Development of the CURED V3A Emissions Model

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Experts in air quality management & assessment

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1 Introduction

1.1 In January 2016, Air Quality Consultants Ltd (AQC) published a review of nitrogen oxides (NOx) emissions from modern diesel vehicles[1] and how these compared with those in Version 4.10 of the European Environment Agency's (EEA's) COPERT[2] model and Version 6.0.2 of Defra's Emissions Factors Toolkit (EFT)[3]. AQC's review showed that NOx emissions from Euro 6 cars were being under-predicted in both COPERT and the EFT. It also suggested that emissions from Euro IV, V, and VI Heavy Duty Vehicles (HDVs) might be under-predicted.

1.2 In order to allow AQC to make robust predictions of future-year NOx and NO_2 concentrations, the Calculator Using Realistic Emissions for Diesels (CURED) (V1A, March 2016) was created. CURED V1A took the emissions functions from the COPERT V4.10 model, as embedded into EFT V6.0.2, and applied uplifts based on the results from real-world emissions tests. The result was that CURED V1A predicted higher future-year NOx emissions (and less year-on-year improvement) than either COPERT V4.10 or EFT V6.0.2.

1.3 In July 2016 AQC issued CURED V2A. This was in response to the EEA publishing COPERT V4.11.0 and Defra incorporating this into EFT V7.0. CURED V2A did not revisit the January 2016 review of real-world emissions and so the overall predictions made using CURED V1A and CURED V2A were very similar.

1.4 Since AQC's January 2016 review[1], the results from further real-world emissions tests have become available (e.g. O'Driscoll *et al*., 2016[4]; Ntziachristos *et al*., 2016[5]; ICCT, 2017[6]). These have supported the approach that CURED V1A and V2A took with respect to Euro 6 diesel cars and vans, but have suggested that the approach to Euro VI HDVs may have been too precautionary, resulting in emissions of these vehicles being over-predicted.

1.5 In September 2016 the EEA published COPERT V5.0, and in December 2017, Defra incorporated this into EFT V8.0.1. COPERT V5.0 takes into account some of the same information that AQC had previously compiled and, as has been shown elsewhere[7], came to much the same conclusions with respect to NOx emissions from the current[8] fleet of Euro 6 diesel cars and vans. As a result, COPERT V5.0 (and thus EFT V8.0.1) predicts very similar NOx emissions as CURED V2A from the current fleet of cars and vans.

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1 http://www.aqconsultants.co.uk/getattachment/Resources/Download-Reports/Emissions-of-Nitrogen-Oxides-from-Modern-Diesel-Vehicles-210116.pdf.aspx

2 Computer Programme to calculate Emissions from Road Transport, developed through the European Environment Agency (EEA). http://emisia.com/products/copert

3 Defra's EFT takes the vehicle-specific emissions functions from the COPERT model and combines them with UK-specific vehicle fleet projections.

4 O'Driscoll, ApSimon, Oxley, Molden, Stettler, and Thiyagarajah. Atmospheric Environment 145 (2016) 81-91

5 Ntziachristos, Papadimitriou, Ligterink, and Hausberger. Atmospheric Environment 141 (2016) 542-551.

6 http://www.theicct.org/nox-europe-hdv-ldv-comparison-jan2017

7 http://www.aqconsultants.co.uk/AQC/media/Reports/Relationship-between-CURED-V2A-and-COPERT-V5_0-July-2017.pdf

8 i.e. those reaching the market prior to 2017.

2 Phased introduction of the Euro 6 Standard

2.1 New cars registered for type approval since 2014 have had to meet the Euro 6 emission standard, which means that diesel cars should emit no more than 80 mg/km of NOx over the official regulatory test drive cycle. Up until 2017, the official regulatory test was based around the New European Drive Cycle (NEDC). This is the same drive cycle that had been used for earlier Euro standards and which has been widely reported as being unrepresentative of real-world driving conditions; thus being implicated in discussions of discrepancies between in-laboratory emissions and those in the real world.

2.2 In 2017, the regulatory test drive cycle changed from the NEDC to the World Light-duty Test Cycle (WLTC), which is a more complex cycle intended to be more representative of real-world driving conditions. 2017 also saw the introduction of 'Real Driving Emissions' (RDE) which involves driving on real roads carrying emissions testing equipment on the vehicle. Up until 2020, the average emissions over the RDE test cycle may be up to 168 mg/km (2.1 x the 80 mg/km standard) and from 2020, these average emissions will need to meet the 80 mg/km standard, albeit with a margin of 50% allowed for measurement uncertainty, i.e. up to 120 mg/km. The three phases of the Euro 6 standard for NOx are often termed "Euro 6a/b" (<2017), "Euro 6c" (2017 – 2020), and "Euro 6d" (>2020).

2.3 An important difference between EFT V8.0.1 and CURED V2A is that EFT V8.0.1 assumes that each subsequent stage of the Euro 6 standard will be associated with lower emissions than the current (Euro 6 a/b) fleet of vehicles, while CURED V2A assumes that all Euro 6 vehicles in the future will be, on average, no better than those that have been tested in the real-world (i.e. that Euro 6c and Euro 6d will be wholly ineffective).

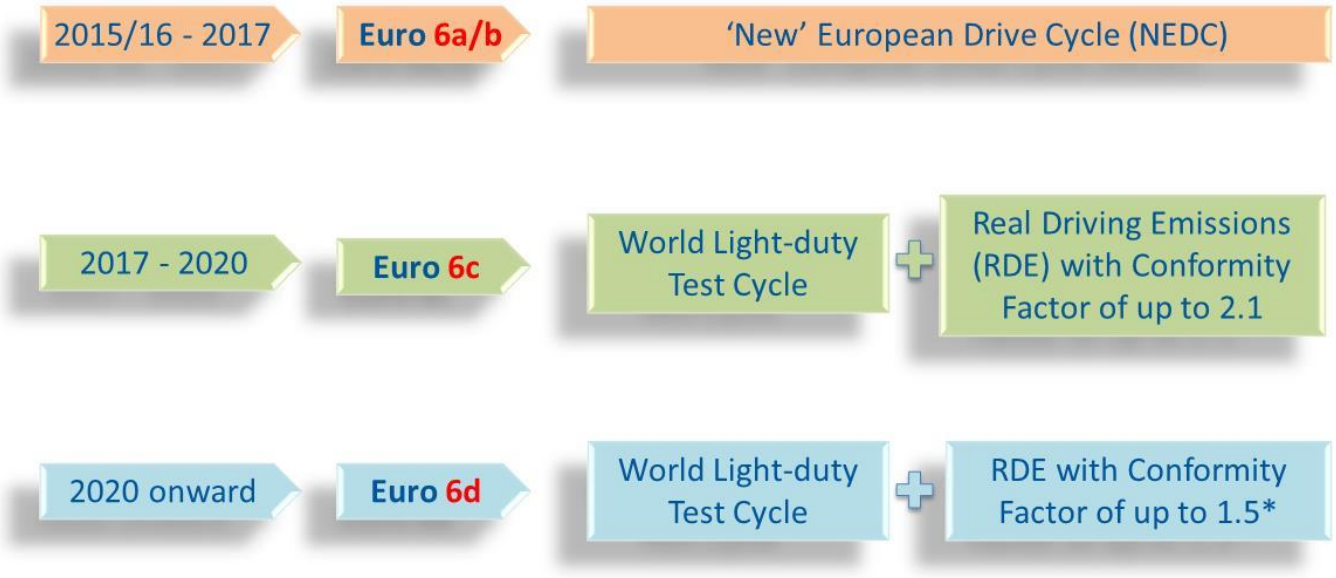

Figure 1: Phasing of Euro 6 Standard for Diesel Cars

* Conformity Factor of 1 with a measurement tolerance of 0.5 to be reviewed yearly

3 Efficacy of Euro 6c and Euro 6d

3.1 It is important to recognise that the Euro standards relate to the average emissions over specified test cycles. This is the case for NEDC, WLTC and RDE. It is not reasonable to expect emissions to remain below the emission standard across all points within a test cycle. This means, for example, that the instantaneous emissions at any time might exceed 80 mg/km without the Euro 6 emission limit being breached (so long as the time-averaged emissions fall below this value).

3.2 Just as is the case with laboratory test cycles, the RDE cycle has specific requirements and it is very common, in the real world, to drive in a way that falls outside of the official RDE cycle. This might be done, for example, by driving in cold (or warm) temperatures, or by idling for longer than is specified in the test. Recent history has shown that vehicles can be configured to meet the requirements of emissions tests, and yet emit much higher NOx levels outside of the test parameters. Concerns thus persist regarding NOx emissions outside of the official test conditions, including the RDE test.

3.3 It is also important to note that, even within a valid RDE test, not all of the emissions data collected are included when calculating the average. This leads to the possibility that a small number of isolated periods with very high emissions might be excluded from the calculation; leaving the highest points on an emissions-time graph effectively unregulated.

3.4 For these reasons, together with an industry-wide scepticism borne from the known failures of the Euro 4 and Euro 5 standards for diesel vehicles, many commentators expect average real-world NOx emissions from Euro 6c and Euro 6d emissions to exceed the emissions standards.

3.5 There are, however, many reasons to be optimistic about the performance of Euro 6c and Euro 6d diesel cars and vans. One reason is the observed performance of Euro VI HDVs in the real world. The type-approval tests for HDVs have always included a requirement for RDE, and this has coincided with a significant observed reduction in NOx emissions when compared with Euro V and Euro IV vehicles. Another reason to be optimistic is the increased public and media interest around this issue. This, coupled with the activities of organisations such as Emissions Analytics who test vehicles in the field and publish the results, means that it is likely to soon become public knowledge if manufacturers produce poorly-performing vehicles. It is likely that many buyers will take this into account in their purchasing decisions. Thus, even if Euro 6c and Euro 6d vehicles emit more NOx than is suggested by the emissions standards, it is highly likely that these vehicles will deliver real improvements when compared with Euro 6a/b vehicles.

3.6 Figure 2 shows how the COPERT V5.0 speed-emissions curves for Euro 6a/b (<2017), Euro 6c (2017-2020) and Euro 6d (>2020) diesel cars compare with the 80 mg/km emission standard. Figure 3 shows the same thing for diesel vans. A notable point from these graphs

is the degree to which COPERT V5.0 already assumes that the emission standards will be exceeded. For example, the lowest point on the >2020 curve for diesel cars in Figure 2 represents an emission of 146 mg/km, which is 83% higher than the 80 mg/km standard. The COPERT V5.0 emissions functions already, therefore, contain an assumption that emissions in the real world will be higher than those implied by the emissions standards themselves.

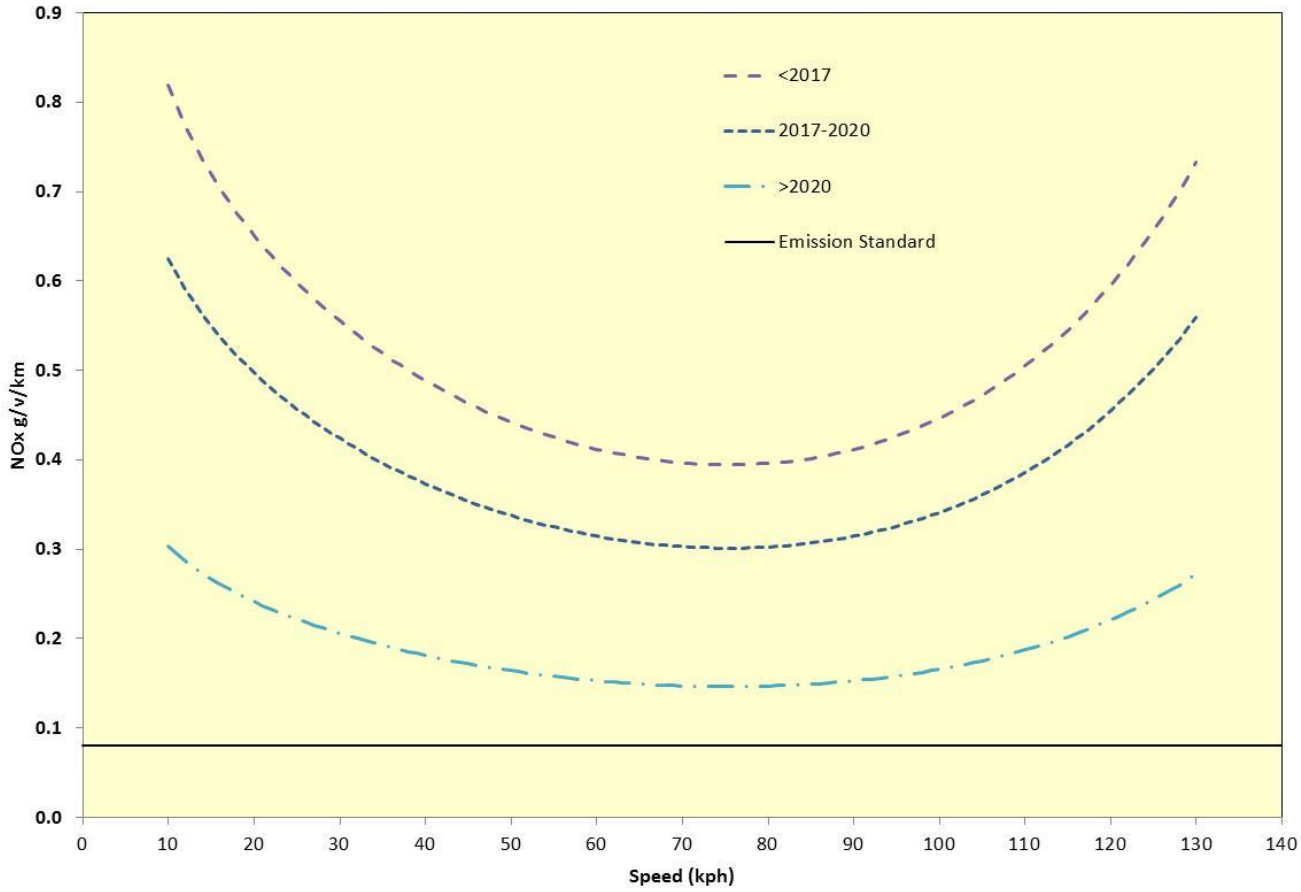

Figure 2: NOx Speed-emission Curves for Euro 6 Diesel Cars in COPERT V5.0[9]

[9] COPERT V5.0 only provides functions for these vehicle types for use between 10 kph and 130kph.

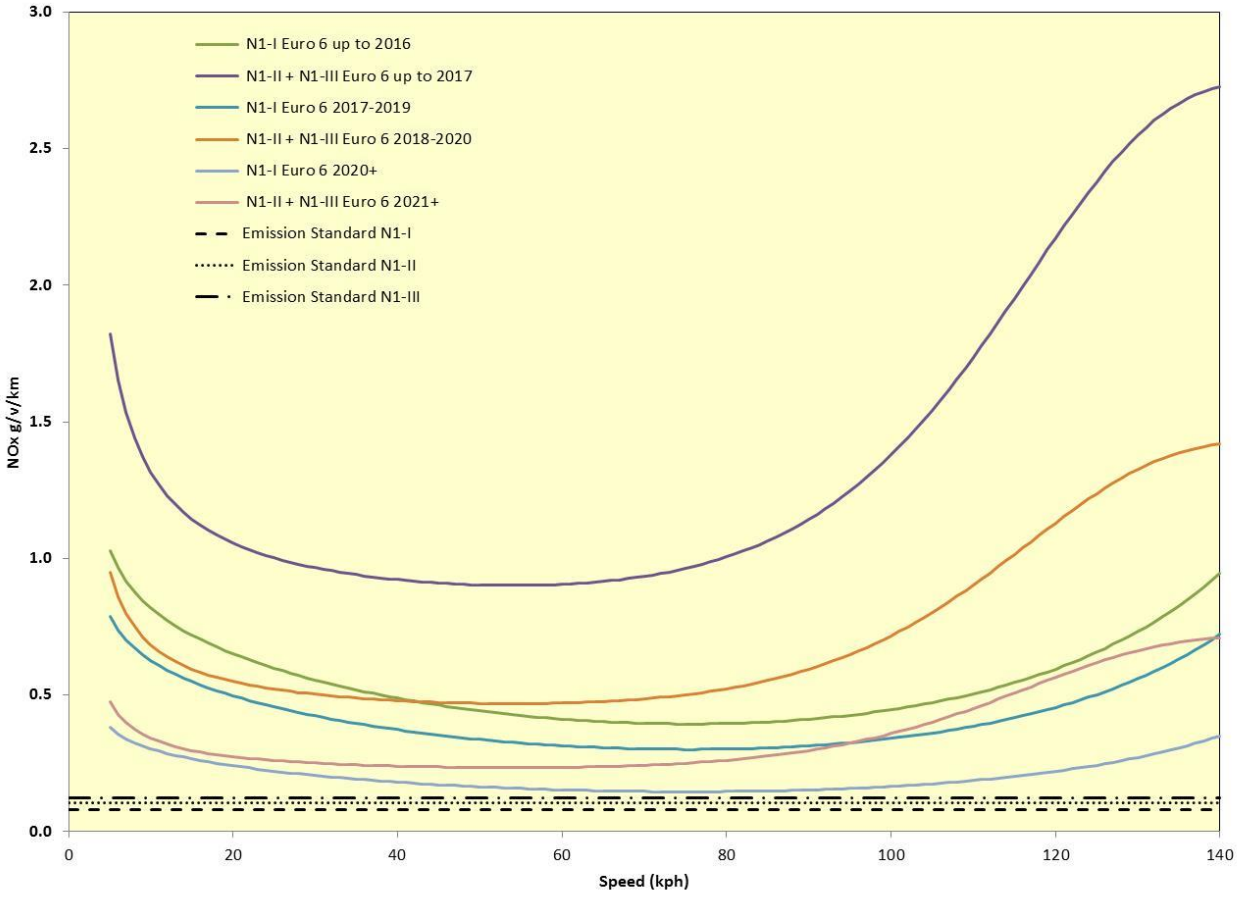

Figure 3: NOx Speed-emission Curves for Euro 6 Diesel Vans COPERT V5.0[10]

[10] For these vehicle types, COPERT V5.0 provides functions for use between 5kph and 140 kph.

4 Vehicle Fleet Projections

4.1 The EFT combines COPERT speed-emissions functions with UK-specific vehicle fleet projections. This includes, for different areas of the UK and different types of roads, assumptions regarding the rate at which old vehicles are retired from the vehicle fleet (in terms of distance driven) and the rate at which newer vehicles are used. It also includes basic assumptions regarding vehicle choice (i.e. petrol vs diesel car etc.). An example of the basic fleet assumption for outer London is shown in Figure 4.

4.2 It is interesting to note, from Figure 4, how little the proportion of diesel cars is projected to change between 2016 and 2030 and how small the projected uptake of fully-electric cars by 2030 is. This contrasts with the expectations of many observers, given recent media attention on NOx emissions from diesel cars, press coverage of falling diesel car sales, national-level commitments to ban the sale of certain vehicles in the future, and the expected response of consumers to climate change concerns. There are thus many reasons to consider that the basic vehicle fleet projections contained in EFT V8.0.1 might prove to be over-precautionary with respect to NOx emissions in the future.

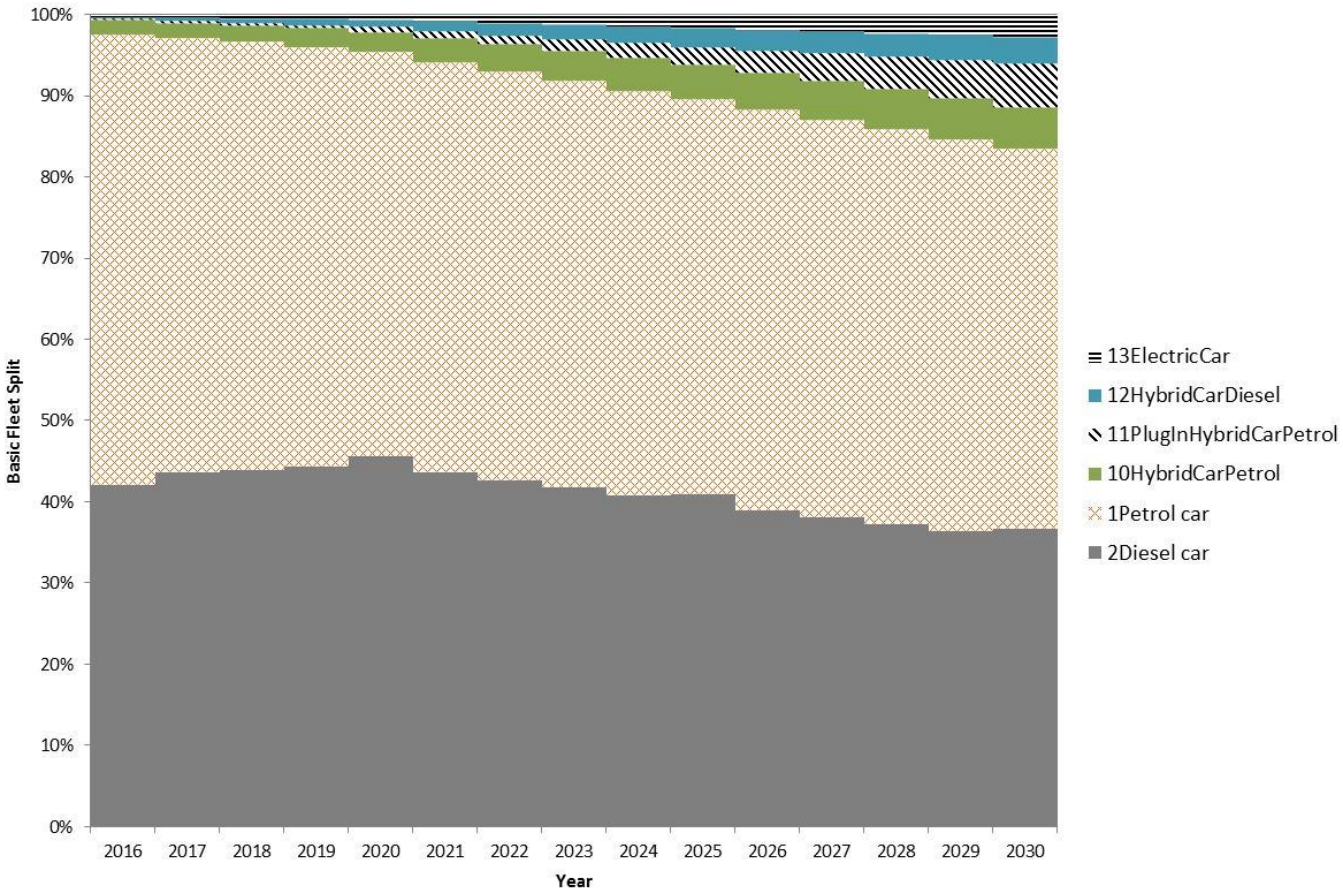

Figure 4: Basic Fleet Assumption for Passenger Cars in Outer London as Used in EFT V8.0.1

4.3 Contrasting with this observation, is the point that some (unpublished) analyses of Automatic Number Plate Recognition data have suggested that historic forecasts of the rate of fleet renewal (i.e. uptake of the latest Euro standards) may have been over-optimistic in some areas and on some types of roads. There are also significant spatial variations in vehicle age[11].

4.4 In practice, it is impossible to know the future composition of the national vehicle fleet. It is considered quite likely that the fleet projection in EFT V8.0.1 may be over-precautionary with respect to future-year NOx emissions, but there is currently no robust basis to improve on these official projections.

[11] www.racfoundation.org/assets/rac_foundation/content/downloadables/MOToring_along_Dr_Sally_Cairns_et_al_November2017.pdf

5 Development of CURED 3A

HDVs

5.1 Most current evidence is that real-world NOx emissions from Euro 6 HDVs are much lower than those from Euro 5 HDVs and often no higher than suggested by the emissions standards themselves[12]. While there is some emerging evidence that, in some applications, HDV engines perform less well than in others[13], at the current time there is insufficient basis to deviate from the assumptions in COPERT V5.0 as contained in EFT V8.0.1 for these vehicles.

5.2 AQC's 2016 report showed that COPERT is likely to under-predict emissions from Euro IV and Euro V HDVs. There is no appreciable new evidence to contradict this finding. It is not, however, considered appropriate to apply an uplift to these vehicles in CURED V3A. The reason for this is that uplifting the emissions from earlier HDVs but not later HDVs risks exaggerating the improvements associated with fleet renewal and thus under-predicting future-year concentrations (since models will be calibrated against current local measurements).

5.3 CURED V3A has thus applied no adjustment to the HDV emissions functions contained in EFT V8.0.1.

LDVs

5.4 As explained in the previous sections, COPERT V5.0 (and thus EFT V8.0.1) now uses calibrated emissions functions for Euro 6a/b vehicles which are very similar to those previously released in CURED (V1A and V2A). Questions remain, however, regarding the treatment of Euro 6c and Euro 6d vehicles in COPERT V5.0. At the time of writing, it has not been possible to identify any published real-world emissions test results for these types of vehicles[14]. For the reasons explained in Paragraphs 3.5 and 3.6, there are some very good reasons to expect that emissions from Euro 6c and Euro 6d will be lower than those from Euro 6a/b vehicles, but there is no robust way in which to quantify this.

5.5 In order to provide a worst-case sensitivity test of the COPERT V5.0 assumptions, CURED V3A assumes that Euro 6d is ineffective (but that Euro 6c has the same effect as is assumed by COPERT V5.0). In other words, for all Euro 6d diesel cars and vans, NOx emissions are assumed to be no different to those from the equivalent Euro 6c vehicles; the assumption in CURED V3A is thus that Euro 6a/b and Euro 6c deliver, but the additional improvement with Euro 6d does not arise. In all other respects, the assumptions in CURED V3A mirror those in EFT V8.0.1.

12 http://www.theicct.org/nox-europe-hdv-ldv-comparison-jan2017

13 https://ee.ricardo.com/news/the-joy-of-(euro)-six?utm_source=Ricardo-AEA%20Ltd&utm_medium=email&utm_campaign=8773330_DW%2FEV91071002%2FRDE%20blog_4_Local%20authority&dm_i=DA4,581JM,FULF5Y,K3QE0,1

14 For example, Emissions Analytics have not currently tested any such vehicles.

Vehicle Fleet Composition

5.6 CURED V3A thus uses the same fleet assumptions as EFT V8.0.1, but this position may be revisited in the future when additional information becomes available.

6 Emissions Comparisons

6.1 Figure 5 shows how the NOx emissions predicted using CURED V3A compare with those from CURED V2A and two versions of the EFT (V7.0 and V8.0.1) for a nominal road. Because CURED V3A does not apply any uplift to HDV emissions, it predicts lower emissions than CURED V2A did. For the reasons outlined previously, CURED V3A predicts the same NOx emissions as EFT V8.0.1 up until around 2019, after which time it becomes more precautionary.

6.2 While Figure 5 is potentially interesting, the pattern that it shows will have little bearing on most air quality assessments. This is because all models should be verified against current base year concentrations. This will almost always involve some form of calibration, which – by definition – compensates for any differences between base-year emissions predictions. Because of this, it is the *rate of change* from one year to another which is much more important than the absolute predicted emissions. This rate of change is shown in Figure 6. Figure 6 shows that, for a model which is verified against concentrations measured in 2016, CURED V3A and EFT V8.0.1 both predict (very) marginally higher concentrations than CURED V2A for years up until around 2020. After 2020, the predictions made using CURED V2A and CURED V3A are almost identical, while those made using EFT V8.0.1 fall significantly (so much so that, by 2029, they equal those of EFT 7.0).

6.3 The patterns shown in Figure 5 and Figure 6 are dependent on the vehicle fleet composition and average speed, and thus different trends occur in different locations. In general terms, however, the trends shown in Figure 6 are broadly representative of most locations.

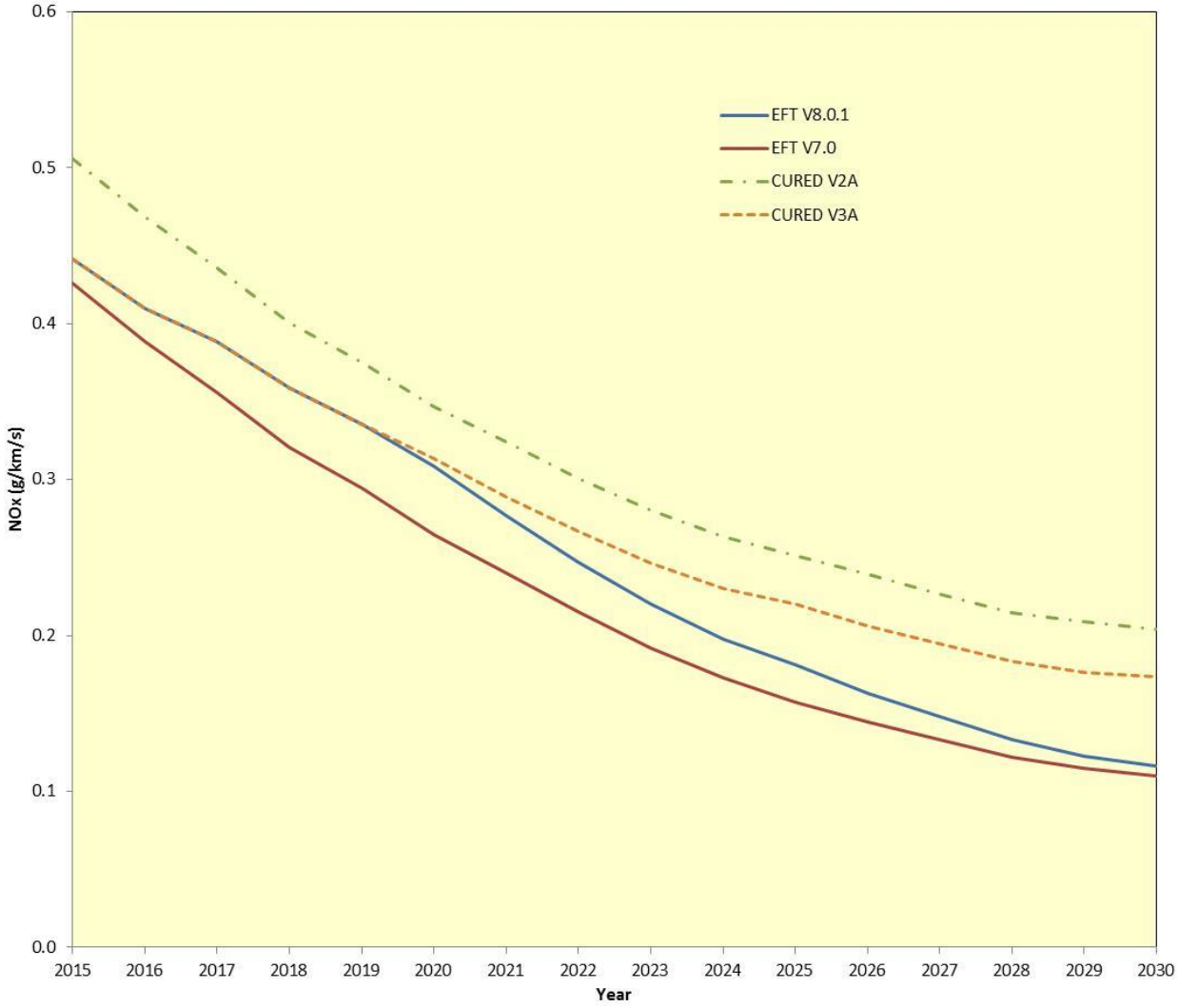

Figure 5: Calculated NOx Emissions over Time from a Nominal Road using Four Different Emissions Models[15]

[15] A road in Outer London carrying 76,341 vehicles per day with 5.2% HDV and an average speed of 50 kph. Flow volume assumed not to change over time.

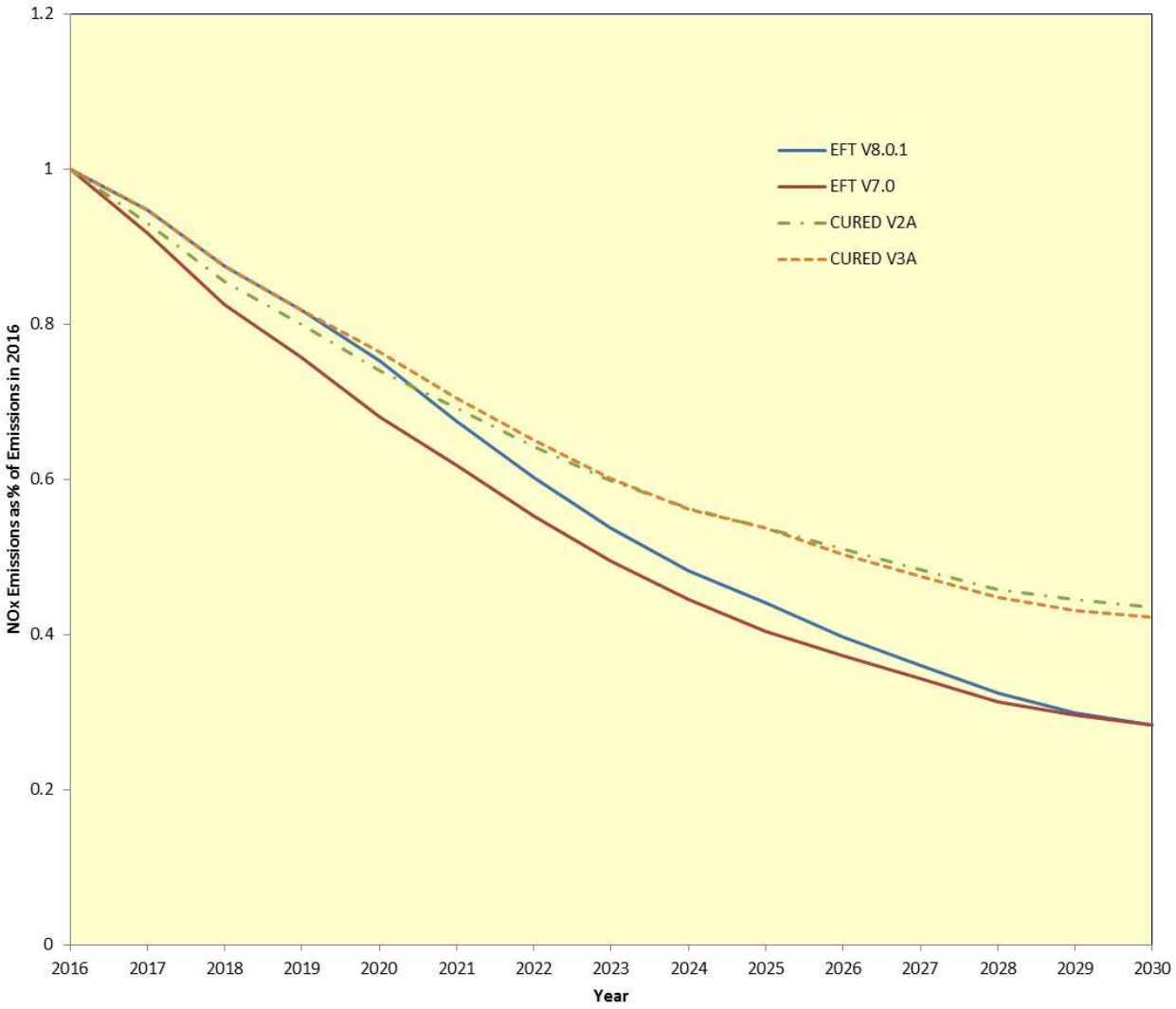

Figure 6: Rate of Change in NOx Emissions over Time from a Nominal Road using Four Different Emissions Models[15]

7 Summary and Conclusions

7.1 In 2016 there was a pressing need for an alternative emissions calculator which took account of the large amount of evidence from real-world emissions tests showing that the EEA's COPERT and Defra's EFT were incorrect. CURED provided a solution to this. For cars and vans, both COPERT and the EFT have since been updated and they now reflect the emissions in CURED (V1A and V2A), while for Euro VI HDVs, new evidence suggests that it is no longer necessary to apply the precautionary uplifts in CURED (V1A and V2A). The result of this is that AQC is now in agreement with both the EEA and Defra that their treatment of the current (pre 2017) vehicle fleet is now broadly appropriate.

7.2 Despite this agreement, there remains some uncertainty regarding how well post-2017 diesel cars and vans will perform in the real world. While there is no strong basis for doubting the assumptions made in COPERT V5.0 or EFT V8.0.1 – in fact there are many reasons to be optimistic about the performance of these vehicles - it seems prudent to continue to apply a sensitivity test to allow for the possibility that EFT V8.0.1 is over-optimistic. CURED V3A has thus been formulated to simulate the failure of Euro 6d to provide any benefits over and above those of Euro 6c.

7.3 In terms of vehicle fleet compositions, it is noted that EFT V8.0.1 does not appear to take account of recent developments, either in national policy or in purchasing trends relating to diesel and non-conventional cars. There may, therefore, be reasons to expect that EFT V8.0.1 will over-predict NOx emissions in the future, but there is currently no robust way to take this into account.

7.4 CURED V3A thus uses the same fleet assumptions as are contained in EFT V8.0.1 but takes a more pessimistic view of the performance of post-2019 diesel cars and vans. It is considered to provide a worst-case sensitivity test. CURED V3A predicts higher NOx emissions than EFT V8.0.1 for all years from 2020 to 2030 (inclusive) but the same emissions as EFT V8.0.1 for all years prior to 2020.