs. The existing requirements, while expected to bring certain improvements, do not appear to be sufficient to capture the expected increase in VOC as a result of the increasing frequency of high temperature and the increase in ethanol content.
- The evaluation also finds that increasingly complex emission control technologies require a more complete demonstration of durability. In this sense, new technologies in the field of on-board monitoring introduce the possible need for a more comprehensive monitoring approach provisions that will be better placed to capture the increasing complexity of the emission control systems.
- All in all, the analysis suggests that current Euro 6/VI standards can only partly contribute to the decrease in pollutant emissions emerging from road transport that is required for the move towards zero-pollution in Europe and the protection of human health. This limited contribution is driven, amongst others, by the fact that some pollutant species which cause significant health issues are not directly controlled with the current Euro 6/VI standards.

6.4. Coherence

The analysis did not identify significant issues in terms of the internal coherence of the Euro 6/VI standards.

- Despite the complexity of the legal framework, the analysis concluded that the features of the Euro 6 and Euro VI standards work together sufficiently well. This was a conclusion supported by most stakeholders: 38 out of 48 stakeholders (including 15 out of 23 industry stakeholders) indicated that industry was provided with a coherent framework to work with.

- Nonetheless, some potential inconsistencies are still identified including testing, the lack of fuel and technology neutrality, and differences in applicability for cars and vans.
    - On testing, stakeholders pointed out several aspects (e.g. on instrumentation and error margins) in the testing procedures that they considered to be internal coherence issues within the testing procedures outlined in the Euro standards. No stakeholders indicated that any of these issues represented important inconsistencies or gaps.
    - On the lack of fuel and technology neutrality, there are different requirements for CI and PI vehicles, and between different technologies available for each fuel. For example, that PFI petrol engines have no limits for their PN emissions, in contrast to GDI engines (which have the same PN limit - $6x10^{11}$ #/km – as diesel engines). In Euro 6, CI vehicles also have higher limits for NOx that PI engines. Still, while there might be practical reasons for the lack of neutrality in some specific instances, the fact is that could be indeed considered an internal coherence issue.
    - On the difference in the applicability for cars and vans, passenger cars and vans are treated by the regulations in terms of conformity factors[220] and the different deadlines for compliance with specific testing procedures without an obvious justification for these differences. In practice, this is seen as making the framework more complicated while allowing to pollute more than comparable passenger cars.

The analysis found that Euro 6 standards are consistent with other key legislation (including the vehicle CO_2 standards, Air Quality and National Emission Ceilings Directives on air quality, and vehicle roadworthiness legislation) in terms of the overall objectives of achieving a higher level of environmental protection in the EU. Still, there are some potential inconsistencies with these pieces of legislation in terms of their provisions. More specifically:

- Vehicle CO_2 standards: Because of the use of different masses (RM or TPMLM) to define the testing regime that a vehicle is subjected to, some N2 vehicles with the same TPMLM could be subjected to different testing regimes for their CO_2 emissions, depending on their RM. While this is indeed an inconsistency, there was no indication that this has been particularly problematic for industry.
- AQD/NECD: Different pollutants are covered by the different interventions, leading to lower effectiveness in reducing pollution. Specifically, AQD NO_2 vs automotive regulated NOx, and AQD particles ($PM_{2.5}$) vs automotive regulated “PM”. However, many of the pollutants regulated in the air quality directives are present in such low concentrations in vehicle exhausts that it is reasonable that they are not regulated pollutants under the Euro standards. For some others practicality or cost/benefit considerations have, to date, meant they are not measured. These considerations are being revisited in other Tasks in this study.
- Vehicle roadworthiness legislation: Existing legislation on periodic testing (PTI) and roadside inspections (RSI) do not support compliance with emission limits as set out in the Euro standards. Still, this is likely more derived from the different nature of these interventions, with PTI and RSI based testing not being designed to help in

[220] Class I N1 vehicles (those with a reference mass of 1,305 kg or less) have the same limits as M vehicles (passenger cars). N1 vehicles with higher reference masses (Class II and III) and N2 vehicles have higher limits.

ensuring ongoing compliance with emission limits than, exactly a coherence issue. Also, OBD checks under Euro 6 cannot effectively help when it comes to identify malfunctions and to support the PTI & RSI emissions tests. As more sensors are added to vehicles for emissions control, and checked as part of the vehicles' OBD system, it is likely that OBD checks become more able to support the type approval emissions standards.

6.5. EU added value

The analysis concludes that there is clear added value from the action taken against air pollution from road vehicles at EU level and that action at national or international level would most probably be less effective and more costly.

- The trans-boundary nature of road transport and subsequent air pollution also highlights the need for EU intervention as it creates a level playing field across the Union, ensuring the proper functioning of the internal market.
- In the absence of EU action to deal with vehicle-related pollution, Member States would generally be expected to take action at national level to limit the impact on health from road transport emissions. This would include including setting emission limits for vehicles at national level, promoting vehicles that fulfil stricter emission limits and establishing national compliance regimes. It is unlikely that a harmonised approach in terms of emission limits would apply across Member States. It is more likely that there would be a fragmented approach across the Member States, or perhaps with some Member States working in groups. This could have negative impacts in terms of effectiveness of adoption of stringent emission limits, and would also lead to increased costs of compliance and enforcement for stakeholders. It would also have a negative impact on the proper functioning of the internal market. The majority of stakeholders appear to agree with this analysis indicating that EU action would be more effective in terms of reducing pollution.
- If action where to happen at international level, it is expected that the process would be slower and less effective in terms of reducing vehicle-related emissions, as there would be a need to agree in a lower common denominator in terms of emissions. The majority of stakeholders appear to agree with this view. Still, a few industry stakeholders expressed scepticism with regard to the added value of EU action as opposed to that of UNECE. It was indicated that the option of a global standard could help achieve greater economies of scale (i.e. more efficient with lower costs for industry) and create a more level playing field even outside of the EU. These views would need to be validated by a cost-benefit analysis of UNECE intervention compared to EU action.

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8. Glossary of Terms

ACEA	European automobile manufacturers association
AECC	Association for Emissions Control by Catalyst
AES	Auxiliary emission strategies
AGVES	Advisory Group on Vehicle Emission Standards
AISPEC	Federchimica Chimica da Biomasse Industrial Group
AQD	Air quality directive
ASC	Ammonia slip catalyst
ATCT	Ambient temperature correction test
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CAFE	Clean Air for Europe
CH4	Methane
CI	Compression ignition
CITA	International motor vehicle inspection committee
CNG	Compressed natural gas
CO	Carbon monoxide
CoP	Conformity of Production
DOC	Diesel oxidation catalyst
DPF	Diesel particulate filters
EC	European Commission
EEA	European Economic Area
EGEA	European garage equipment association
EGR	Exhaust gas recirculation
EIB	European Investment Bank
ELR	European Load Response
EOBD	European onboard diagnostics
EPA	United States Environmental Protection Agency

ESC	European Stationary Cycle
ETRMA	European Type and Rubber Manufacturers' Association
EU	European Union
EUPC	European plastic converters
EVAP	Evaporative emissions control system
FQD	Fuel quality directive
GDI	Gasoline direct injection
GHG	Greenhouse Gas(es)
GPF	Gasoline particulate filter
GTAAs	Granting type approval authorities
GTR	Global technical regulation
HBEFA	Handbook Emission Factors for Road Transport
HC	Hydrocarbons
HDV	Heavy duty vehicle
IA	Impact assessment
ICCT	International Council on Clean Transportation
ICE	Internal combustion engine
IIA	Inception Impact Assessment
ISC	In-service Conformity
LDV	Light duty vehicle
LEZ	Low emission zone
LNG	Liquified natural gas
LNT	Lean NOx Trap
M category	Passenger vehicles, including categories M1, M2 and M3
MS	Member States
M1 vehicles	Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat
M2 vehicles	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tonnes

M3 vehicles	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass exceeding 5 tonnes.
MaSA	Market surveillance authorities
MAW	Moving average window
MECA	Manufacturers of Emission Controls Association
MS	Member State
N2	Nitrogen
N category	Goods vehicles, including categories N1, N2 and N3
N1 vehicles	Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tonnes
N2 vehicles	Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes
N3 vehicles	Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 12 tonnes
NECD	National emissions ceiling directive
NEDC	New E driving cycle
NGO	Non-governmental organisation
NH3	Ammonia
NMHC	Non-methane hydrocarbons
NMOG	Non methane organic gases
NMVOCs	Non-methane volatile organic compounds
NOx	Nitrogen oxides
NPV	Net present value
NRMM	Non-Road Mobile Machinery
NTE	Not-to-exceed
O3	Ozone
OBD	On-board diagnostics
OBFCM	On-board Fuel and Energy Consumption Monitor
OCE	Off-cycle emissions
OEM(s)	Original equipment manufacturer(s)
PC	Public Consultation

PEMS	Portable emission measurement system
PFI	Port fuel injection
PHEM	Passenger Car and Heavy Duty Emission
PI	Positive ignition
PM	Particulate matter mass
PN	Particle number
PPP	Purchasing power parity
PTI	Periodic technical inspection
R&D	Research and development
RDE	Real driving emissions
RM	Reference mass
RS	Remote sensing
RSI	Roadside inspection
SCR	Selective catalytic reduction
SCRF	SCR with a soot filter
SDPF	SCR-Catalysed Diesel Particulate Filter
SEMS	Smart emission measurement system
SI	Spark-ignited
SWD	Staff working document
TA	Type approval
TAAEG	Type-approval authorities' expert group
TAAs	Type approval authorities
TFEU	Treaty on the Functioning of the EU
THC	Total hydrocarbons
TMH	Test Mass High (the heaviest vehicle in a family)
TML	Test Mass Low (the lightest vehicle in a family)
TPMLM	Total permissible maximum laden mass
TWC	Three-way catalytic converters
UITP	International Association of Public Transport

ULEZ	Ultra-low emission zone
UNECE	United Nations Economic Commission for Europe
VECTO	Vehicle Energy Consumption Calculation Tool
VOC	Volatile organic compound
WHO	World health organisation
WHSC	Worldwide harmonised stationary cycle
WHTC	World harmonised transient cycle
WLTC	Worldwide harmonised light vehicles test cycle
WLTP	World harmonised light vehicle test procedure
WVTA	Whole vehicle type approval
ZEZ	Zero emission zone

9. Annexes VOLUME 1 (in separate document)

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