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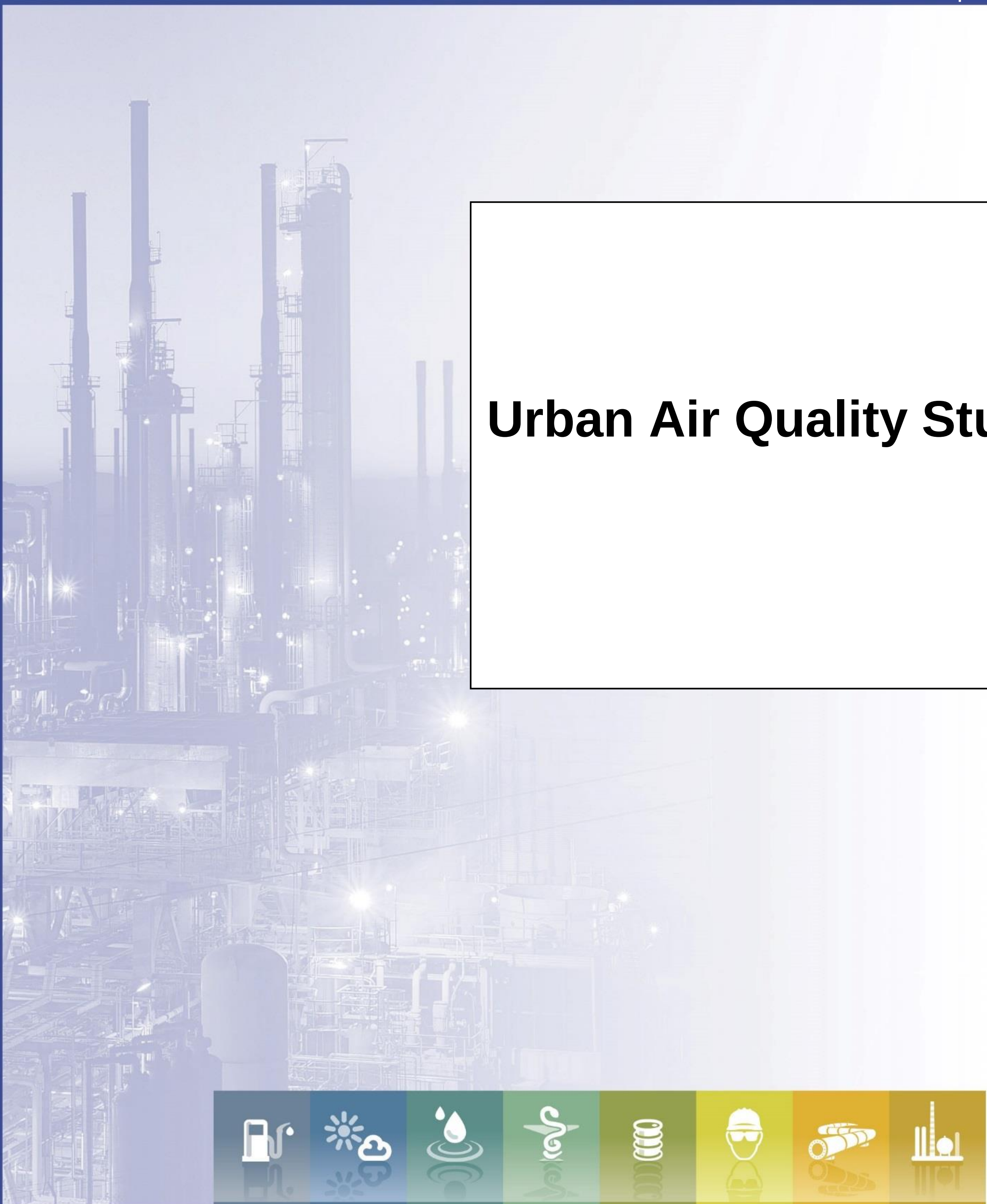

Urban Air Quality Study

Environmental science for the European refining industry

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URBAN AIR QUALITY STUDY

COMMISSIONED BY CONCAWE

AN EXPLORATION INTO THE EFFECT OF EMISSION REDUCTION SCENARIOS ON COMPLIANCE WITH THE AMBIENT AIR QUALITY LIMIT VALUES FOR THE EU27 COUNTRIES IN URBAN ENVIRONMENTS

Les White, Chris Boocock, John G. Cooper, Adam Miles, Stephen Mills

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- The GAINS model of the International Institute of Applied Systems Analysis, Laxenburg, Austria

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1 EXECUTIVE SUMMARY

Despite considerable improvements in European air quality resulting from the progressive implementation of emission reduction measures over the past decade, non-compliance with specific ambient air quality limit values set forth in the Ambient Air Quality Directive (2008/50/EC) persists. The recent revision to the Thematic Strategy on Air Pollution (TSAP) and the accompanying package of measures proposed by the European Commission[1] have taken steps to address this issue, identifying both particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen dioxide (NO_2) as requiring attention.

For both particulate matter (PM) and nitrogen oxides (NO_X), the primary focus for emission reductions at both national and local levels is road transport. Against this background it is vital that the current and future contribution of road transport, and in particular diesel road transport to overall urban air quality in Europe is quantified to provide an appropriate perspective for effective further action at European, national and local levels. The impact of successive improvements in vehicle emission standards which have taken place over the last fifteen years, together with the further impact of Euro 6 requirements (commencing September 2015) also needs to be understood. These Euro 6 requirements include the impact of the forthcoming testing regime based on the recently agreed real driving emissions (RDE) conformity factors (CF).[2]

This report documents the principal findings of a study performed to better understand the air quality compliance issues for PM and NO_2 in the EU27 countries, with a particular focus on the urban environment. The emissions inventory and projections[3] considered in the Base Case are the most up to date European estimates available at the time of writing but do not take into account the effects of legislation for which the actual impact on future activity levels could not be quantified[4]. As a result, the Base Case should be considered as conservative with respect to anticipated emissions reductions. Road transport emissions have been calculated using the fleet projections included in the TREMOVE 'alternative' scenario and the emission factors of COPERT v4.11, representing a Euro 6 diesel passenger car NO_X emissions conformity factor of approximately 2.8[5].

The study was undertaken in two phases: The first phase (Scenarios A to D) was aimed at understanding the maximum possible improvements in $PM_{2.5}$, PM_{10}, and NO_2 compliance from taking action that targets road transport and domestic combustion. This included exploring some extreme 'beyond the Base Case' scenarios, for example the hypothetical immediate replacement of all diesel powered road transport with zero exhaust emission vehicles (Scenario B). In the specific context of PM_{10}/$PM_{2.5}$ compliance, given the increasing use of wood burning as a renewable fuel and the continued use of coal in the domestic sector in a number of Eastern European Member States, the impact of a complete removal of solid fuel burning emissions from the domestic sector was also explored (Scenario A).

The second phase (Scenario E) focussed on NO_2 compliance and the contribution from diesel passenger cars. This included exploring the impact on NO_2 compliance of varying degrees of conformance with legislated Euro 6 emission limits under real driving conditions. An overview of the scenarios explored in this study is included in Table 1.1.

The study utilised a suite of emission and air quality modelling tools developed and maintained by Aeris Europe which together facilitate the assessment of $PM_{2.5}$, PM_{10} and NO_2 air quality compliance at individual

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[1] December 2013

[2] A conformity factor is a multiplication coefficient of the NO_X emissions legislated limited value: (0.08gNO_X/km) for Euro 6 PCD vehicles.

[3] IIASA TSAP Report 16, WPE 2014 CLE for 2030 using the PRIMES 2013 Reference Activity Projection and COPERT v4.11 emission factors

[4] Including the Medium Combustion Plants Directive (MCPD) and the review of the National Emissions Ceilings Directive (NECD)

[5] The COPERT 4 methodology is part of the EMEP/EEA Air Pollutant Emission Inventory Guidebook for the calculation of air pollutant emissions. The emission factors generated are vehicle and country specific. The PCD NO_X Conformity Factor of 2.8 is an indicative value implicit within COPERT that allows for comparison to the Real Driving Emissions legislation.

monitoring station level for the whole of the EU. The modelling approach is semi-empirical, drawing on detailed historical data from more than three thousand monitoring stations in the EEA AirBase database[1] together with other exogenous inputs used to support air policy development in Europe, including national emissions inventories and transboundary source-receptor data. The robustness of the modelling approach was verified by hind-casting and comparing the predicted concentration levels with historical measurement data from the EEA AirBase database.

All findings in this report utilise a three tier system of compliance representation[2], assigning each measuring station or air quality management zone (AQMZ) a red, amber or green value based upon the relationship between the modelled concentration and the relevant air quality limit value (AQLV). A green value indicates "likely compliance" (modelled concentration below the AQLV by at least $5\mu g/m^3$), amber indicates "uncertain compliance" (modelled concentration within $5\mu g/m^3$ of the AQLV) and red indicates "likely non-compliance" (modelled concentration above the AQLV by at least $5\mu g/m^3$).

Air quality management zones are designated under the ambient air quality directive (2008/50/EC) and oblige Member States to divide their entire territory into zones. Zones can be regarded as the primary territorial units for assessment and management of air quality under the air quality directive. The compliance of individual stations within each zone is used to determine overall zone compliance, specifically the single least compliant station is chosen for $PM_{2.5}$ and NO_2. This means that zone compliance is reflective of the "worst" compliance situation within that zone.

Whilst AQMZ are intended to be representative of the air quality over the entire area covered it is likely that a single station modelled as non-compliant will result in the entire population of a zone being interpreted as exposed to levels of PM or NO_2 above the limit value. Given that a zone may have a population of 500,000 or more and a traffic station may be measuring an area as little as $200m^2$; exceedance at the traffic station level clearly cannot be taken to be indicative of population exposure within a whole zone. No attempt has been made to allow for this circumstance and detailed analysis of population exposure needs to be undertaken with care.

Some zones are excluded from the modelled results; this is due to either the zone containing no measuring stations or any measuring stations present lacking the required pre-requisites for inclusion in the model.

[1] AirBase is the air quality information system maintained by the EEA, it contains air quality data from networks and individual stations measuring ambient air pollution within the Member States delivered annually under 97/101/EC Council Decision

[2] Further details can be found in the "Uncertainty Bounds" section of the main "Urban Air Quality Study" report

Table 1.1. Overview of scenarios explored in this study

Scenario		Description	Euro 6 Conformity Factor [1]
Ambient Air Quality standard $PM_{2.5}$		Air quality limit value of 20 µg/m^3 for $PM_{2.5}$ from 2020	-
A		Removal of solid fuel combustion from the domestic sector by 2020	-
B		Removal of all diesel exhaust emissions from urban areas by 2020	2.8
C	C1	Acceleration of older vehicle replacement: 100% of pre-Euro 5 vehicles replaced with Euro 6 vehicles in each horizon year (2020, 2025, 2030)	2.8
	C2	Acceleration of older vehicle replacement: 25% of pre-Euro 5 vehicles replaced with Euro 6 vehicles in each horizon year (2020, 2025, 2030)	2.8
D	D1	Removal of exhaust emissions from all diesel passenger cars (PCD) in the urban environment by 2020	2.8
	D2	As scenario D1, additionally removing diesel light duty vehicles (LDV)	2.8
	D3	As scenario D2, additionally removing diesel heavy duty vehicles (HDV)	2.8
	D4	As scenario D3, additionally removing buses (BUS)	2.8
E	BC0	Scenario E Base Case	2015 onwards : 2.8
	SN1a	These scenarios consider different Euro 6 performance levels and the effect of improving performance by specific dates	2015-2020: 7 2020 onwards: 2.8
	SN1b		2015-2020: 7 2020 onwards: 1.5
	SN1c		2015-2017: 7 2017 onwards: 1.5
	7xLLV		7
	ZEPCD	All diesel passenger cars registered from January 1st, 2015 to produce zero NO_X emissions	

[1] The COPERT 4 methodology is part of the EMEP/EEA Air Pollutant Emission Inventory Guidebook for the calculation of air pollutant emissions. The emission factors generated are vehicle and country specific. The PCD NOX Conformity Factor of 2.8 is an indicative value implicit within COPERT that allows for comparison to the Real Driving Emissions legislation.

1.1 KEY FINDINGS - PARTICULATES ($PM_{2.5}$ & PM_{10})

Primary $PM_{2.5}$ and PM_{10} (PPM) emissions from road transport: This study clearly highlights the diminishingly small contribution from the exhaust of road transport to overall PM concentrations between now and 2030. By 2020 non-exhaust[1] emissions emerge as the dominant emission from road transport (albeit small as a contribution to the total concentration) and by 2030 primary $PM_{2.5}$ emissions from road transport are essentially independent of the powertrain, meaning that all vehicles, regardless of motive force, would produce equivalent PPM emissions.

Table 1.2. Contribution from road transport to total PPM emissions EU27 - kilo tonnes (% of total) [2]

		2015	2020	2025	2030
PM_{10}	Road-transport exhaust emissions	77 (4%)	38 (2%)	21 (1%)	15 (1%)
	Road-transport non-exhaust emissions	149 (7%)	186 (9%)	199 (11%)	208 (11%)
$PM_{2.5}$	Road-transport exhaust emissions	77 (5%)	38 (3%)	21 (2%)	15 (1%)
	Road-transport non-exhaust emissions	50 (4%)	53 (4%)	54 (5%)	56 (5%)

Base Case $PM_{2.5}$ AQLV Compliance: The Base Case results indicate that in 2015 the percentage of the EU population living in "likely non-compliant" zones is only 4%; with 68% of the population in "likely compliant" zones and 28% of the population living in zones that are close to the AQLV (within zones of "uncertain compliance"). The EU population living in these zones of "uncertain compliance" continues to decline between 2015 and 2030 as already legislated measures take effect so that the population living in likely compliant zones increases to 77% by 2020 and to 81% by 2030. At the same time, the population living in zones of uncertain compliance reduces to 19% by 2020 and to 15% by 2030. The percentage of population living in likely non-compliant zones remains unchanged at 4% from 2015.

Most of the residual $PM_{2.5}$ non-compliance is seen in Eastern Europe and is attributable to the PPM emissions from domestic combustion of solid fuels that continues to take place in this region of the EU. The results from Scenario A where solid fuel (e.g. coal, wood) burning in the domestic sector is replaced by "low PPM" generating fuel (e.g. gas or heating oil) indicates that this measure would improve the compliance picture for $PM_{2.5}$ and consequently PM_{10}.

Base Case Sensitivity Scenario - Investigating the 'Stage 2' $PM_{2.5}$ AQLV: Annex XIV, Section E of the Ambient Air Quality Directive (2008/50/EC) sets forth $PM_{2.5}$ annual mean limit values in two stages. The 'Stage 1' limit of 25µg/m^3 requires full compliance by January 1, 2015. The 'Stage 2' limit of 20µg/m^3 is noted as: *'…indicative limit value to be reviewed by the Commission in 2013 in the light of further information on health and environmental effects, technical feasibility and experience of the target value in Member States.'*[3]. Although such a review has not yet been published by the Commission, this sensitivity scenario explores the effect that this reduced limit value would have on compliance.

Instead of using zone populations for this analysis the actual number of stations has been used, these station counts allow for a more accurate judgement of compliance change. This is due to zone population compliance being determined by the measuring station with the highest concentration rendering it impossible to observe how many individual stations of the 2,954 included in the model are affected.

[1] Brake, road and tyre wear: these sources are present in all road transport including 100% battery powered vehicles

[2] All road transport exhaust emissions are $PM_{2.5}$, this fraction is included in the PM_{10} emissions total

[3] DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe

The effect of an AQLV reduction in 2020 would see the number of non-compliant air quality measuring stations (AQMS) increasing from 84 to 141 whilst those measuring close to the AQLV in "uncertain compliance" would increase from 223 to 713. 2030 shows a similar increase with an increase in non-compliant AQMS from 77 to 121 and an increase in those of "uncertain compliance" from 149 to 504. This suggests that there are a large number of measuring stations close to the current AQLV in all modelled years.

Diesel Exhaust PM (Scenario B): Given the small contribution of exhaust emissions from road transportation to total PPM emissions the elimination of diesel vehicles neither improves the overall air quality compliance picture in the future nor does it accelerate the achievement of improved compliance, this is shown in Table 1.3 and Table 1.4.

Domestic Solid Fuel Combustion (Scenario A): In contrast to the negligible effect that diesel exhaust emissions have on PM concentrations the removal of solid fuel combustion and its replacement with gas or heating oil shows a marked difference in the proportion of the EU population in zones that are borderline compliant for both $PM_{2.5}$ and PM_{10} resulting in a significant overall improvement in air quality by 2020 and beyond (Table 1.3 and Table 1.4). The difference is particularly evident in the case of PM_{10} where approximately 92% of the EU population would live in "likely compliant" areas and less than 1% in "likely non-compliant" areas by 2025.

The greatest improvement is observed in those countries with high levels of solid fuel burning, particularly Eastern Europe and suggests that those countries experiencing PM_{10} compliance issues could significantly reduce this problem by reducing or eliminating solid fuel combustion in the domestic sector.

Table 1.3. Percentage of EU population living in zones achieving compliance with ambient air quality standards for $PM_{2.5}$ in the Base Case and when reducing PPM emissions from solid fuel combustion (A) and removing all diesel exhaust emissions (B)

$PM_{2.5}$	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	Scenario A	Scenario B	Base case	Scenario A	Scenario B
2015	68%	68%	68%	4%	4%	4%
2020	77%	85%	77%	4%	3%	4%
2025	80%	88%	80%	4%	3%	4%
2030	81%	89%	81%	4%	3%	4%

Table 1.4. Percentage of EU population living in zones achieving compliance with ambient air quality standards for PM_{10} (daily exceedances) in the Base Case and when reducing PPM emissions from solid fuel combustion (A) and removing all diesel exhaust emissions (B)

PM_{10}	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	Scenario A	Scenario B	Base case	Scenario A	Scenario B
2015	66%	66%	66%	7%	7%	7%
2020	77%	89%	78%	4%	2%	4%
2025	81%	92%	81%	3%	1%	3%
2030	83%	93%	83%	3%	1%	3%

1.2 KEY FINDINGS - NITROGEN DIOXIDE (NO_2)

NO_2 AQLV Compliance in the Base Case: The Base Case modelling results indicate that in 2015 the percentage of EU population living in "non-compliant" zones (modelled concentration above 45µg/m^3) is approximately 18%; while 69% of the population live in "likely compliant" zones (modelled concentration below 35µg/m^3) and 13% of the population live in zones that are close to the AQLV and so within zones of "uncertain-compliance" (modelled concentration between 35 and 45µg/m^3).

The population living in zones of "uncertain compliance" continues to decline between 2015 and 2030 as already legislated measures take effect and by 2030 the population living in "likely compliant" zones increases to 93%. Importantly, in the period from 2015 to 2030, the pattern of residual non-compliance moves from large contiguous areas to discrete islands of non-compliance. This has important implications for the design of efficient mitigation strategies.

Diesel Exhaust NO_X: The immediate removal of all diesel exhaust emissions (HGV, LGV, PCD and Buses) from the urban environment (Scenario B) does improve compliance with the NO_2 air quality limit value in the short term, however the study indicates that the incremental benefit in compliance terms is relatively small in comparison to those improvements already delivered by the Base Case and reduces with time. As an alternative; targeted measures to remove older diesel vehicles (pre-Euro V) from the urban environment is likely to be easier to implement than the complete removal of all diesel vehicles and would similarly accelerate the achievement of improved compliance.

Another practical option would be to accelerate turnover of the vehicle fleet, effectively replacing[1] all pre-Euro 5 passenger cars with Euro 6 technology faster than the natural rate of replacement (Scenario C1). This option does offer some improvement by 2020 with the percentage population living in compliant zones increasing from 83% to 88% and the percentage population living in likely non-compliant zones decreasing from 10% to 6%. The benefits of the early replacement of pre-Euro 5 vehicles reduce with time as Euro 6 vehicles naturally achieve prevalence in the fleet, so that the impact from 2025 is negligible. Table 1.5 presents an overview of these two scenarios and their effect on compliance.

Table 1.5. Percentage of EU 27 population living zones achieving compliance with ambient air quality standards for NO_2 in the Base Case, when removing all diesel emissions (B) and accelerating fleet turnover (C1)

NO_2	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	Scenario B	Scenario C1	Base case	Scenario B	Scenario C1
2015	69%	69%	69%	18%	18%	18%
2020	83%	94%	88%	10%	0%	6%
2025	90%	95%	91%	5%	0%	5%
2030	93%	95%	93%	5%	0%	5%

Diesel Exhaust NO_X - Euro 6 Performance Scenarios: In Scenario E, several sensitivity cases regarding the performance of Euro 6 vehicles have been explored, see Table 1.1 for more details.

Scenario SN1b attempts to reflect[2] the recently proposed conformity factors agreed by the Member States Representatives at the "Technical Committee - Motor Vehicles" on the 28 October 2015[3], however a CF of 7 is used to 2020[4] rather than the 2.8 discussed earlier[1] as this was the best available data at the time this work

[1] The retrofitting of Euro 6 equivalent NO_X control technologies to pre-Euro 5 diesel passenger cars is not currently a practical option.

[2] Further details can be found in the "Scenario E" section of the main "Urban Air Quality Study" report.

[3] E. Commission, "Commission welcomes Member States' agreement on robust testing of air pollution emissions by cars," 28 October 2015. [Online]. Available: http://europa.eu/rapid/press-release_IP-15-5945_en.htm.

[4] "REAL-WORLD EXHAUST EMISSIONS FROM MODERN DIESEL CARS" ICCT Whitepaper - October 2014

was undertaken. The ZEPCD scenario represents the immediate substitution of new diesel passenger car sales with zero NO_X emissions alternatives. Comparing the SN1b "real-world" scenario with a potential "best-case" helps to highlight how much improvement might be achieved in practical terms.

In the SN1b scenario; by 2020 the percentage of the EU population living in "non-compliant" zones is 12% reducing to 6% by 2025 and 5% by 2030. This compares to 9% by 2020, 5% by 2025 and 0% by 2030 in the ZEPCD scenario. The plateauing of compliance from 2025 in SN1b is due to a very small number (0.5%) of non-compliant roadside air quality measuring stations. This number does reduce to 0.2% by 2030; however they are located in large urban conurbations with high population density.

Table 1.6. Percentage of EU 27 population living in zones achieving compliance with ambient air quality standards for NO_2 in the Base Case, for a Euro 6 "central conformity" scenario (SN1b), scenario SN1c, and removing diesel vehicles from sale (ZEPCD)

NO_2	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	SN1b[2]	ZEPCD	Base case	SN1b	ZEPCD
2015	69%	69%	69%	18%	18%	18%
2020	83%	80%	85%	10%	12%	9%
2025	90%	89%	92%	5%	6%	5%
2030	93%	93%	94%	5%	5%	0%

The high level of compliance observed in the SN1b scenario is consistent with the recent assessment work undertaken in the UK by the Department for Environment, Food and Rural Affairs (DEFRA)[3]. Based on modelling about 2000 individual road links in Greater London, this work indicates that by 2025 any residual NO_2 compliance issues will be confined to very small areas within a largely compliant urban agglomeration. Such small islands of non-compliance lend themselves to local, tailored strategies rather than significantly more costly and potentially disruptive city or country-wide responses.

In conclusion, while today NO_2 air quality limit value compliance varies widely in the urban environment; future non-compliance is foreseen to be limited to small, discrete areas. The distribution of this non-compliance strongly supports the implementation of targeted, specific solutions rather than sweeping or wide-ranging measures.

[1] Please refer to note 5 on page 3
[2] SN1b uses a "worse than base case" CF of 7 from 2015 to 2020 for Euro 6 PCD; this is responsible for the initial decrease in compliance observed in this scenario.
[3] DEFRA, "Improving air quality in the UK Tackling nitrogen dioxide in our towns and cities," DEFRA, 2015.

2 CONTENTS

3 INTRODUCTION

Despite considerable improvements in European air quality resulting from the progressive implementation of emission reduction measures over the past decade, non-compliance with specific ambient air quality limit values set forth in the Ambient Air Quality Directive (2008/50/EC) persists. The recent revision to the Thematic Strategy on Air Pollution (TSAP) and the accompanying package of measures proposed by the European Commission[1] have taken steps to address this issue, identifying both particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen dioxide (NO_2) as requiring attention.

For both particulate matter (PM) and nitrogen oxides (NO_X), the primary focus for emission reductions at both national and local levels is road transport. Against this background it is vital that the current and future contribution of road transport, and in particular diesel road transport to overall urban air quality in Europe is quantified to provide an appropriate perspective for effective further action at European, national and local levels. The impact of successive improvements in vehicle emission standards which have taken place over the last fifteen years, together with the further impact of Euro 6 requirements (commencing September 2015) also needs to be understood. These Euro 6 requirements include the impact of the forthcoming testing regime based on the recently agreed real driving emissions (RDE) conformity factors (CF).[2]

This report documents the principal findings of a study performed to better understand the air quality compliance issues for PM and NO_2 in the EU27 area countries, with a particular focus on the urban environment. The emissions inventory and projections[3] considered in the Base Case are the most up to date European estimates available at the time of writing but do not take into account the effects of legislation for which the actual impact on future activity levels could not be quantified[4]. As a result, the Base Case should be considered as conservative with respect to anticipated emissions reductions. Road transport emissions have been calculated using the fleet projections included in the TREMOVE 'alternative' scenario and the emission factors of COPERT v4.11, representing a Euro 6 diesel passenger car NO_X emissions conformity factor of approximately 2.8[5].

An assessment of the impact of solid fuel burning in the domestic sector on particulate concentrations across Europe has also been incorporated into the study together with an examination of the "non-exhaust" fraction of road transport particulates, i.e. those particulates that stem from sources such as road abrasion and brake wear.

The study was undertaken in two phases: The first phase (Scenarios A to D) was aimed at understanding the maximum possible improvements in $PM_{2.5}$, PM_{10}, and NO_2 compliance from taking action that targets road transport and domestic combustion. This included exploring some extreme 'beyond the Base Case' scenarios e.g. the hypothetical immediate replacement of all diesel powered road transport with zero exhaust emission vehicles (Scenario B). In the specific context of $PM_{10}/PM_{2.5}$ compliance, given the increasing use of wood burning as a renewable fuel and the continued use of coal in the domestic sector in a number of Eastern European Member States, the impact of a complete removal of solid fuel burning emissions from the domestic sector was also explored (Scenario A).

The second phase (Scenario E) focussed on NO_2 compliance and the contribution from diesel passenger cars. This included exploring the impact on NO_2 compliance of varying degrees of conformity with legislated Euro 6

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[1] December 2013

[2] A conformity factor is a multiplication coefficient of the NO_X emissions legislated limited value: (0.08gNO_X/km) for Euro 6 PCD vehicles.

[3] IIASA TSAP Report 16, WPE 2014 CLE for 2030 using the PRIMES 2013 Reference Activity Projection and COPERT v4.11 emission factors

[4] Including the Medium Combustion Plants Directive (MCPD) and the review of the National Emissions Ceilings Directive (NECD)

[5] The COPERT 4 methodology is part of the EMEP/EEA Air Pollutant Emission Inventory Guidebook for the calculation of air pollutant emissions. The emission factors generated are vehicle and country specific. The PCD NOx Conformity Factor of 2.8 is therefore an indicative value identified to allow for comparison with the Real Driving Emissions legislation.

emission limits under real driving conditions. An overview of the scenarios explored in this study is included in Table 3.1.

Table 3.1. - Overview of scenarios explored in this study

Scenario		Description	Euro 6 Conformity Factor [1]
Ambient Air Quality standard $PM_{2.5}$		Air quality limit value of 20 µg/m^3 for $PM_{2.5}$ from 2020	-
A		Removal of solid fuel combustion from the domestic sector by 2020	-
B		Removal of all diesel exhaust emissions from urban areas by 2020	2.8
C	C1	Acceleration of older vehicle replacement: 100% of pre-Euro 5 vehicles replaced with Euro 6 vehicles in each horizon year (2020, 2025, 2030)	2.8
	C2	Acceleration of older vehicle replacement: 25% of pre-Euro 5 vehicles replaced with Euro 6 vehicles in each horizon year (2020, 2025, 2030)	2.8
D	D1	Removal of exhaust emissions from all diesel passenger cars (PCD) in the urban environment by 2020	2.8
	D2	As scenario D1, additionally removing diesel light duty vehicles (LDV)	2.8
	D3	As scenario D2, additionally removing diesel heavy duty vehicles (HDV)	2.8
	D4	As scenario D3, additionally removing buses (BUS)	2.8
E	BC0	Scenario E Base Case	2015 onwards : 2.8
	SN1a	These scenarios consider different Euro 6 performance levels and the effect of improving performance by specific dates	2015-2020: 7 2020 onwards: 2.8
	SN1b		2015-2020: 7 2020 onwards: 1.5
	SN1c		2015-2017: 7 2017 onwards: 1.5
	7xLLV		7
	ZEPCD	All diesel passenger cars registered from January 1st, 2015 to produce zero NO_X emissions	

The Base Case upon which all of the scenarios were based uses the emissions inventory of the IIASA Thematic Strategy on Air Pollution (TSAP) Report 16, Working Party on the Environment (WPE) for the European Council under 2014 Current Legislation (CLE) for 2030 using the PRIMES 2013 Reference Activity Projection and COPERT v4.11 emission factors. This scenario was chosen as it is the most recent (at time of writing) scenario, based upon updated emission control scenarios provided by each Member State and is less optimistic about the effects of climate policies than the original 2013 commission proposal. The emission projections can be considered as conservative as they don't take into account the effects of legislation for which the actual impact on future activity levels could not be quantified[2].

The study utilised a suite of emission and air quality modelling tools developed and maintained by Aeris Europe which together facilitate the assessment of $PM_{2.5}$, PM_{10} and NO_2 air quality compliance at individual monitoring station level for the whole of the EU. The modelling approach is semi-empirical, drawing on

[1] The COPERT 4 methodology is part of the EMEP/EEA Air Pollutant Emission Inventory Guidebook for the calculation of air pollutant emissions. The emission factors generated are vehicle and country specific. The PCD NO_X Conformity Factor of 2.8 is an indicative value implicit within COPERT that allows for comparison with the Real Driving Emissions legislation.
[2] Including the Medium Combustion Plants Directive (MCPD) and the review of the National Emissions Ceilings Directive (NECD)

detailed historical data from more than three thousand monitoring stations in the EEA AirBase database[1] together with other exogenous inputs used to support air policy development in Europe, including national emissions inventories and transboundary source-receptor data. The robustness of the modelling approach was verified by hind-casting and comparing the predicted concentration levels with historical measurement data from the EEA AirBase database.

The European Commission employed the “Greenhouse Gas and Air Pollution Interactions and Synergies” (GAINS) model developed and maintained by the International Institute for Applied Systems Analysis (IIASA) as the key tool to support its review of the Thematic Strategy on Air Pollution. As part of the initial phase of this study care was taken to ensure that Base Case predictions made using the Aeris Europe suite of software tools were in-line with GAINS model outputs.

All findings in this report utilise a three tier system of compliance representation[2], assigning each measuring station or air quality management zone (AQMZ) a red, amber or green value based upon the relationship between the modelled concentration and the relevant air quality limit value. A green value indicates “likely compliance” (modelled concentration below the AQLV by at least $5\mu g/m^3$), amber indicates “uncertain compliance” (modelled concentrations within $5\mu g/m^3$ of the AQLV) and red indicates “likely non-compliance” (modelled concentration above the AQLV by at least $5\mu g/m^3$).

Figure 3.1 - Compliance uncertainty representation

- Likely compliant (the modelled concentrations are less than the AQLV by at least $5\mu g/m^3$)
- Uncertain compliance (the modelled concentrations are within $5\mu g/m^3$ of the AQLV)
- Likely non-compliant (the modelled concentrations are greater than the AQLV by at least $5\mu g/m^3$)

[1] AirBase is the air quality information system maintained by the EEA, it contains air quality data from networks and individual stations measuring ambient air pollution within the Member States delivered annually under 97/101/EC Council Decision

[2] Further details can be found in the “Uncertainty Bounds” section of the main “Urban Air Quality Study” report

4 KEY FINDINGS

4.1 PARTICULATES ($PM_{2.5}$ AND PM_{10})

$PM_{2.5}$ and PM_{10} compliance with current air quality limit values (AQLV) is largely achieved in the Base Case (Figure 6.4) with the exception of recently joined Eastern European member states where solid fuel continues to be widely burned in the domestic sector, an example of this is illustrated in Figure 6.3.

The Base Case results (Figure 6.4 - Figure 6.8) indicate that in 2015 the percentage of the EU 27 population living in “likely non-compliant” (modelled concentrations above 30µg/m^3) zones is only 4%; with approximately 68% of the population in “likely compliant” (modelled concentrations below 20µg/m^3) zones and 28% of the population living in zones that are close to the AQLV (within zones of “uncertain compliance” between 20 and 30µg/m^3). The EU population living in these zones of “uncertain compliance” continues to decline between 2015 and 2030 as already legislated measures take effect so that the population living in likely compliant zones increases to 77% by 2020 and to 81% by 2030. At the same time, the population living in zones of uncertain compliance reduces to 19% by 2020 and to 15% by 2030. The percentage of population living in likely non-compliant zones remains unchanged at 4% from 2015.

Most of the PM non-compliance is seen in Eastern Europe and based on these results is directly attributable to the domestic combustion of solid fuels and associated primary particulate matter (PPM) emissions that continues to take place in this region of the EU. A shift from solid fuel (e.g. coal, wood) burning to “low PPM” generating fuel (e.g. gas or heating oil) in the domestic sector would significantly improve the compliance picture in this part of Europe for both $PM_{2.5}$ and PM_{10} from 2020 onwards (Figure 6.3, Figure 7.1 - Figure 7.6). The improvement is particularly evident in the case of PM_{10} where 92% of the EU population would live in “likely compliant” areas and less than 1% in “likely non-compliant” areas by 2025 with the majority of the improvement predicted by 2020.

Annex XIV, Section E of the Ambient Air Quality Directive (2008/50/EC) sets forth $PM_{2.5}$ annual mean limit values in two Stages. The ‘Stage 1’ limit of 25µg/m^3 requires full compliance by January 1, 2015. The ‘Stage 2’ limit of 20µg/m^3 is noted as: *‘…indicative limit value to be reviewed by the Commission in 2013 in the light of further information on health and environmental effects, technical feasibility and experience of the target value in Member States*’.[1] Although such a review has not yet been published by the Commission, this sensitivity scenario explores the effect that this ‘Stage 2’ limit value would have on compliance versus the ‘Stage 1’ limit explored in the Base Case.

Instead of using zone populations for this analysis, the actual number of stations has been used, these station counts allow for a more accurate judgement of compliance change. This is due to zone population compliance being determined by the measuring station with the highest concentration rendering it impossible to observe how many individual stations of the 2,954 included in the model are affected.

The effect of this reduction in 2020 (summarised in Table 7.14 and Table 7.15) would result in the number of non-compliant air quality measuring stations (AQMS) increasing from 84 to 141 whilst those measuring close to the AQLV in “uncertain compliance” would increase from 223 to 713. 2030 shows a similar increase with an increase in non-compliant AQMS from 77 to 121 and an increase in those of “uncertain compliance” from 149 to 504. This suggests that there are a large number of measuring stations close to the current AQLV in all modelled years.

[1] DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 May 2008 on ambient air quality and cleaner air for Europe

A significant finding of this study has been that diesel PPM from exhaust emissions is a diminishingly small contributor to urban air quality (Table 4.1) and its elimination has no impact on earlier compliance with the current air quality limit values or to the overall compliance picture in 2020 and beyond (Figure 7.7 - Figure 7.8). The dominating contributor to primary PM emissions from road transport in 2020 is brake and tyre wear, a source present in all road transport including 100% battery powered vehicles. Therefore, in the case of particulates, the elimination of the contribution made by diesel vehicle exhaust emissions neither improves the overall air quality compliance picture in the future nor does it accelerate the achievement of improved compliance.

Table 4.1. Contribution from road transport to total PPM emissions EU27 - kilo tonnes (% of total) [1]

		2015	2020	2025	2030
PM_{10}	Road-transport exhaust emissions	77 (4%)	38 (2%)	21 (1%)	15 (1%)
	Road-transport non-exhaust emissions	149 (7%)	186 (9%)	199 (11%)	208 (11%)
$PM_{2.5}$	Road-transport exhaust emissions	77 (5%)	38 (3%)	21 (2%)	15 (1%)
	Road-transport non-exhaust emissions	50 (4%)	53 (4%)	54 (5%)	56 (5%)

In contrast to the negligible effect that diesel exhaust emissions have on PM concentration the removal of solid fuel combustion and its replacement with gas or heating oil shows a marked difference in the proportion of the EU population in zones that are borderline compliant for both $PM_{2.5}$ and PM_{10} resulting in a significant overall improvement in air quality by 2020 and beyond (Table 4.2). The difference is particularly evident in the case of PM_{10} where approximately 92% of the EU population would live in "likely compliant" areas and less than 1% in "likely non-compliant" areas by 2025.

Table 4.2. Percentage of EU population living in zones achieving compliance with ambient air quality standards for $PM_{2.5}$ in the Base Case and when reducing PPM emissions from solid fuel combustion (A) and removing all diesel exhaust emissions (B)

$PM_{2.5}$	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	Scenario A	Scenario B	Base case	Scenario A	Scenario B
2015	68%	68%	68%	4%	4%	4%
2020	77%	85%	77%	4%	3%	4%
2025	80%	88%	80%	4%	3%	4%
2030	81%	89%	81%	4%	3%	4%

The greatest improvement is observed in those countries with high levels of solid fuel burning, particularly Eastern Europe and suggests that those countries experiencing PM_{10} compliance issues could significantly reduce this problem by reducing or eliminating solid fuel combustion in the domestic sector. This was highlighted during the technical phase of the European Commission's Air Policy Review which resulted in the December 2013 proposed Air Policy Package. [1]

Table 4.3. Percentage of EU population living in zones achieving compliance with ambient air quality standards for PM_{10} (24hr exc.) in the Base Case and when reducing PPM emissions from solid fuel combustion (A) and removing all diesel exhaust emissions (B)

PM_{10}	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	Scenario A	Scenario B	Base case	Scenario A	Scenario B
2015	66%	66%	66%	7%	7%	7%
2020	77%	89%	78%	4%	2%	4%
2025	81%	92%	81%	3%	1%	3%
2030	83%	93%	83%	3%	1%	3%

[1] All road transport exhaust emissions are $PM_{2.5}$, this fraction is included in the PM_{10} emissions total

4.2 NITROGEN DIOXIDE (NO_2)

The Base Case modelling results (Figure 6.15 - Figure 6.19) indicate that in 2015 the percentage of the EU population living in “non-compliant” zones (modelled concentrations above 45µg/m^3) is approximately 18%, while 69% of the population live in “likely compliant” zones (modelled concentrations below 35µg/m^3) and 13% of the population live in zones that are close to the AQLV and so within zones of “uncertain-compliance” (modelled concentrations between 35 and 45µg/m^3). Please refer to Figure 3.1 and Section 5.5 for more information on compliance categories.

The population living in zones of “uncertain compliance” continues to decline between 2015 and 2030 as already legislated measures take effect and by 2030 the population living in “likely compliant” zones increases to 93%. Importantly, in the period from 2015 to 2030, the pattern of residual non-compliance moves from large contiguous areas to discrete islands of non-compliance (Figure 6.16 - Figure 6.19). This has important implications for the design of efficient mitigation strategies.

The model outcomes of “Phase 1” (Scenarios B to D) provide important insights as to what is potentially possible. The first road transport case (Scenario B), exploring the total removal of diesel emissions (HGV, LGV, PCD and Buses) in urban areas, improves compliance with the NO_2 air quality limit value in the short term (Figure 7.9). However, against a Base Case which sees significant improvements in compliance by 2025 the incremental benefit in compliance terms is reduced to only 2% of the population beyond 2025 even for this extreme and hypothetical scenario. As a total cessation of emissions is a somewhat unlikely situation, a more practical example of improvement is demonstrated by accelerating turnover of the vehicle fleet i.e. replacing[1] all pre-Euro5 vehicles with Euro 6 sooner than natural turnover would bring about. This does show improvement by 2020 largely due to the effect of the differing Euro emissions standards. However, by the time Euro 6 has naturally achieved significant fleet penetration (2025 and beyond) there is little room for further improvement (Figure 7.14 - Figure 7.15 and Table 7.1). It should be noted that the transport emissions from the Euro 6 fleet in “Phase 1” are based on a conformity factor (CF) of 2.8[2] for all years to 2030, see Section 7.5 for more information on the conformity factors used.

Although accelerating the replacement of all pre-Euro 5 vehicles does result in achieving a given level of compliance earlier than in the Base Case, for the case of 25% uptake, the improvements are marginal (Figure 7.15).

The “Phase 2” results using the SN1b[3] scenario when compared with the results of the ZEPCD (representing the immediate substitution of new diesel vehicle sales with zero NO_X emissions alternatives) (Figure 7.22, Figure 7.24), indicate the following; by 2020 the percentage of the EU population living in “non-compliant” zones is 12% reducing to 6% by 2025 and 5% by 2030. This compares to 9% by 2020, 5% by 2025 and 0% by 2030 in the ZEPCD scenario. The plateauing of compliance from 2025 in SN1b is due to a very small number (0.5%) of non-compliant roadside air quality measuring stations. This number does reduce to 0.2% by 2030; however they are located in large urban conurbations with high population densities.

The high level of compliance observed in the SN1b scenario is consistent with the recent assessment work undertaken in the UK by the Department for Environment, Food and Rural Affairs (DEFRA)[4]. Based on

[1] The retrofitting of Euro 6 equivalent NO_X control technologies to pre-Euro 5 diesel passenger cars is not currently a practical option.

[2] The COPERT 4 methodology is part of the EMEP/EEA Air Pollutant Emission Inventory Guidebook for the calculation of air pollutant emissions. The emission factors generated are vehicle and country specific. The PCD NOx Conformity Factor of 2.8 is therefore an indicative value identified to allow for comparison to the Real Driving Emissions legislation.

[3] SN1B scenario: Conformity factor for Euro 6 is 7 from 2015 to 2020 and 1.5 from 2020 onwards. While erring on the conservative side for the period 2015-2020, this was chosen because it most closely matches the conformity factors agreed by the Member States Representatives at the recent meeting of their “Technical Committee - Motor Vehicles”-28th October 2015

[4] “Improving air quality in the UK Tackling nitrogen dioxide in our towns and cities,” DEFRA, 2015.

modelling about 2000 individual road links in Greater London, this work indicates that by 2025 any residual NO_2 compliance issues will be confined to very small areas within a largely compliant urban agglomeration. Such small islands of non-compliance lend themselves to local, tailored strategies rather than significantly more costly and potentially disruptive city or country-wide responses.

In conclusion, while today NO_2 air quality limit value compliance varies widely in the urban environment; future non-compliance is foreseen to be limited to small, discrete areas. The distribution of this non-compliance strongly supports the implementation of targeted, specific solutions rather than sweeping or wide-ranging measures.

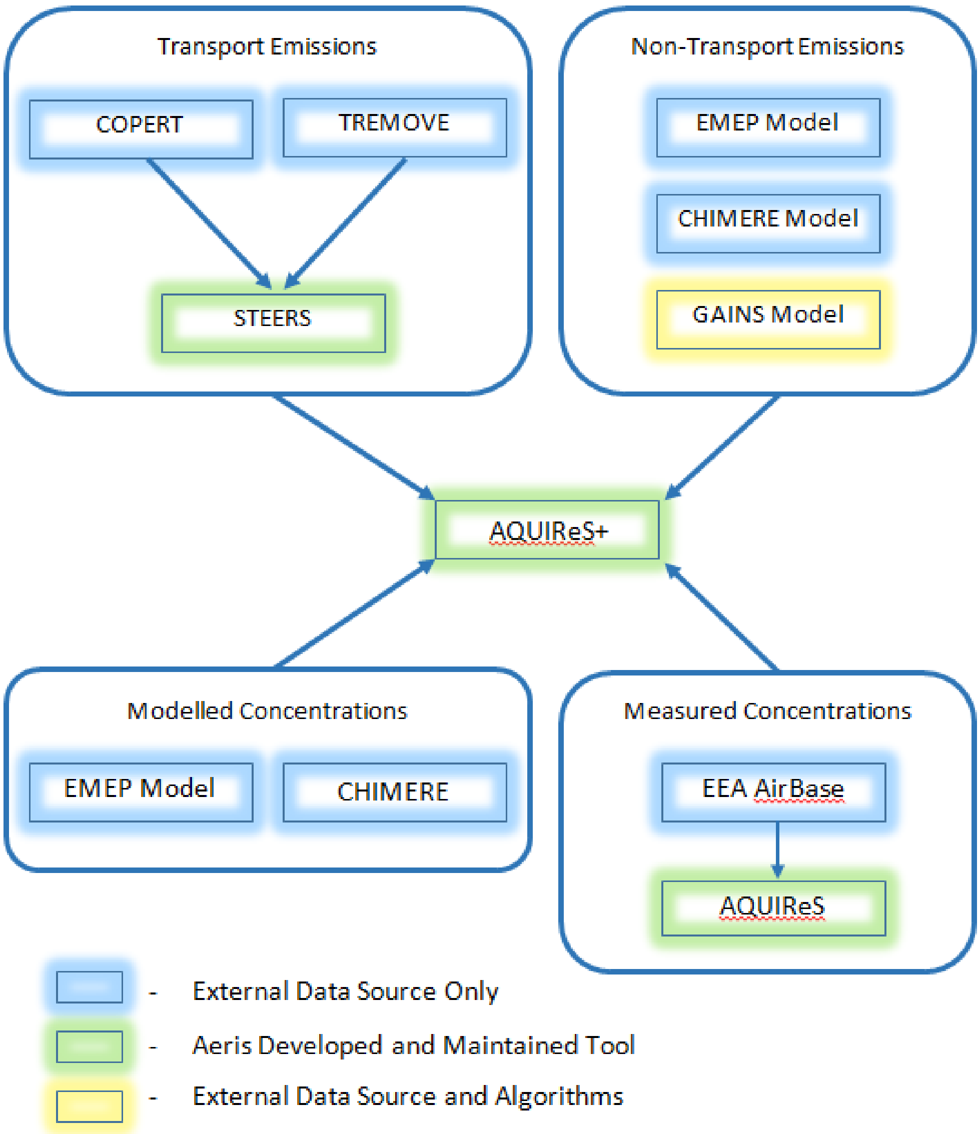
5 METHODOLOGY OVERVIEW

This study utilised data and results from a number of third-party and proprietary modelling tools, the interactions between these tools are illustrated in Figure 5.1. At the centre of the flowchart lies AQUIReS+, developed by Aeris Europe. This modelling tool is designed to assess the impact on air quality for any given emissions scenario at both individual measuring station level and Air Quality Management Zone level.

The inputs to AQUIReS+ include: Road-transport emissions derived from COPERT, TREMOVE and CONCAWE's STEERS model. STEERS is a road transport emissions forecasting model developed and maintained by Aeris Europe. STEERS was configured specifically for this study using the latest version of COPERT 4 for emission factors and TREMOVE 3.3.2 ALT data for the vehicle fleet, speeds, usage splits and vehicle population decay functions. Non-road transport emissions are obtained from published outputs of the EMEP, GAINS and CHIMERE models.

Atmospheric concentration data is incorporated into AQUIReS+ from both modelled (EMEP and CHIMERE models) and measured (EEA AirBase) datasets.

Figure 5.1 - AQUIReS+ data interactions



5.1 EMISSIONS MODELLING

Road transport emission attenuation profiles representing the normalised change of emissions over time, were generated using emission forecasts from the STEERS model, initially to generate a Base Case emissions scenario using the TREMOVE 3.3.2 Alt fleet and COPERTv11 (June 2015 update) emission factors (EF). Although significant effort was made to identify the basis for the transport emissions modelling used to generate the scenarios found in the GAINS model, the required level of detail was not available.

In order to maintain consistency between this work and previously published IIASA scenarios developed in support of the TSAP revision process, the emissions for the various scenarios explored were generated using attenuation factors applied to GAINS sourced sectoral emissions. The specific GAINS baseline data set was the "Working Party on Environment (WPE) 2014 CLE: The updated current legislation projection for 2030 of the PRIMES 2013 reference activity projection". [2] This data provided the non-road transport emissions used in this study.

For scenarios involving the removal of selected elements of the vehicle fleet (Scenarios B and D), STEERS was used to segregate and subtract the relevant fleet specific emissions from the STEERS predicted total emissions. In order to calculate the attenuation factors to be applied to the GAINS emissions, the reduced emissions total was then divided by the unmodified emissions total.

For the accelerated fleet turnover scenario (Scenario C), COPERT emission factors within STEERS were modified to produce the modified emissions profile. This was achieved by replacing pre-Euro 5 Passenger Car Diesel (PCD) EF with Euro 6 EF. In the same way as above, the modified emissions total was divided by the unmodified emissions total to calculate the required attenuation factors to apply to the GAINS emissions.

The NO_X attenuation factors for scenario E "Euro 6 Diesel Performance" were calculated in the same manner (modified emissions/unmodified emissions) but, instead of using COPERT emission factors, the "Conformity Factor" (CF) approach was used to calculate emission factors based on multiples of the Euro 6 PCD Legislated Limit Value (LLV) of 0.08gNO_X/km[1]. This allowed scenarios based on the approach of the forthcoming Euro Real Driving Emissions (RDE) step to be explored.

Concurrent with the development of this study, there has been much debate over the reliability of the results from vehicle emissions testing programs and the emissions factors associated with them. In this study COPERT emission factors were used and on 9 October 2015 the European Research Group on Mobile Emission Sources (ERMES) issued an Information Paper: "Diesel light duty vehicle NO_X emission factors". In this document, the difference between "on-the-road" Euro 5 passenger car NO_X EF and "the modelled" EF currently in use is stated to be small and not in need of urgent revision. In the information paper, there is a clear recognition of the difference between passenger car EFs and those for light duty commercial vehicles and a revision to the light duty commercial emission factors is in hand. [3]

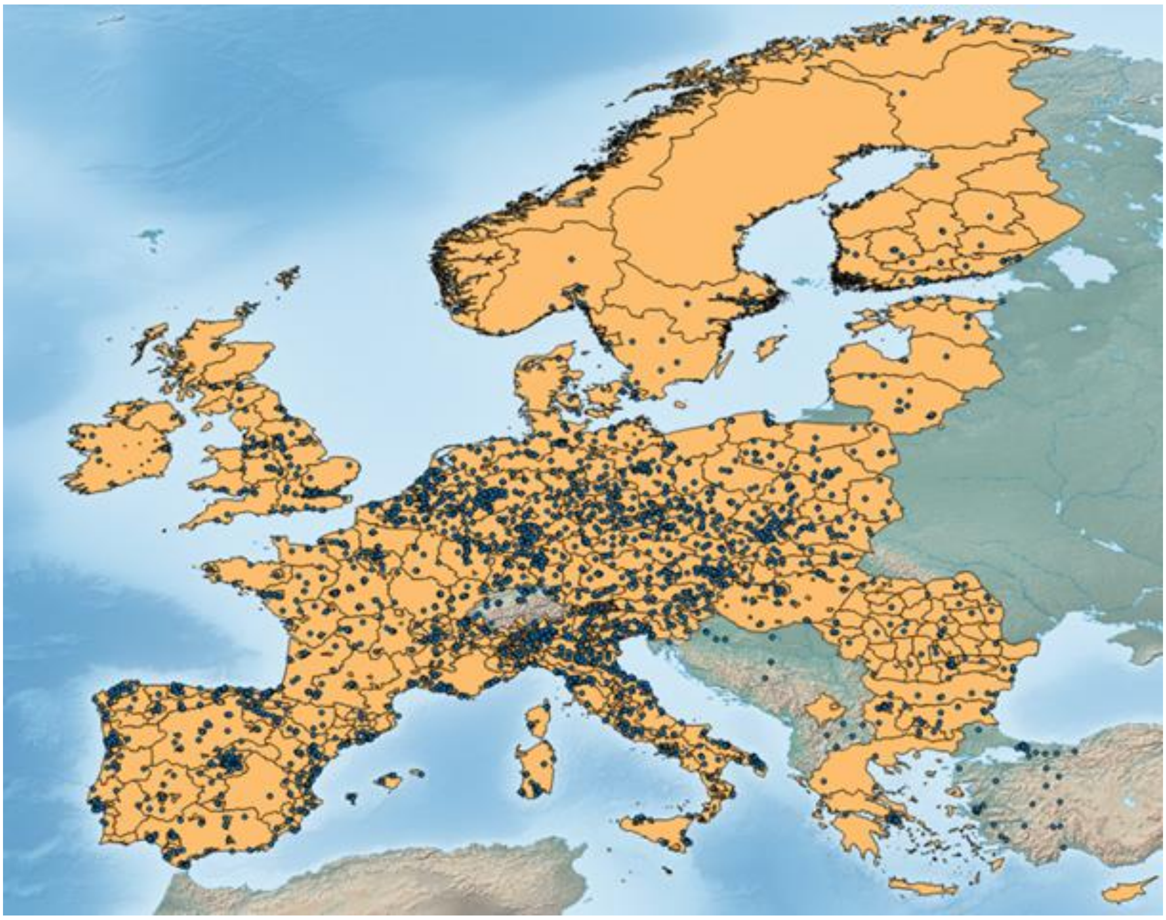
Regarding Euro 6 vehicles, the ERMES paper indicates that early test data is showing that NO_X emissions are of the order of 0.3g/km. This is believed to be around 30% higher than the average Euro 6 emission factor produced by the major EF models (including COPERT). However ERMES point out that the actual "on the road" emission factors are anticipated to reduce significantly as the RDE certification program is implemented.

[1] REGULATION (EC) No 715/2007 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, 20th June 2007

5.2 AQUIRES+

AQUIReS+ was used to model the concentrations of $PM_{2.5}$, PM_{10} and NO_2 at air quality management zone (AQMZ) and measuring station resolutions. Air quality management zones are designated under the ambient air quality directive (2008/50/EC) and oblige Member States to divide their entire territory into zones. Zones can be regarded as the primary territorial units for assessment and management of air quality under the air quality directives. Figure 5.2 illustrates the European zones and distribution of measuring stations used in this report.

Figure 5.2 - European AQMZ and measuring stations



The compliance of individual stations within each zone is used to determine overall zone compliance, specifically the single least compliant station is chosen for $PM_{2.5}$ and NO_2. This means that zone compliance is reflective of the "worst" compliance situation within that zone. Whilst zones are intended to be representative of the air quality over the entire area covered it is likely that a single station modelled as non-compliant will result in the entire population of a zone being interpreted as exposed to levels of PM or NO_2 above the limit value. Given that a zone may have a population of 500,000 or more and a traffic station may be measuring an area as little as $200m^2$; exceedance at the traffic station level clearly cannot be taken to be indicative of population exposure within a whole zone. This may be of little issue when a zone is limited to a single city or region within an urban agglomeration however when the zone simultaneously contains large rural and urban areas the concentration across the zone could vary significantly. No attempt has been made to allow for this circumstance and detailed analysis of population exposure needs to be undertaken with care. In the case of PM_{10} an average of the stations within each zone is used. Some zones are excluded from the modelled results; this is due to either the zone containing no measuring stations or any measuring stations present lacking the required pre-requisites for inclusion in the model.

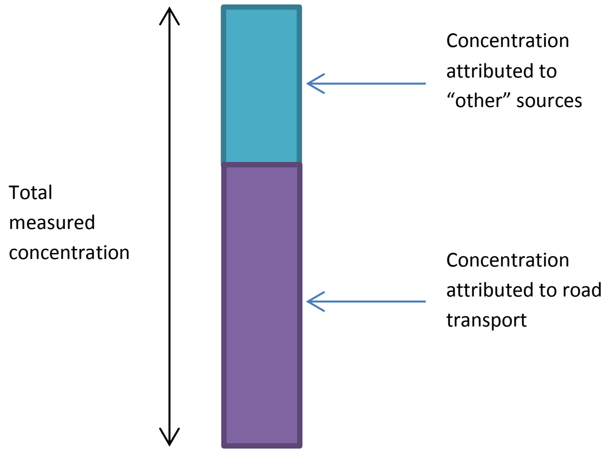
5.3 AQUIRES+ METHODOLOGY - NITROGEN DIOXIDE (NO_2)

The relationship between NO_X emissions and NO_X and NO_2 concentrations is a complex one that has to include a number of different location specific factors. In complex atmospheric chemistry models, allowances must be made for local oxidation potentials; the influence of ozone and how this varies with season, altitude and temperature; the specific mix of road transport in the area and local driving patterns; domestic combustion and other NO_X sources in the immediate vicinity.

Due to the extensive historical data included in AQUIReS, many of these factors can be derived, at least at a screening level. For example from measured annual mean concentrations of both NO_X and NO_2 at a specific measuring station in combination with AQUIReS+, we are able to determine how this relates to historical changes in emissions in the local area as well as nationally.

Given its focus on road transport, an important aspect of this study is to robustly determine the proportion of road transport derived NO_2 as opposed to that attributable to other sources. For each measuring station AQUIReS+ is able to tailor the local emissions profile by adjusting the contribution of the urban emissions to total concentration using actual (real world) measurements to provide a best fit with historical measurements. Figure 5.3 illustrates an example NO_2 concentration apportionment.

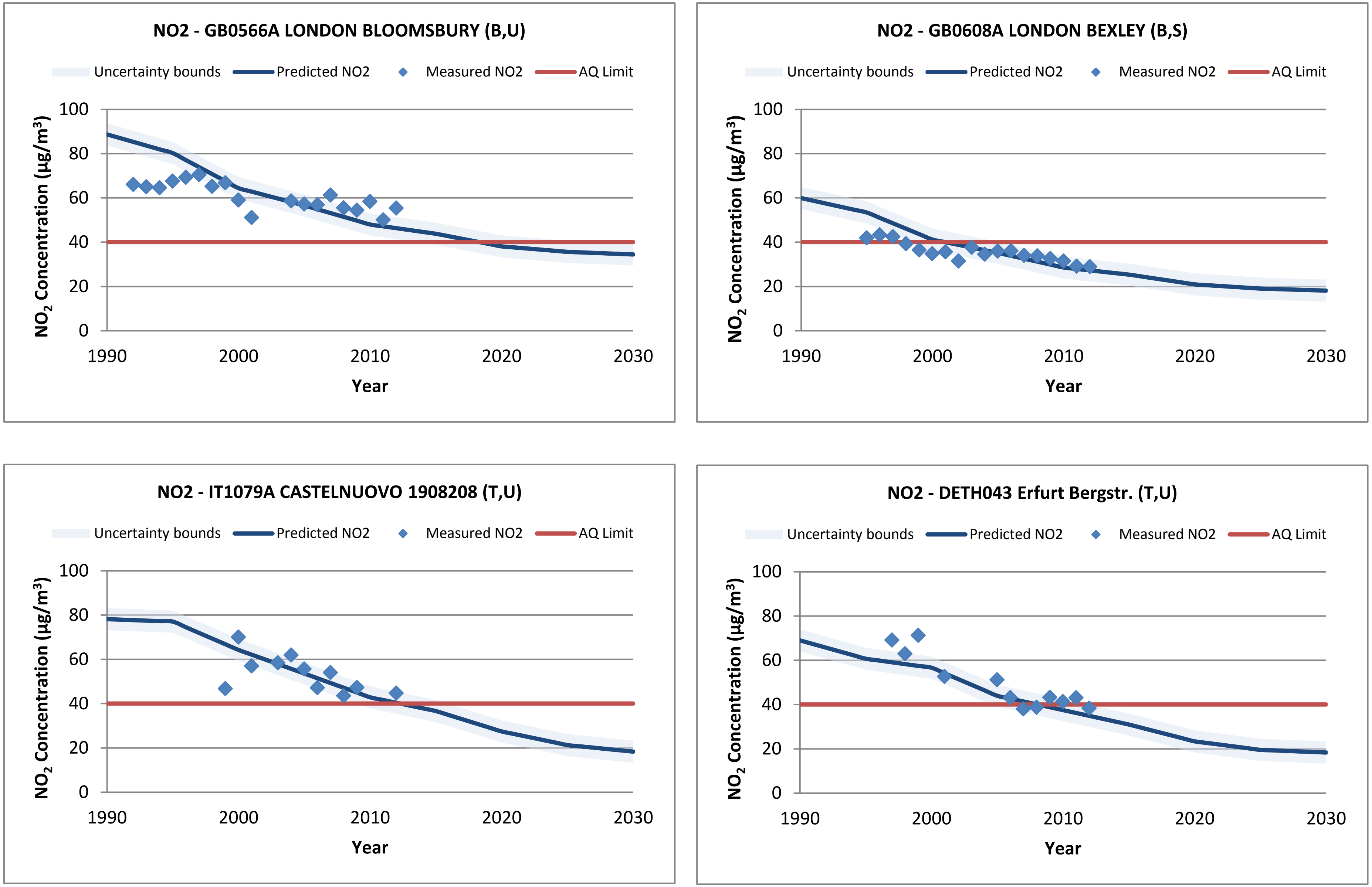
Figure 5.3 - NO_2 source apportionment



The reliability of the predictions is verified using a "hindcasting" technique and root mean square RMS error calculation. Hindcasting operates much like forecasting however by predicting past values and comparing them with historical measured values we can best ensure a robust assessment of future compliance.

Figure 5.4 shows the measured concentrations of NO_2 at four example measuring stations for all valid years from 1990 to 2012 and the predicted concentrations from 1990 to 2030. The predicted data are derived using the AQUIReS+ methodology.

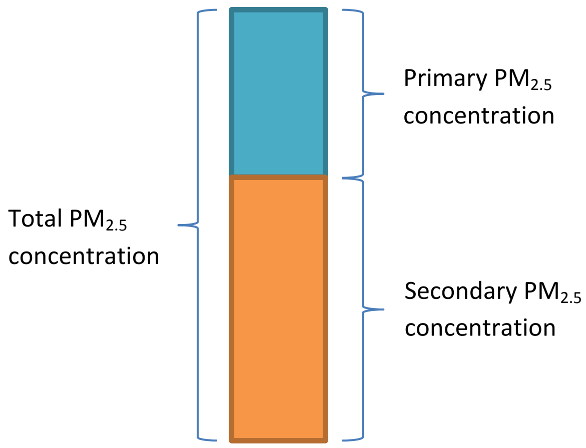
Figure 5.4 - Measuring station modelled-vs-measured comparisons (NO_2)



5.4 AQUIRES+ METHODOLOGY - $PM_{2.5}/PM_{10}$

The relationship between emissions and particulate matter (PM) concentration is particularly complex due to the fact that a significant, but varying portion of the total PM concentration derives from secondary sources. PM is made up of a primary and a secondary component; primary PM (PPM) is emitted at source with subsequent changes due to physical processes only e.g. agglomeration. Secondary PM (SPM) is formed from SO_2, NO_X, NH_3 & VOC emissions by chemical & physical processes in the atmosphere. This means that much of the PM measured at an air quality measuring station may have been emitted as a totally different chemical elsewhere, including transboundary sources. Figure 5.5 shows an example primary/secondary PM split.

Figure 5.5 - $PM_{2.5}$ source apportionment

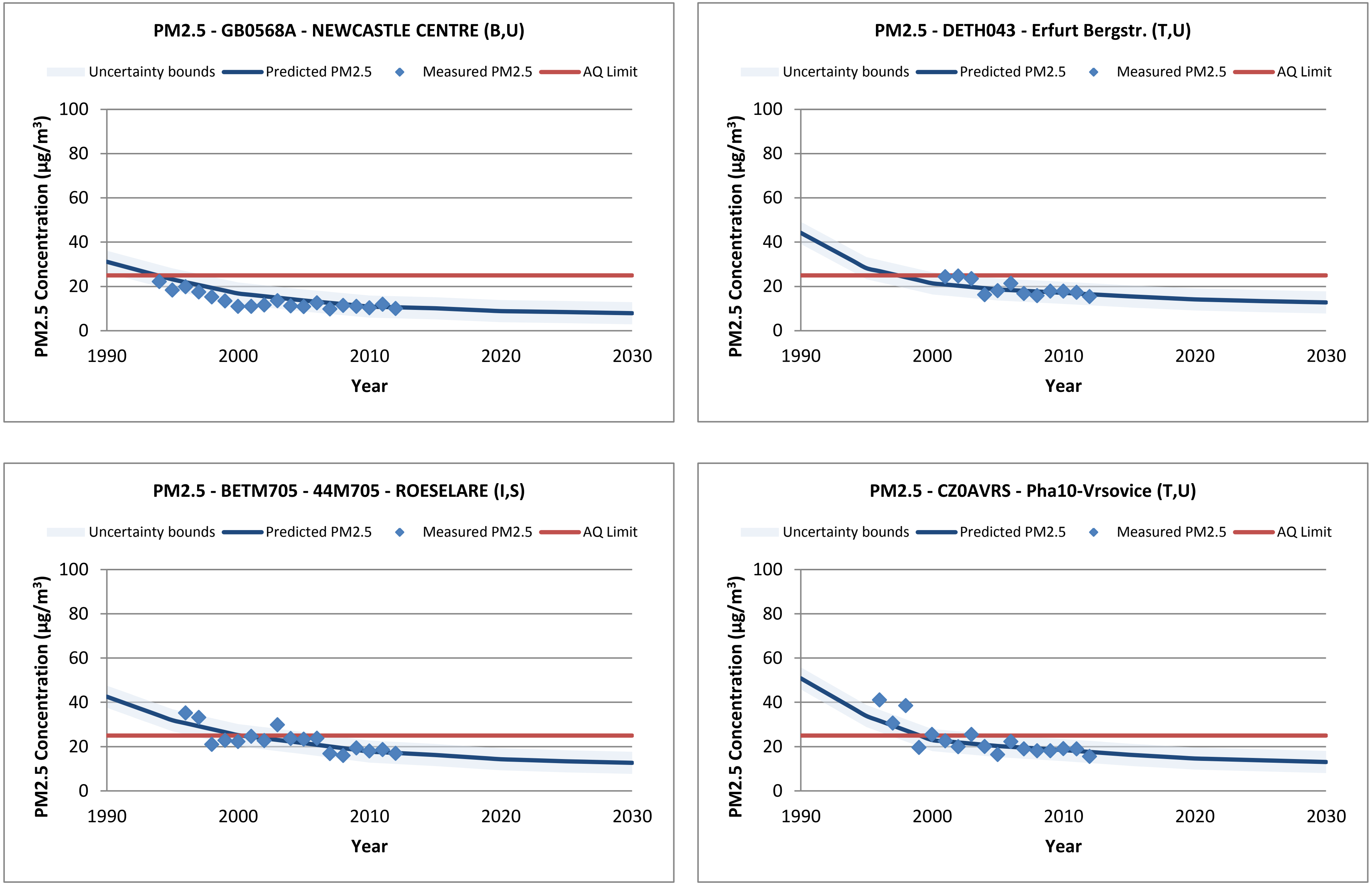


In the case of PM_{10} there are two limit values, an annual mean and a daily exceedance limit. As the daily exceedance limit is “stricter” than the annual mean - i.e. a member state will breach the daily exceedance limit before the annual mean limit - daily exceedances for this pollutant were therefore the focus in this study. Based on an analysis of the large number of daily measurements contained in AQUIReS data base, the median of the annual mean that corresponds to the annual limit value 35 of exceedances of the 50µg/m^3 daily mean PM_{10} is about 31µg/m^3. Of course, in reality this “surrogate” annual mean value varies depending on the measuring station location. To account for this, the IIASA approach has been adopted. [4] This uses an annual mean surrogate value of >35µg/m^3 to imply a high likelihood of exceeding the 35 allowed daily exceedances in that year (i.e. non-compliance); an annual mean < 25µg/m^3 to imply a low likelihood of exceeding the 35 allowed daily exceedances in that year (i.e. compliance) and in-between compliance/non-compliance is uncertain.

As for NO_2, the reliability of the predictions is verified using a “back-casting” technique and RMS error calculation.

Figure 5.6 shows the measured concentrations pf $PM_{2.5}$ at four example measuring stations for all valid years from 1990 to 2012 and the predicted concentrations from 1990 to 2030, the predicted data is derived entirely using the AQUIReS+ methodology.

Figure 5.6 - Measuring station modelled-vs-measured comparisons ($PM_{2.5}$)



5.5 UNCERTAINTY BOUNDS

All predictions contain an element of uncertainty and it is important not to misrepresent the certainty of modelled outputs, therefore all representations of the data in this study incorporate uncertainty bounds. These are represented by an allowance either side of the predicted value that reflects the actual value appearing somewhere within that range of values.

These uncertainty bounds reflect unavoidable uncertainties in monitoring data, modelling techniques and future meteorological conditions. They should be set wide enough to have little influence when discussing highly compliant or highly non-compliant measuring stations, however where a station concentration is predicted to be close to the air quality limit value it is important to show that the station may or may not be compliant within the sensitivity of the system. Essentially, for any station modelled within the uncertainty bound, compliance is possible but uncertain.

In accordance with already published works[1] on this matter a 5 µg/m^3 allowance either side of the limit value has been chosen.

Table 5.1 summarises the uncertainty bounds used for each pollutant.

Table 5.1 - Uncertainty bounds by pollutant

Pollutant	Limit Value	Uncertainty Bounds
$PM_{2.5}$	25 µg/m^3	±5 µg/m^3
PM_{10}	30* µg/m^3	±5 µg/m^3
NO_2	40 µg/m^3	±5 µg/m^3

* Exceedance surrogate value

To make it easier to visualise these uncertainty bounds a simple traffic-light system has been adopted, the following figures illustrate this.

NO_2 UNCERTAINTY BOUNDS

Likely Compliant	< 35 µg/m^3
Uncertain Compliance	35-45 µg/m^3
Likely Non-Compliant	> 45 µg/m^3

$PM_{2.5}$ UNCERTAINTY BOUNDS

Likely Compliant	< 20 µg/m^3
Uncertain Compliance	20-30 µg/m^3
Likely Non-Compliant	> 30 µg/m^3

PM_{10} UNCERTAINTY BOUNDS

Likely Compliant	< 25 µg/m^3
Uncertain Compliance	25-35 µg/m^3
Likely Non-Compliant	> 35 µg/m^3

[1] Amann, M. TSAP Report# 11 - The Final Policy Scenarios of the EU Clean Air Policy Package, Feb. 2014 - International Institute for Applied Systems Analysis (IIASA)

5.6 AQUIRES+ PERFORMANCE EVALUATION

To further evaluate the performance of AQUIReS+, direct comparison of the model output has been compared to actual measuring station data submitted to the EEA AirBase database by EU Member States.

In order to achieve a meaningful comparison only those stations that have valid measurements for 2013 and also appear in the model are considered (Table 5.2). The number of “common” urban stations is 800, somewhat lower than the modelled number; this is primarily due to the large number of NO_2 measuring stations that have been commissioned in the last few years. These stations have an insufficient number of ‘data years’ to enable robust prediction algorithms to be developed for inclusion in AQUIReS+. However, as time progresses and these stations record enough data to become “predictable”, they will be included in the model.

Table 5.2 - Common urban station compliance comparison (NO_2)

Measured (2013)			Predicted (2013)		Predicted (2015)	
Concentration	# Stations	% Stations	# Stations	% Stations	# Stations	% Stations
< 35 µg/m^3	635	79%	636	80%	663	83%
35-45 µg/m^3	111	14%	99	12%	89	11%
> 45 µg/m^3	54	7%	65	8%	48	6%
Total	800		800		800	
< 40 µg/m^3	701	88%	685	86%	707	88%
> 40 µg/m^3	99	12%	115	14%	93	12%

The first section of Table 5.2 employs the previously defined “uncertainty bounds” and applies these to both the measured and the modelled concentrations. This shows a high degree of agreement, with the model predicting slightly higher (1%) non-compliance in 2013 than is actually observed. The second section shows the strict AQLV cut-off of 40µg/m^3 for both the measured and modelled concentrations; again the model is predicting slightly higher non-compliance than is measured.

To ascertain whether the non-common stations affect the accuracy of the model the above table is produced below (Table 5.3) with all stations from AirBase and the model included.

Table 5.3 - All urban stations compliance comparison (NO_2)

Measured (2013)			Predicted (2013)		Predicted (2015)	
Concentration	# Stations	% Stations	# Stations	% Stations	# Stations	% Stations
< 35 µg/m^3	1110	75%	920	78%	967	82%
35-45 µg/m^3	215	15%	159	13%	146	12%
> 45 µg/m^3	152	10%	107	9%	73	6%
Total	1477		1186		1186	
< 40 µg/m^3	1218	82%	1000	84%	1040	88%
> 40 µg/m^3	260	18%	186	16%	146	12%

When including all urban stations the output of the model is within 1% of the non-compliance count for 2013 using the uncertainty bounds and shows good agreement, (2% difference) when using the strict AQLV cut-off. These results provide a high level of confidence that the model is ‘fit for purpose’ in assessing future compliance.

NOTE - UNCERTAINTY BOUNDS

The results given in Table 5.3 also provide further insight into the overall compliance situation derived from the uncertainty bands. The actual (measured) compliance with 40µg/m^3 in 2013 is 82%. When the uncertainty band are applied to this measured data only 75% fall into the “likely compliant” category with 15% falling into the “uncertain compliance category”. This means that half of the “uncertain compliance” stations are actually compliant. When interpreting the results of the modelled compliance presented in this report the number of “amber” stations (those predicted with “uncertain compliance”) should be divided equally between the “likely compliant” and “likely non-compliant” categories to provide an overall compliance/non-compliance perspective. This approach is supported by sensitivity analysis performed on the outputs as part of this study; these reveal that as a general rule there are approximately an equal number of stations below the limit value as above the limit value within the uncertainty band.

6 THE "BASE CASE"

The “Base Case” scenario generated for this study is calibrated to measured concentrations (“real world”) PM and NO_2 concentrations, and uses attenuation profiles[1] to predict future compliance and to inform each scenario. As the Base Case is emissions profile driven, it is possible to run scenarios that reflect changes to emissions at a sector specific level. It is therefore possible to attenuate a specific proportion of a country’s future emissions and determine how this modification will affect atmospheric concentrations in both the immediate vicinity and across the larger European area. Each scenario is represented by a unique attenuation profile and all scenarios entered into the system include attenuated emissions of a specific sector, e.g. “road transport” or “domestic combustion”.

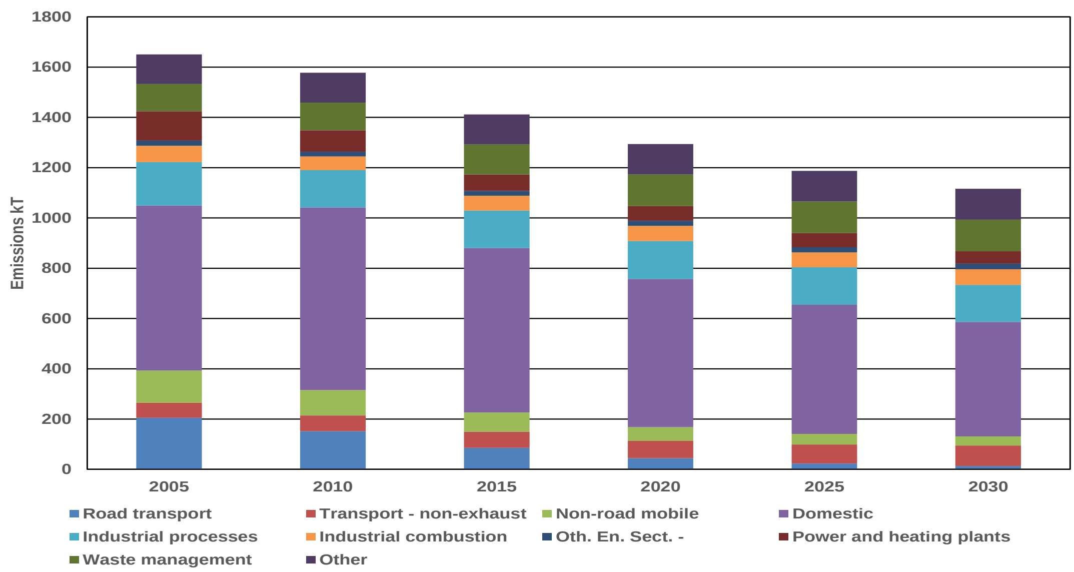
6.1 $PM_{2.5}$

PRIMARY $PM_{2.5}$ EMISSIONS

It is important to understand how primary $PM_{2.5}$ emissions from road transport compare to other sources of primary $PM_{2.5}$ and how this changes with time. Figure 6.1 shows the evolution of anthropogenic primary $PM_{2.5}$ in the EU for the January 2015 TSAP16 WPE Baseline Scenario associated with the EU Air Policy Review process as generated by IIASA’s GAINS model. This clearly illustrates the diminishingly small contribution from the engine/exhaust of road transport in the period from now to 2030. In the case of road transport, non-exhaust becomes the dominant source (albeit small as a contribution to the total concentration) rendering primary $PM_{2.5}$ emissions from road transport independent of the power train (e.g. a diminishingly small difference between a diesel power train and an electric vehicle on a per kilometre basis).

Figure 6.1 also highlights the importance of domestic fuel burning to the overall inventory of primary $PM_{2.5}$. These emissions largely derive from the continued use of solid fuels in the domestic sector in the Eastern part of the EU.

Figure 6.1 - EU27: $PM_{2.5}$ Emissions Aggregated by Key Sector (Source: IIASA GAINS TSAP16 CLE WPE Scenario)



[1] An emission attenuation profile represents the normalised change of emissions over time

$PM_{2.5}$ AIR QUALITY

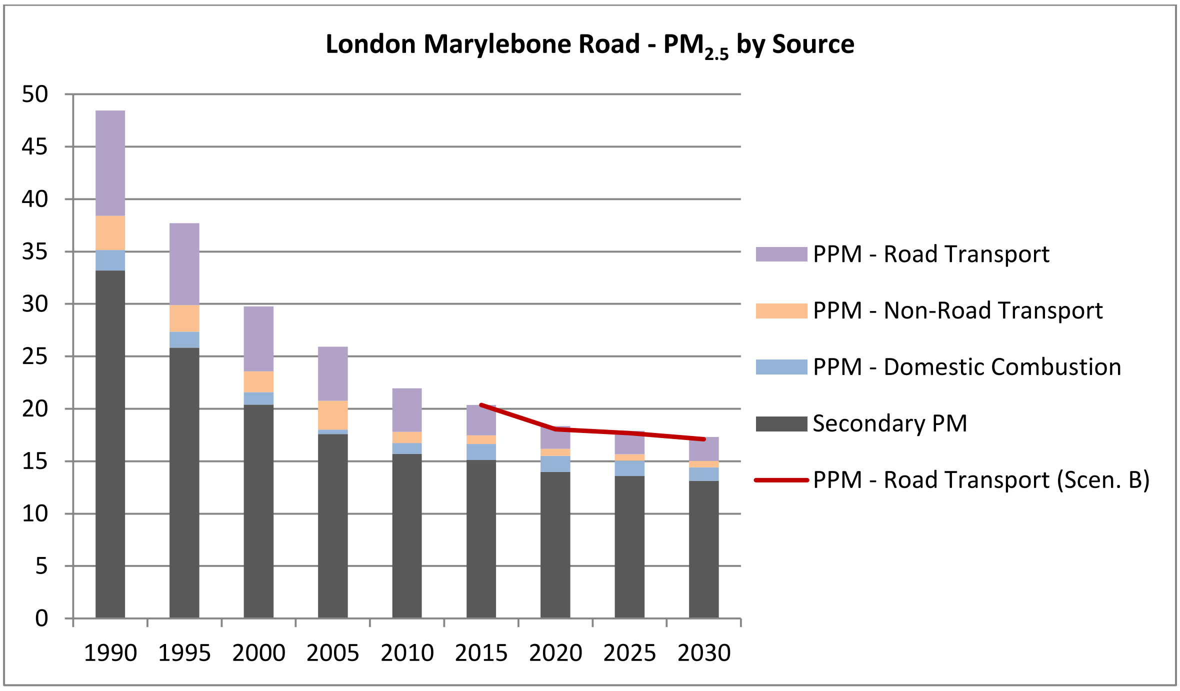
The Base Case results (see Figure 6.4 - Figure 6.8) indicate that in 2015 the percentage of the EU population living in "likely non-compliant" zones (max modelled concentrations above 30µg/m^3) is only 4%; with 68% of the population in "likely compliant" (modelled concentrations below 20µg/m^3) zones and 28% of the population living in zones that are close to the AQLV (within zones of "uncertain compliance" between 20 and 30µg/m^3). The EU population living in these zones of "uncertain compliance" continues to decline between 2015 and 2030 as already legislated measures take effect so that the population living in likely compliant zones increases to 77% by 2020 and to 81% by 2030. At the same time, the population living in zones of uncertain compliance reduces to 19% by 2020 and to 15% by 2030. The percentage of population living in likely non-compliant zones remains unchanged at 4% from 2015. Please refer to Section 5.5 for more information on compliance categories.

The population living in zones with uncertain compliance continues to decline between 2015 and 2030 as already legislated measures take further effect. By 2030 the population living in likely compliant zones (modelled concentrations below 20µg/m^3) is approximately 81%.

Most non-compliance is seen in Eastern Europe and, based on the modelling results, is directly attributable to the domestic combustion of solid fuels that continues to take place in this region of the EU.

Figure 6.2 shows the modelled source contributions to total Base Case $PM_{2.5}$ concentrations at the "London - Marylebone Road" air quality measuring station (stacked bars). The overlaid red line shows the effect on total concentration that the elimination of *all diesel exhaust emissions* would have from 2015 onwards. This illustrates the increasingly small contribution of diesel exhaust to overall $PM_{2.5}$ concentrations as discussed above with reference to Figure 6.1.

Figure 6.2 - London Marylebone Road measuring station, $PM_{2.5}$ source apportionment



The stacked bars in Figure 6.3 show the Base Case modelled contributions to $PM_{2.5}$ concentrations at an urban background station in Krakow, Poland. Here the significant contribution from the continuation of burning solid fuel in the domestic sector is very evident with half of the contribution to overall $PM_{2.5}$ concentration coming from this source. To illustrate the impact at this station of switching to either fuel oil or gas in the domestic sector the overlaid red line has been included. Here, as explored later under "Scenario A" this has a profound impact on compliance with the $PM_{2.5}$ air quality limit value of 25µg/m^3.

Figure 6.3 - Krakow (PL0039A) measuring station, $PM_{2.5}$ source apportionment

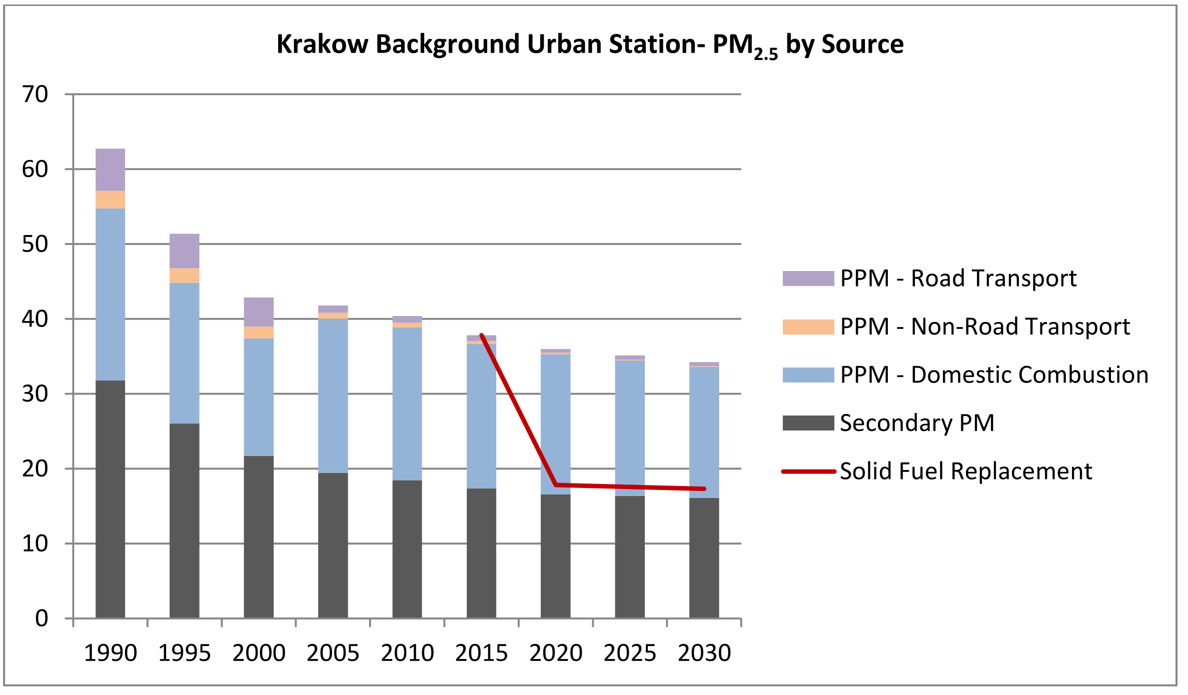


Figure 6.4 - $PM_{2.5}$ compliance by percentage of AQ zone population.

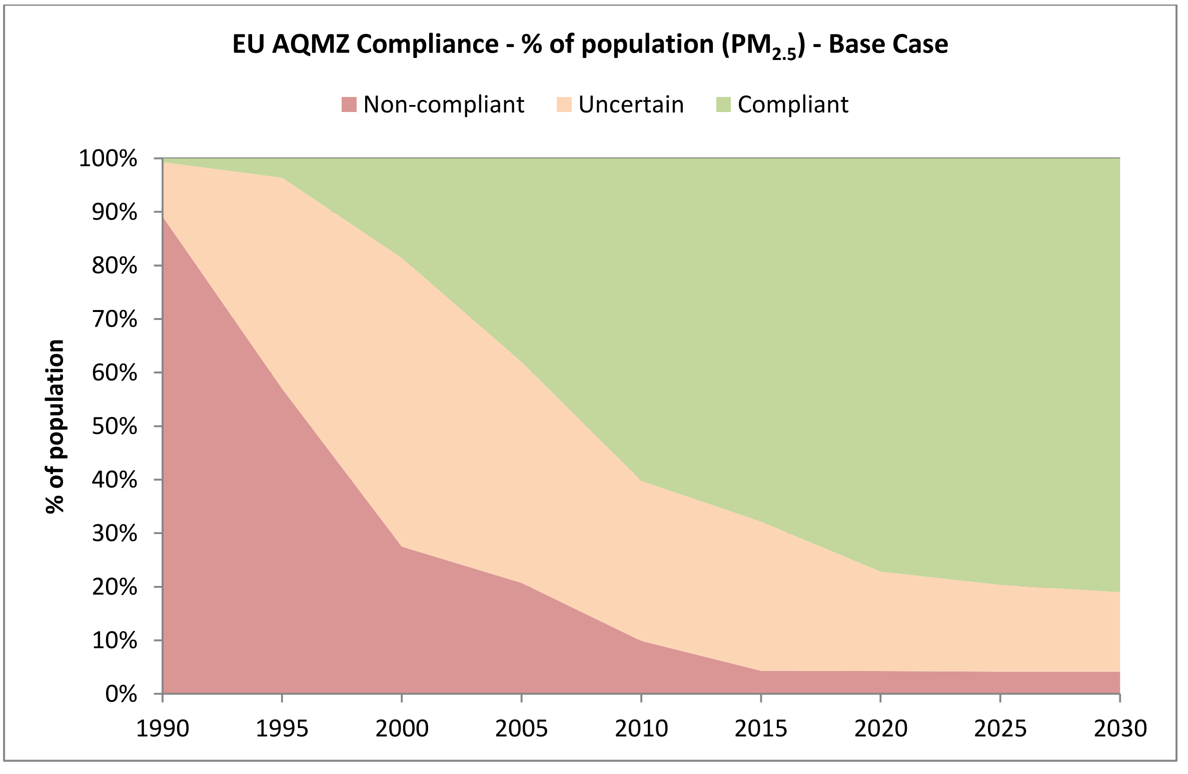


Figure 6.5 - Base Case - $PM_{2.5}$ - Air Quality Management Zone Compliance - 2010

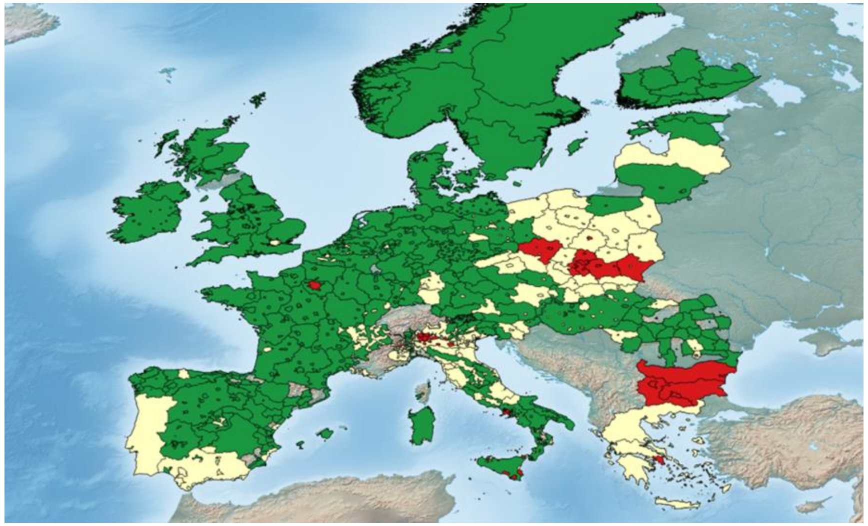


Figure 6.6 - Base Case - $PM_{2.5}$ - Air Quality Management Zone Compliance - 2020

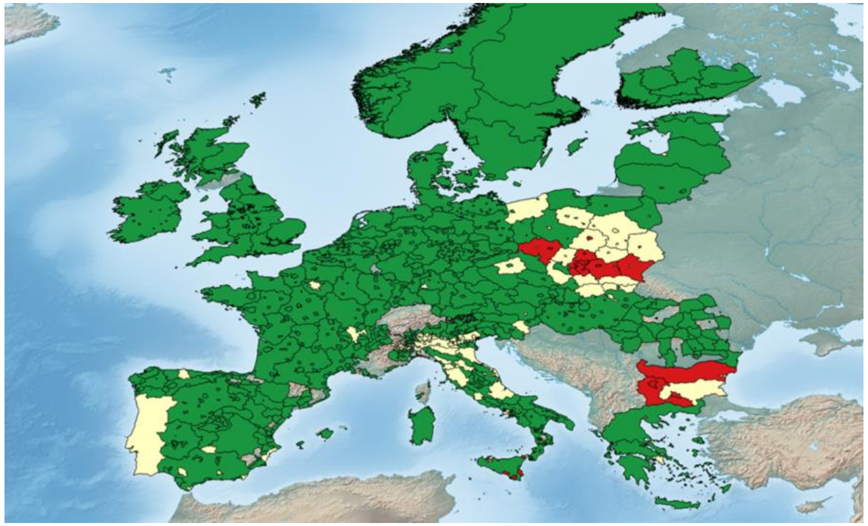


Figure 6.7 - Base Case - $PM_{2.5}$ - Air Quality Management Zone Compliance - 2025

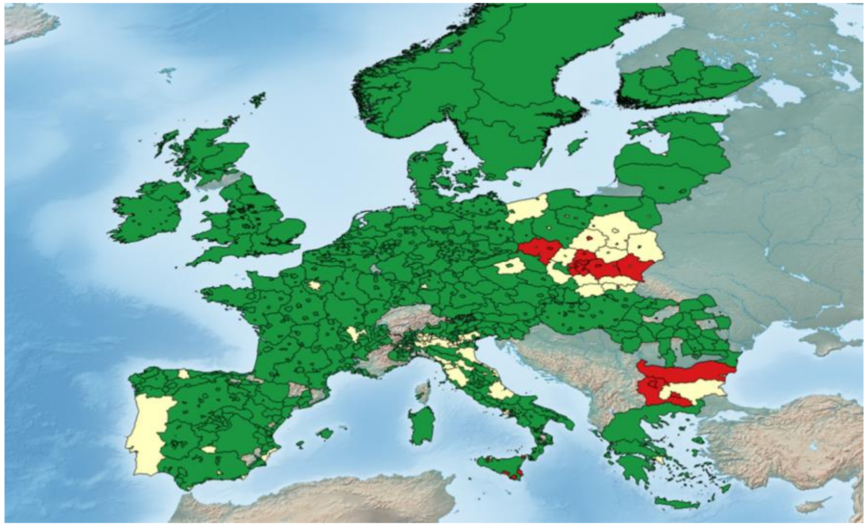
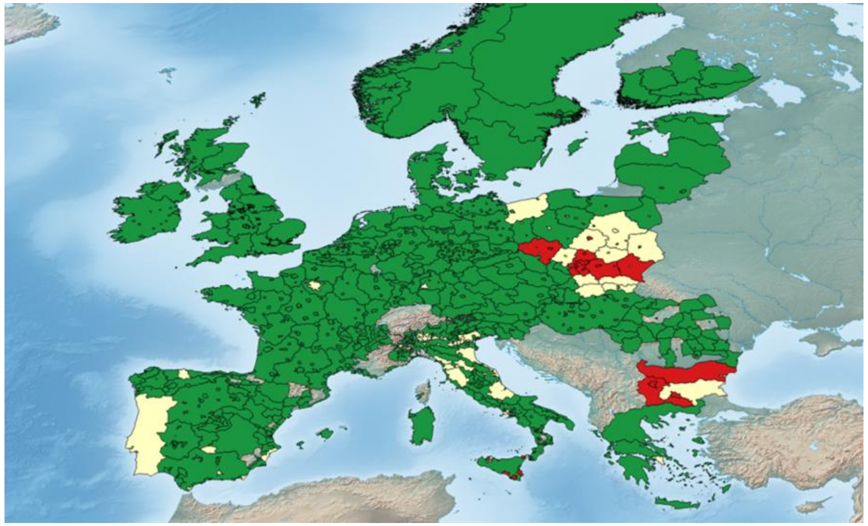


Figure 6.8 - Base Case - $PM_{2.5}$ - Air Quality Management Zone Compliance - 2030



6.2 PM_{10}

The Base Case modelling results (Figure 6.9 - Figure 6.13) indicate that in 2015 the percentage of EU population living in PM_{10} "non-compliant" zones (max modelled concentrations above 35µg/m^3) is approximately 7%; 66% of the population are living in "likely compliant" zones (modelled concentrations below 25µg/m^3) and 27% of the population live in zones that are within the modelled uncertainty bounds (between 25 and 35µg/m^3). Please refer to Section 5.5 for more information on compliance categories.

The population living in zones with uncertain compliance continues to decline from 2015 as already legislated measures take effect. By 2030 the population living in likely compliant zones (modelled concentrations below 25µg/m^3) is 83% and likely non-compliant zones near 3%.

As is the case for $PM_{2.5}$, most of the non-compliance is seen in Eastern Europe and based on the modelling results, is directly attributable to the domestic combustion of solid fuels that continues to take place in this region of the EU.

Figure 6.9 - PM_{10} compliance by percentage of AQ zone population.

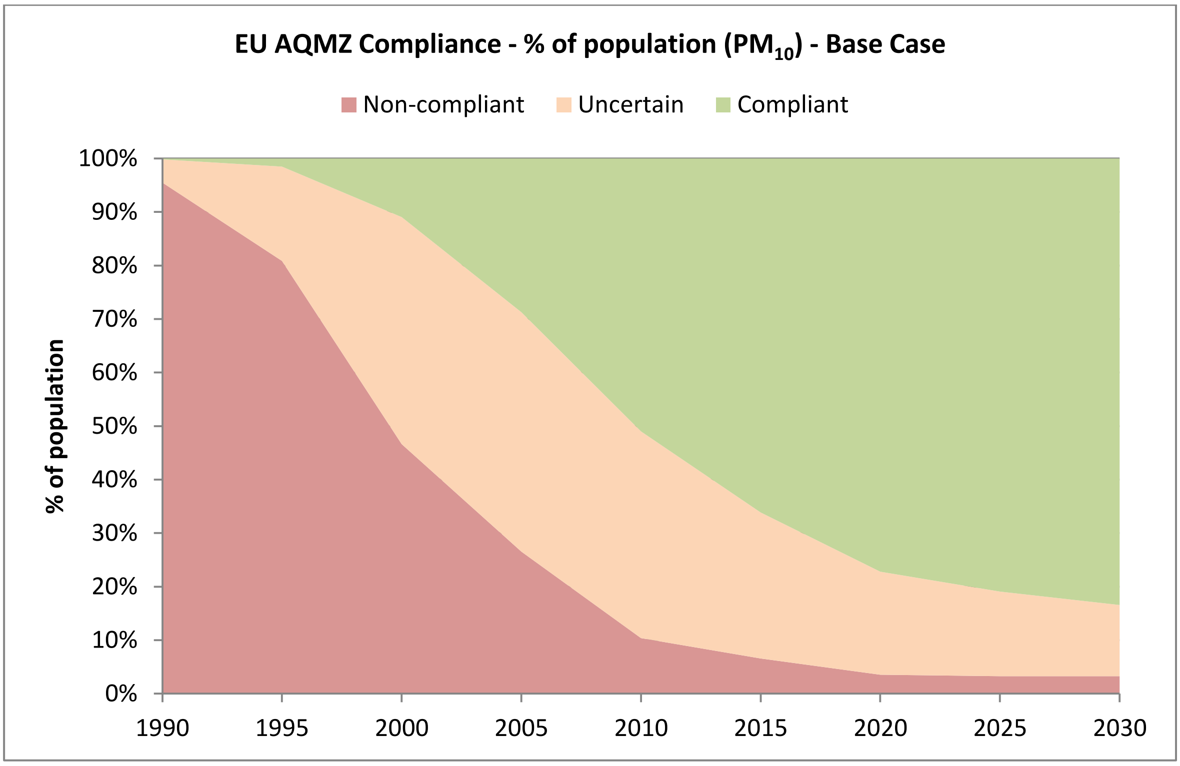


Figure 6.10 - Base Case - PM_{10} - Air Quality Management Zone Compliance - 2010

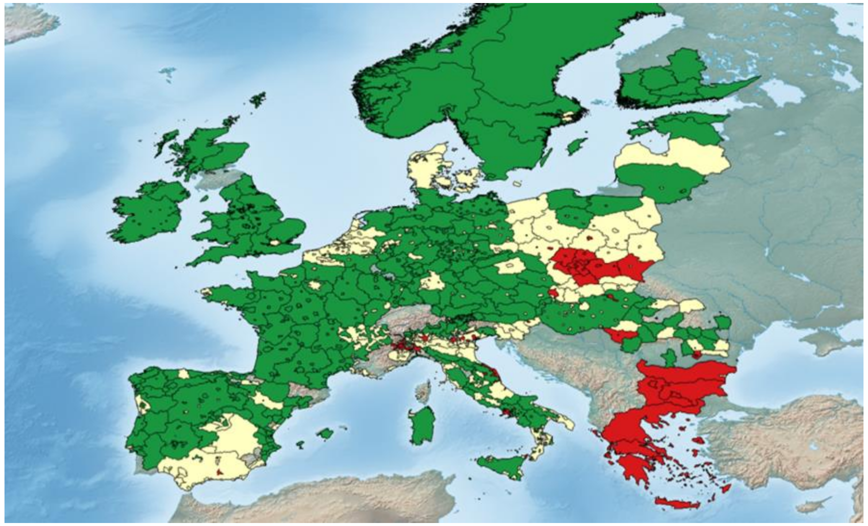


Figure 6.11 - Base Case - PM_{10} - Air Quality Management Zone Compliance - 2020

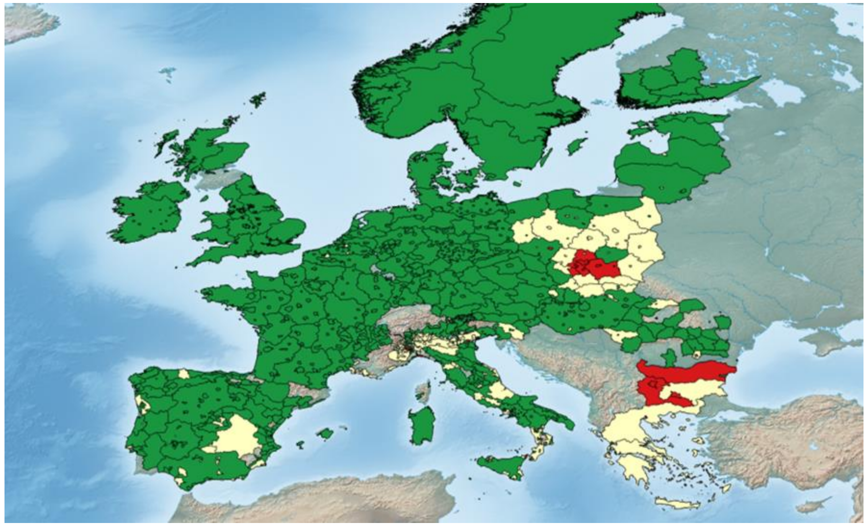


Figure 6.12 - Base Case - PM_{10} - Air Quality Management Zone Compliance - 2025

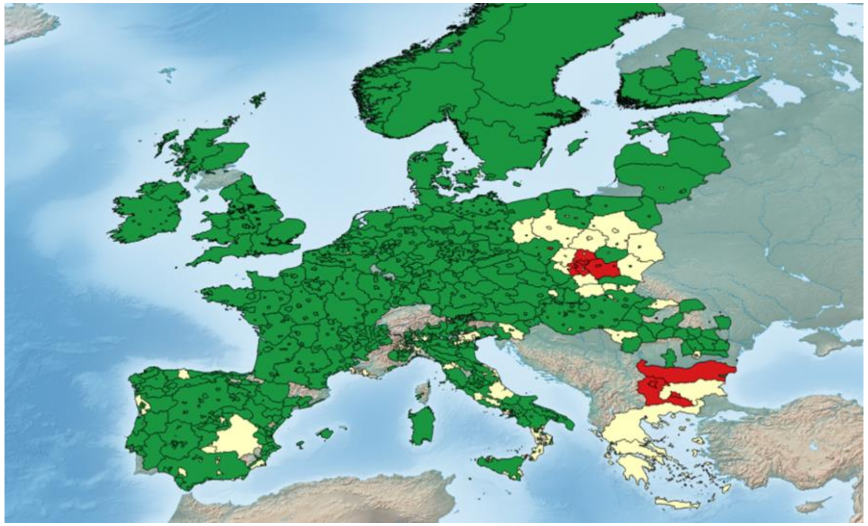
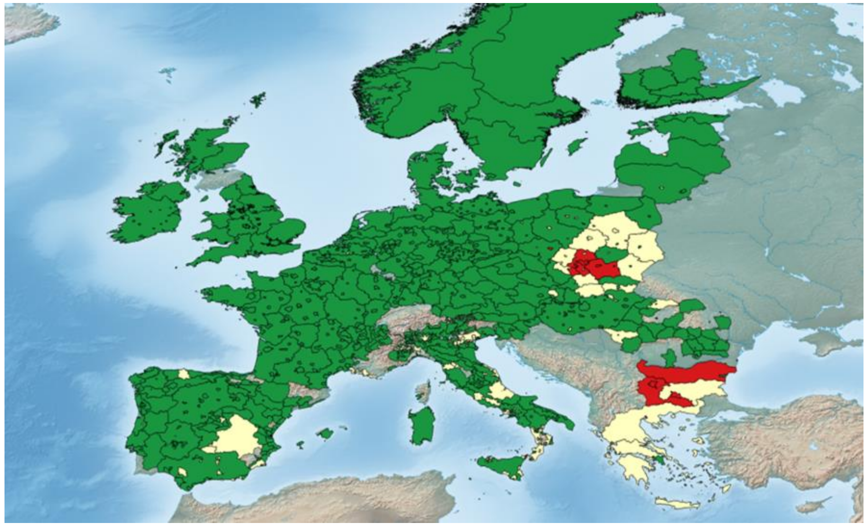


Figure 6.13 - Base Case - PM_{10} - Air Quality Management Zone Compliance - 2030



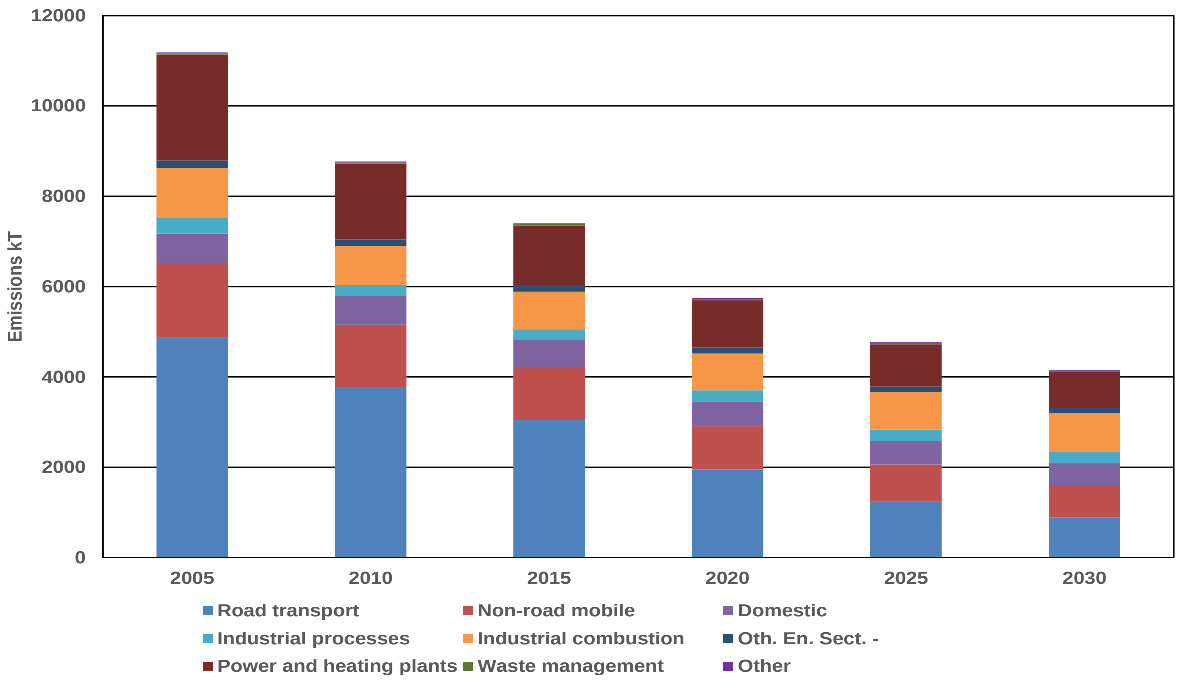
6.3 NITROGEN DIOXIDE (NO_2)

NO_X EMISSIONS

For NO_X emissions the proportion produced by road transport is reducing over time, this is consistent across all EU27 countries. By 2030 road transport is still a relatively large source of NO_X emissions, however by this time it only accounts for 21% of the total emissions compared with 41% in 2015.

It is important to understand how NO_X emissions from road transport compare to other sources and how this changes with time. Figure 6.14 below shows the evolution of NO_X emissions in the EU for the January 2015 TSAP16 WPE Current Legislation Baseline Scenario[1] associated with the EU Air Policy Review process as generated by IIASA's GAINS model and clearly illustrates the reducing contribution from road transport over time.

Figure 6.14 - EU27 NO_X Emissions by Key Sector (IIASA GAINS TSAP16 CLE WPE Scenario)



[1] The emission projections should be considered as conservative given that they do not reflect the effects of legislation for which the actual impact on future activity levels could not be quantified e.g. the Medium Combustion Plants Directive (MCPD) or the review of the National Emissions Ceilings Directive (NECD)

NO_2 AIR QUALITY

The Base Case modelling results (Figure 6.15 - Figure 6.19) indicate that in 2015 the percentage of EU population living in "non-compliant" zones (modelled concentrations above 45µg/m^3) is approximately 18%; while 69% of the population live in "likely compliant" zones (modelled concentrations below 35µg/m^3) and 13% of the population live in zones that are close to the AQLV and so within zones of "uncertain-compliance" (modelled concentrations between 35 and 45µg/m^3). Please refer to Section 5.5 for more information on compliance categories.

The population living in zones of "uncertain compliance" continues to decline between 2015 and 2030 as those already legislated measures that are included in the emissions inventories take effect and by 2030 the population living in "likely compliant" zones increases to almost 93%. Importantly, in the period from 2015 to 2030, the pattern of residual non-compliance moves from large contiguous areas to discrete, small islands of non-compliance. This has important implications for the design of efficient mitigation strategies.

Figure 6.15 - NO_2 compliance by percentage of AQ zone population.

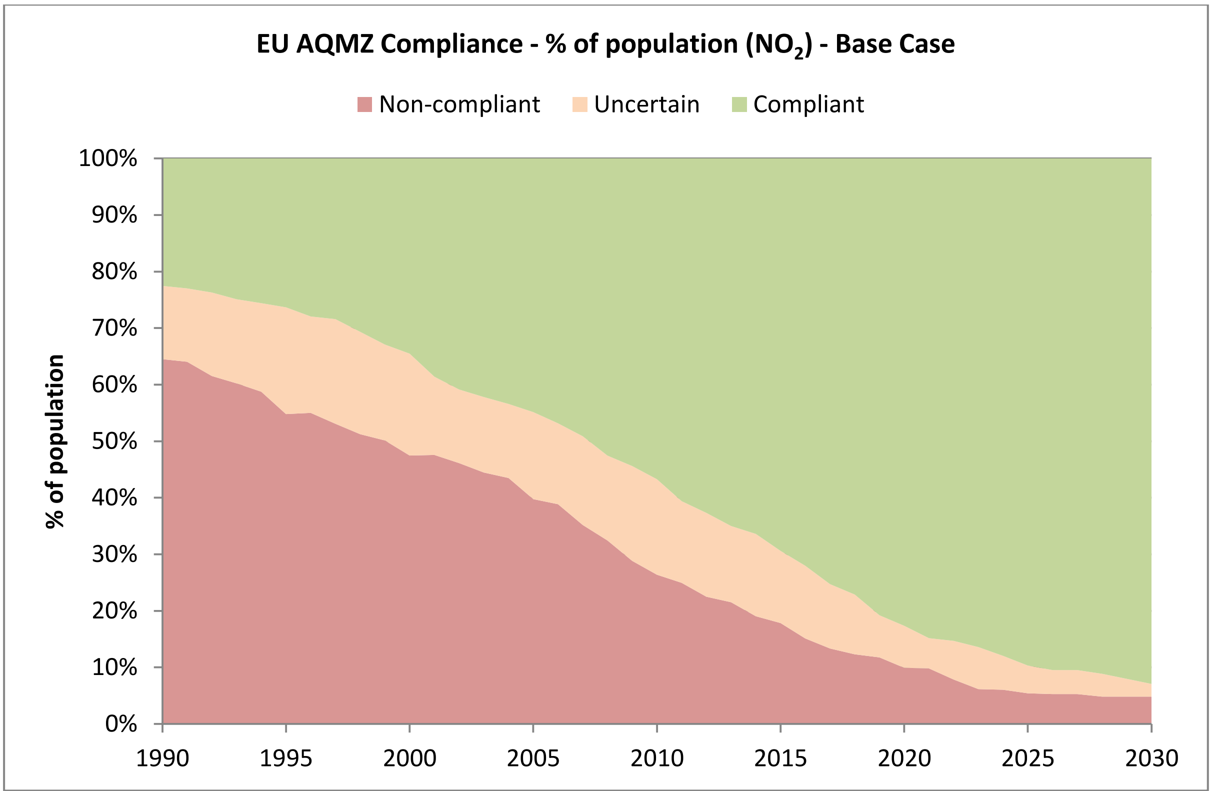


Figure 6.16 - Base Case - NO_2 - Air Quality Management Zone Compliance - 2010

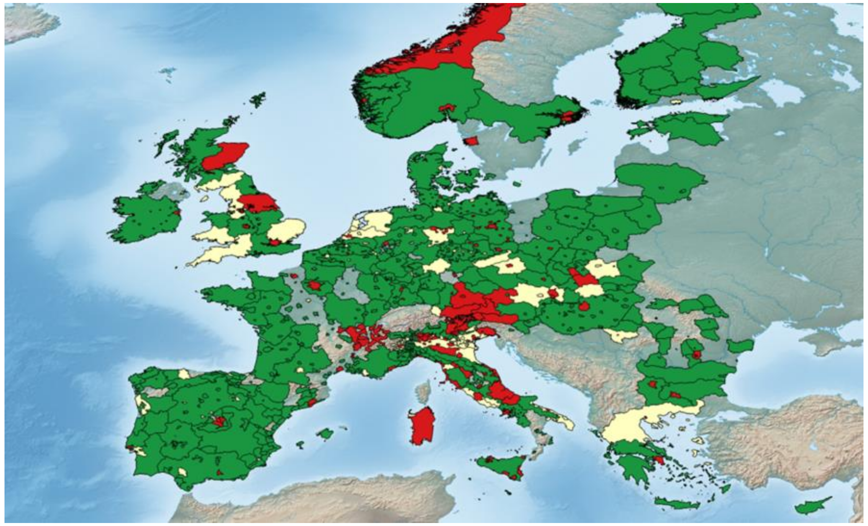


Figure 6.17 - Base Case - NO_2 - Air Quality Management Zone Compliance - 2020

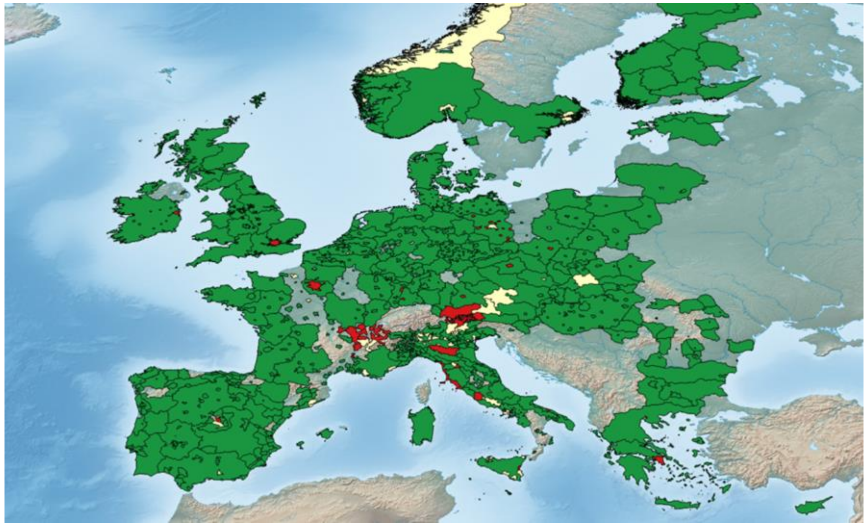


Figure 6.18 - Base Case - NO_2 - Air Quality Management Zone Compliance - 2025

Figure 6.19 - Base Case - NO_2 - Air Quality Management Zone Compliance - 2030

7 SCENARIOS

7.1 SCENARIO A - REMOVE DOMESTIC SOLID FUEL COMBUSTION

In this scenario all solid fuel combustion in the domestic sector is substituted by either gas or heating oil. On an energy released basis, natural gas and domestic heating oil generate about 1% and 2.5% respectively of the primary particulates that solid fuels such as wood and coal generate. To be conservative this scenario assumes that 2.5% of the solid fuel emissions are still produced.

The removal of solid fuel combustion and its replacement with gas or heating oil shows a marked difference in the proportion of the EU population in zones that are borderline compliant for both $PM_{2.5}$ and PM_{10} resulting in a significant overall improvement in air quality by 2020 and beyond. The difference is particularly evident in the case of PM_{10} where approximately 92% of the EU population would live in “likely compliant” areas and less than 1% in “likely non-compliant” areas by 2025 (Figure 7.2).

As anticipated, the greatest improvement is observed in those countries with high levels of solid fuel burning, particularly Eastern Europe (Figure 7.3 - Figure 7.6). Improvements are also seen in France and Italy due to the high level of wood burning in the domestic sector in these countries.

This indicates that countries currently experiencing PM_{10} compliance issues could significantly reduce this problem by reducing or eliminating solid fuel combustion in the domestic sector. This was highlighted during the technical phase of the European Commission’s Air Policy Review which resulted in the December 2013 proposed Air Policy Package [1].

Figure 7.1 - $PM_{2.5}$ compliance by percentage of AQ zone population. Scenario A

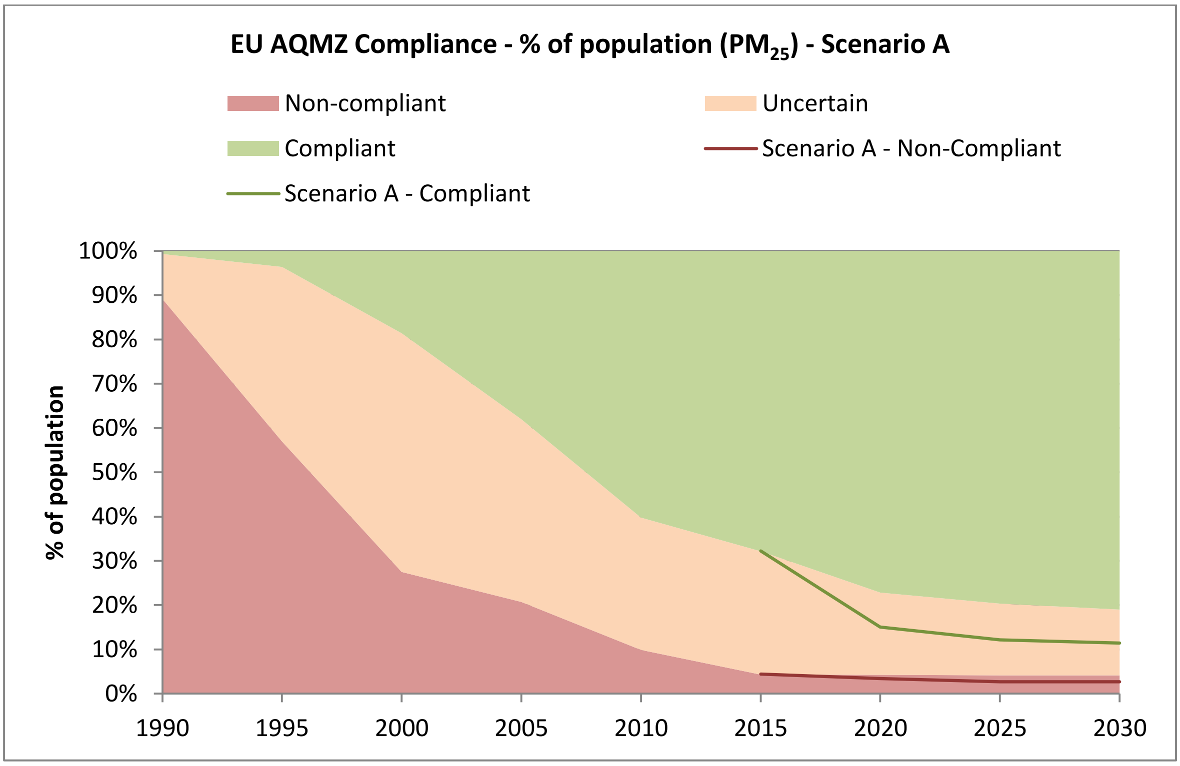


Figure 7.2 - PM_{10} compliance by percentage of AQ zone population. Scenario A

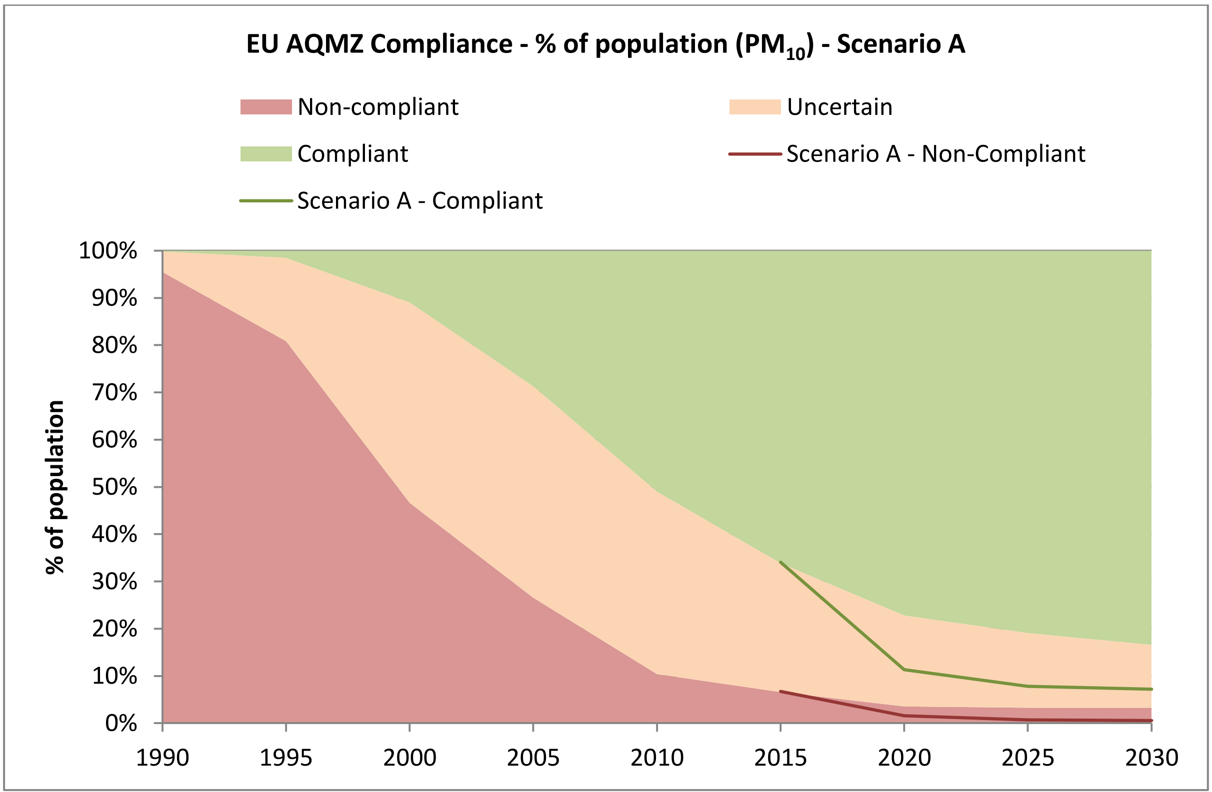


Figure 7.3 - Scenario A - $PM_{2.5}$ - Air Quality Management Zone Compliance - 2020

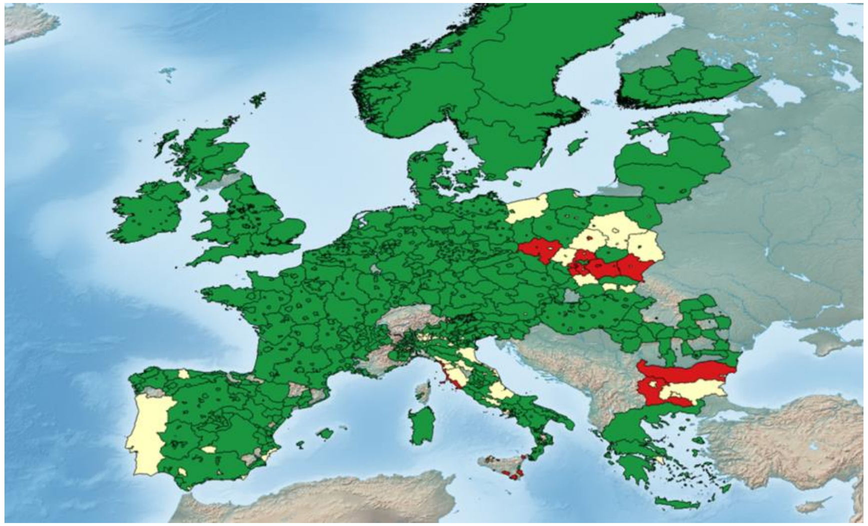


Figure 7.4 - Scenario A - $PM_{2.5}$ - Air Quality Management Zone Compliance - 2030

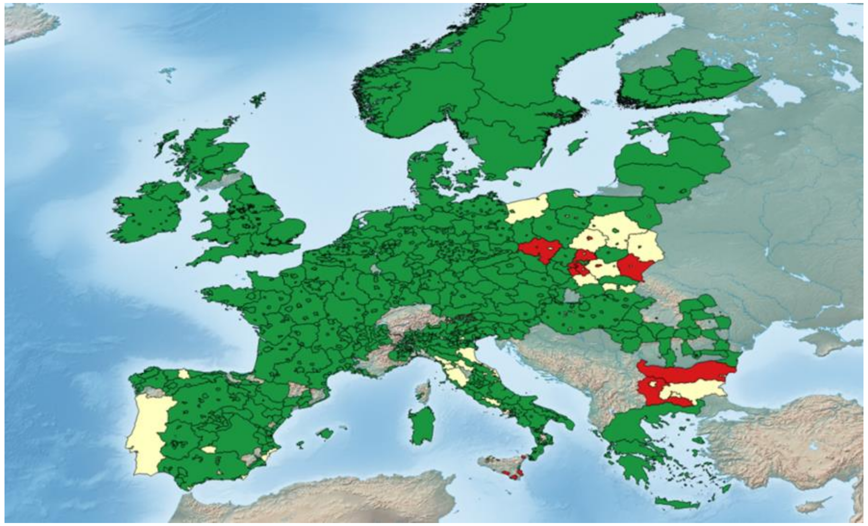


Figure 7.5 - Scenario A - PM_{10} - Air Quality Management Zone Compliance - 2020

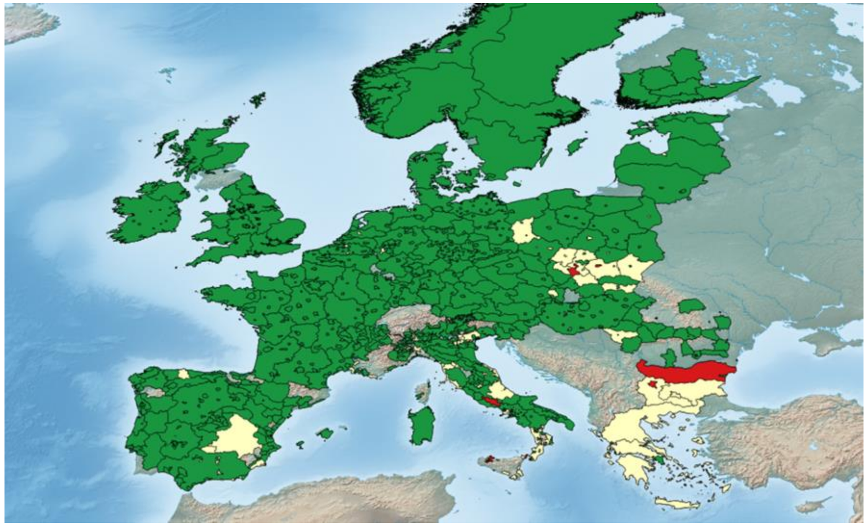
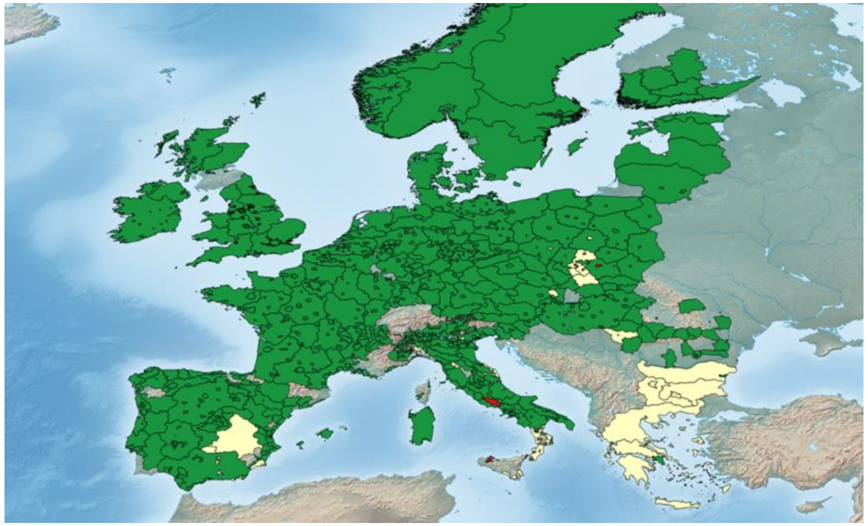


Figure 7.6 - Scenario A - PM_{10} - Air Quality Management Zone Compliance - 2030



7.2 SCENARIO B - REMOVE ALL DIESEL EXHAUST EMISSIONS FROM URBAN AREAS

In this somewhat hypothetical scenario all diesel power train vehicles (from passenger cars up to heavy duty trucks) are replaced with zero exhaust emission alternatives in the urban environment. This scenario represents an extreme surrogate for an instantaneous replacement of all diesel powered vehicles by zero exhaust emission alternatives capable of providing the same level of vehicle activity (billions of vehicle kilometres). Although it is a hypothetical scenario, it does serve to identify the absolute maximum improvement in compliance. This said, no account has been taken of any consequential increases in emissions from other sectors in meeting the alternative energy needs of the zero exhaust vehicle alternatives (e.g. increased electrical power generation emissions).

PARTICULATE MATTER

European compliance with $PM_{2.5}$ and PM_{10} air quality limit values (Figure 7.7, Figure 7.8) is essentially unaffected by removing diesel exhaust emissions from the urban environment. As already highlighted in the discussion of the Base Case, this is because by 2030 only a very small proportion of primary PM emissions from diesel vehicles are a product of exhaust emissions. Vehicle non-exhaust emissions, e.g. tyre wear and brake wear constitute the overwhelming majority of road transport generated particulate emissions and this remains largely unchanged whatever the power train of the vehicle (including electric).

In the case of particulates, the banning of diesel exhaust neither improves the overall air quality compliance picture in the future nor does it accelerate the achievement of improved compliance.

NO_2

European compliance with NO_2 air quality limit values is significantly improved in the period to 2020 (Figure 7.9 - Figure 7.13), by instantly removing all diesel exhaust emissions from the urban environment. However, against a Base Case which sees significant improvements in compliance by 2025 the incremental benefit in compliance terms is reduced as time progresses even for this extreme and hypothetical scenario.

Figure 7.7 - $PM_{2.5}$ compliance by percentage of AQ zone population. Scenario B

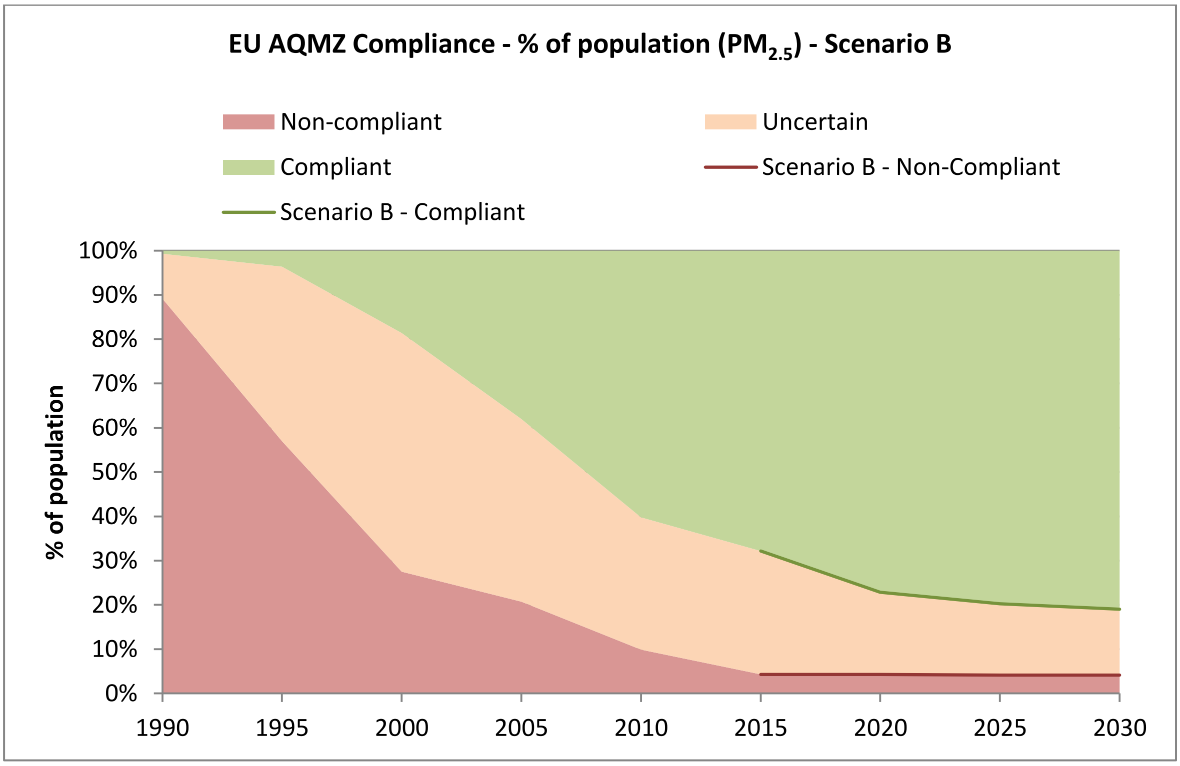


Figure 7.8 - PM_{10} compliance by percentage of AQ zone population. Scenario B

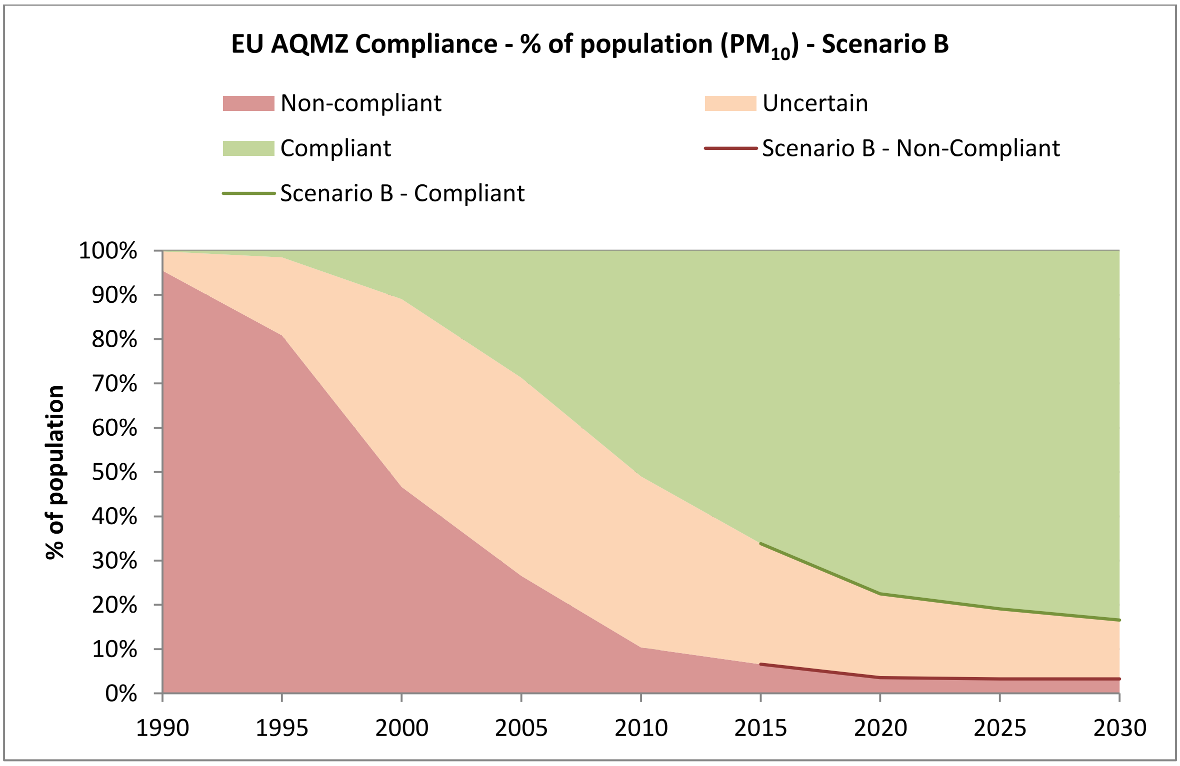


Figure 7.9 - NO_2 compliance by percentage of AQ zone population. Scenario B

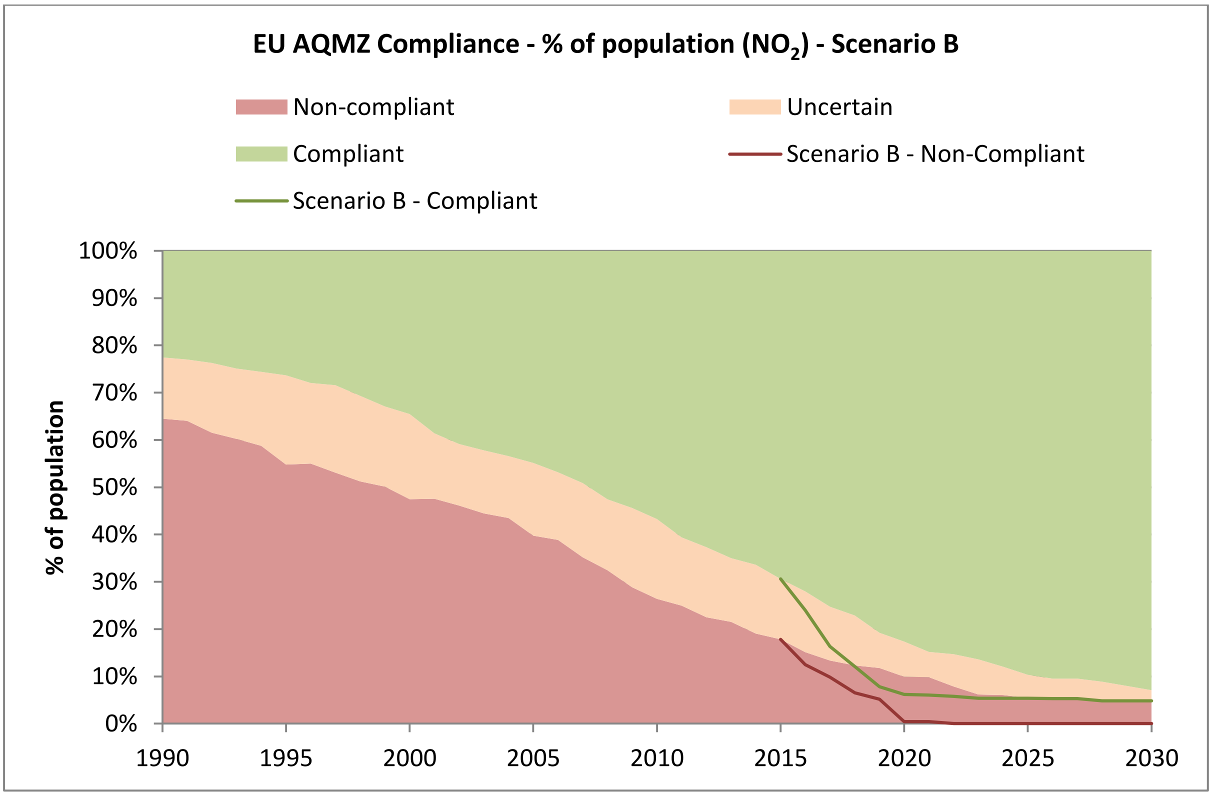


Figure 7.10 - Scenario B - NO_2 - Air Quality Management Zone Compliance - 2010

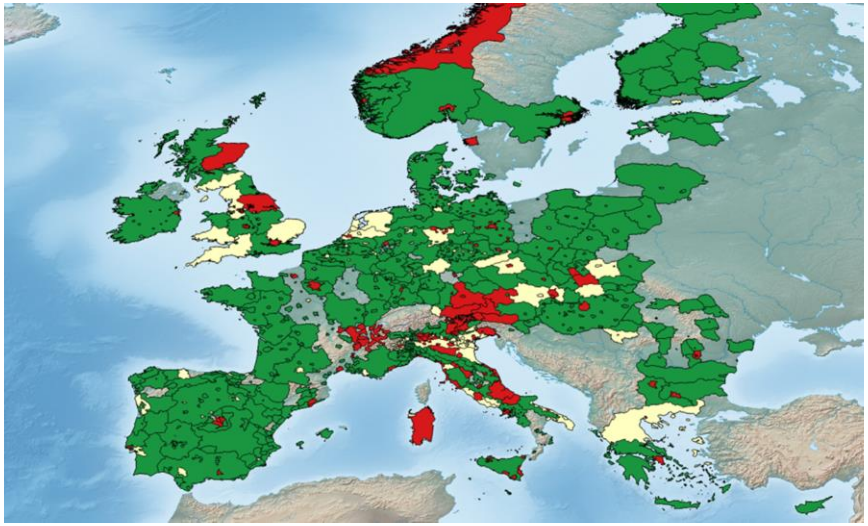


Figure 7.11 - Scenario B - NO_2 - Air Quality Management Zone Compliance - 2020

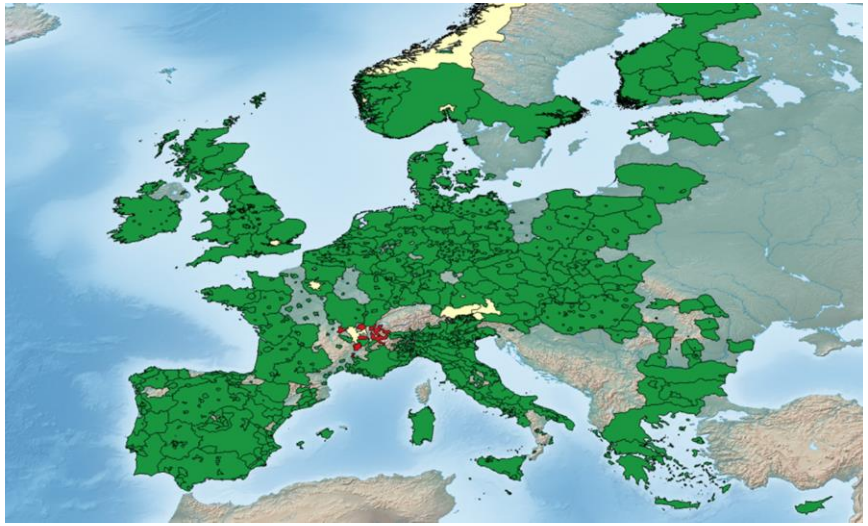


Figure 7.12 - Scenario B - NO_2 - Air Quality Management Zone Compliance - 2025

Figure 7.13 - Scenario B - NO_2 - Air Quality Management Zone Compliance - 2030

7.3 SCENARIO C - ACCELERATED FLEET TURNOVER OF PRE-EURO 5 VEHICLES

While Scenario B served to show that urban NO_2 compliance is significantly influenced by NO_X emissions from diesel transport, the instant elimination of all diesel exhaust NO_X is clearly not a realistic assumption. In this scenario we explore the effectiveness of accelerating the removal of pre-Euro 5 diesel passenger cars and their replacement with lower emitting Euro 6 vehicles, usually by a scrappage scheme. Since the impact on emissions of such schemes depends entirely on the remaining number of pre-Euro 5 vehicles in the overall fleet, a number which reduces with time, three different time horizons for such a scheme were explored: 2020, 2025 and 2030. Each time horizon examines the effect of introducing the scheme at that point in time and that the replacement would take place equally across the EU. Two options are examined: In the first (Scenario C.1) 100% of remaining pre-Euro 5 vehicles are replaced and in the second (Scenario C.2) 25% are replaced. The results are given in Table 7.1, Figure 7.14 and Figure 7.15.

Particulate compliance was not explored as part of this scenario since the results of scenario B demonstrated that only NO_X emissions are affected by this approach to emission reduction.

Table 7.1 - Percentage of EU 27 zone population living in compliance with ambient air quality standards for NO_2 in the Base Case, when accelerating fleet turnover by 100% (C1) and 25% (C2)

NO_2	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	Scenario C1	Scenario C2	Base case	Scenario C1	Scenario C2
2015	69%	69%	69%	18%	18%	18%
2020	83%	88%	85%	10%	6%	10%
2025	90%	91%	90%	5%	5%	5%
2030	93%	93%	93%	5%	5%	5%

Accelerating the replacement of pre-Euro 5 vehicles via an early scrappage scheme does bring results in achieving a given level of compliance earlier than in the Base Case, but for the practical upper limit case of 25% uptake (C2) the improvements are marginal. Most of the compliance benefits are seen by 2020 largely due to the effect of the differing Euro emissions standards. By the time Euro 6 has naturally achieved significant fleet penetration (2025 and beyond) there is little room for further improvement. It should be noted that the transport emissions for the Euro 6 fleet in this scenario, as in all "Phase 1" scenarios (the Base Case and scenarios A to D) use a conformity factor of 2.8[1] for all years to 2030.

[1] The COPERT 4 methodology is part of the EMEP/EEA Air Pollutant Emission Inventory Guidebook for the calculation of air pollutant emissions. The emission factors generated are vehicle and country specific. The PCD NOx Conformity Factor of 2.8 is therefore an indicative value identified to allow for comparison to the Real Driving Emissions legislation.

Figure 7.14 - NO_2 compliance by percentage of AQ zone population. Scenario C.1

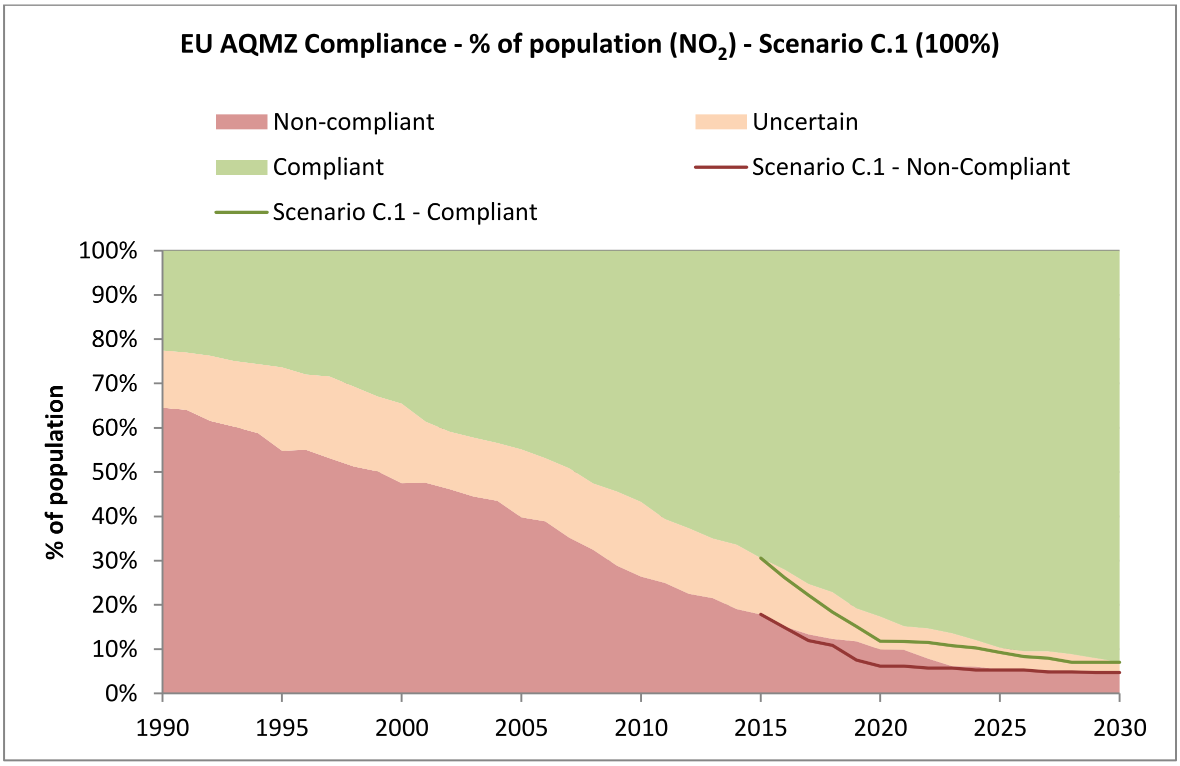
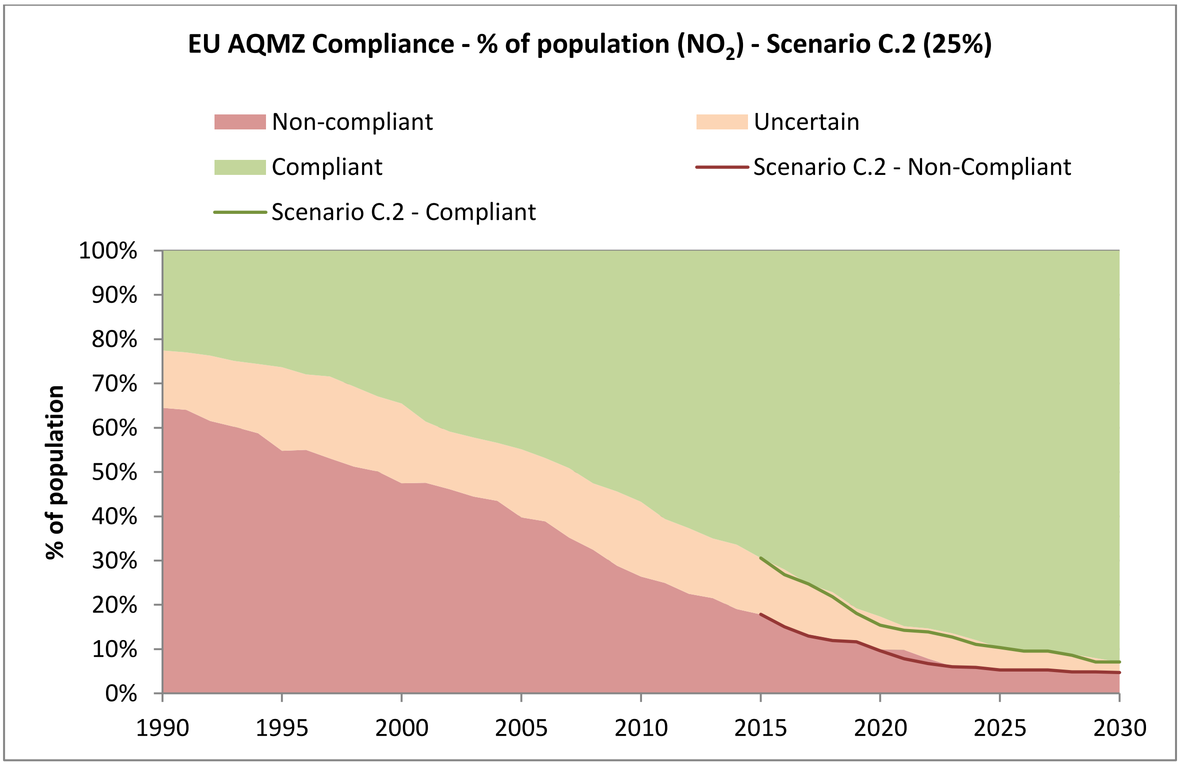


Figure 7.15 - NO_2 compliance by percentage of AQ zone population. Scenario C.2



7.4 SCENARIO D - CUMULATIVE REMOVAL OF VEHICLE EXHAUST EMISSIONS

In this scenario all diesel road transport is incrementally removed and replaced with zero emissions alternatives in the urban environment. The effect of this is to remove all diesel vehicle exhaust emissions from urban areas in a stepwise fashion. As such this is a more detailed version of Scenario B discussed in section 7.2. Four increments were chosen as described below;

Scenario D.1 removes the exhaust emissions from: all diesel passenger cars (PCD) in the urban environment (Figure 7.16).

Scenario D.2 removes the exhaust emissions from: all diesel passenger cars (PCD) and all diesel light duty vehicles (LDV) in the urban environment (Figure 7.17).

Scenario D.3 removes the exhaust emissions from: all diesel passenger cars (PCD), all diesel light duty vehicles (LDV) and all diesel heavy duty vehicles (HDV) in the urban environment (Figure 7.18).

Scenario D.4 removes the exhaust emissions from: all diesel passenger cars (PCD), all diesel light duty vehicles (LDV), all diesel heavy duty vehicles (HDV) and all buses (BUS) in the urban environment (Figure 7.19).

As scenario B has demonstrated, road transport exhaust emissions have a negligible effect on particulate concentrations and so this section will focus on NO_2 compliance.

The results of these scenarios help highlight the important contributors to the overall urban NO_2 concentration. By 2020, eliminating PCD vehicles (D.1) reduces “likely non-compliance” by 4% over the Base Case; in the same timeframe eliminating all diesel exhaust produces a further 6% reduction. By 2030 there is no difference in the proportion of the EU population living in “likely non-compliant” zones regardless of the measures taken and shows an improvement over the Base Case of 5%.

The changes that are seen in the “uncertain compliance” category illustrate that a number of the modelled stations are only marginally non-compliant and relatively small reductions in emissions can generate large increases in the population living in “likely compliant” regions, particularly in the short term.

Figure 7.16 - NO_2 compliance by percentage of AQ zone population. Scenario D.1 (Removal of PCD Exhaust Emissions)

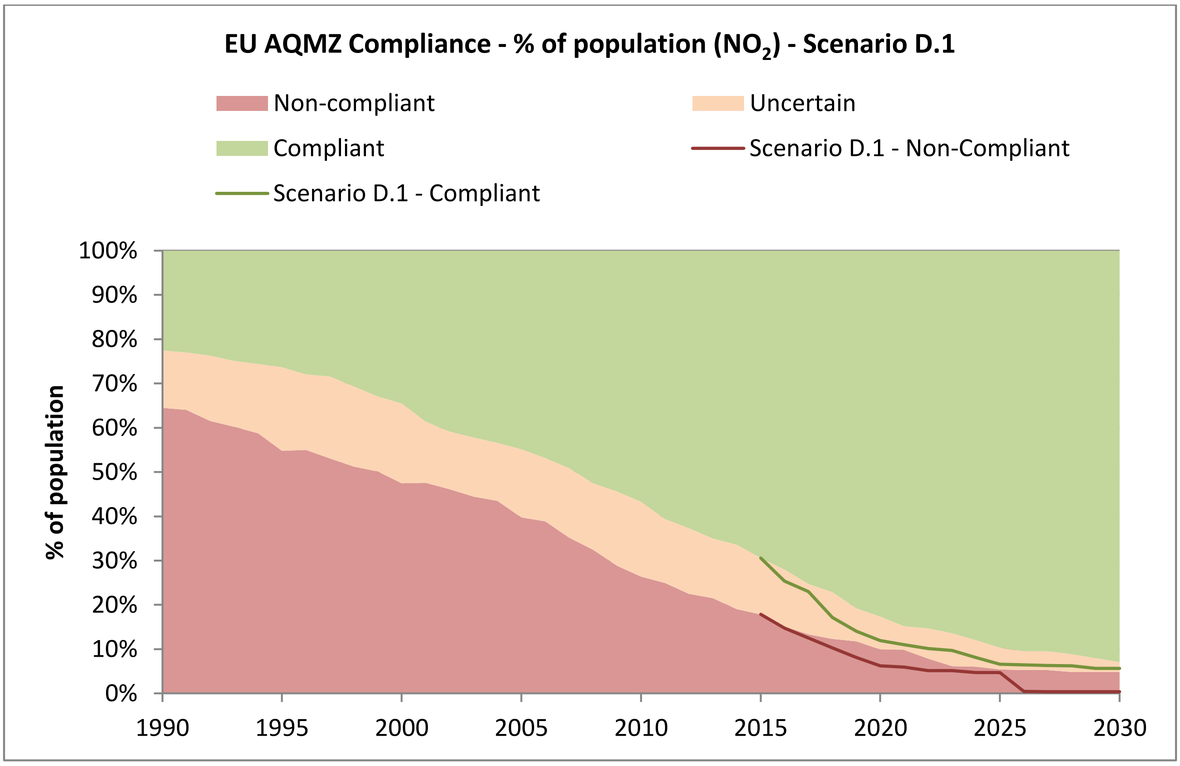


Figure 7.17 - NO_2 compliance by percentage of AQ zone population. Scenario D.2 (Removal of PCD + LDV Exhaust Emissions)

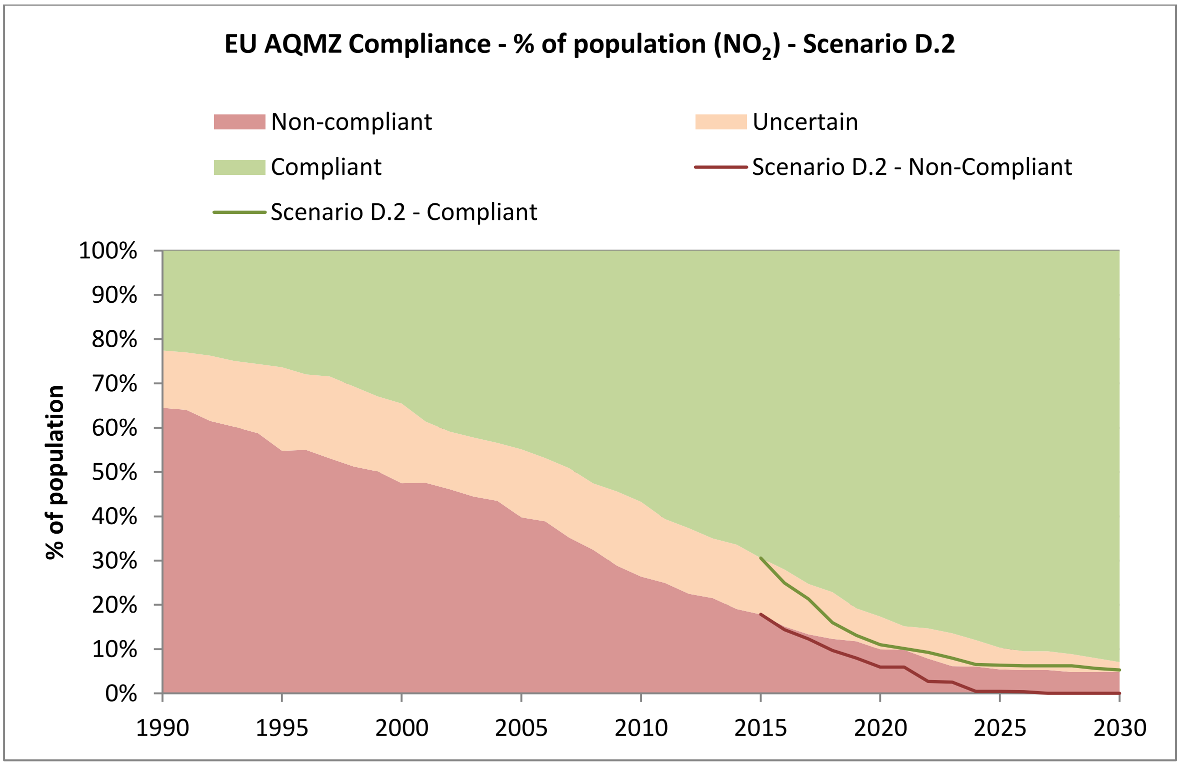


Figure 7.18 - NO_2 compliance by percentage of AQ zone population. Scenario D.3 (Removal of PCD + LDV + HDV Exhaust Emissions)

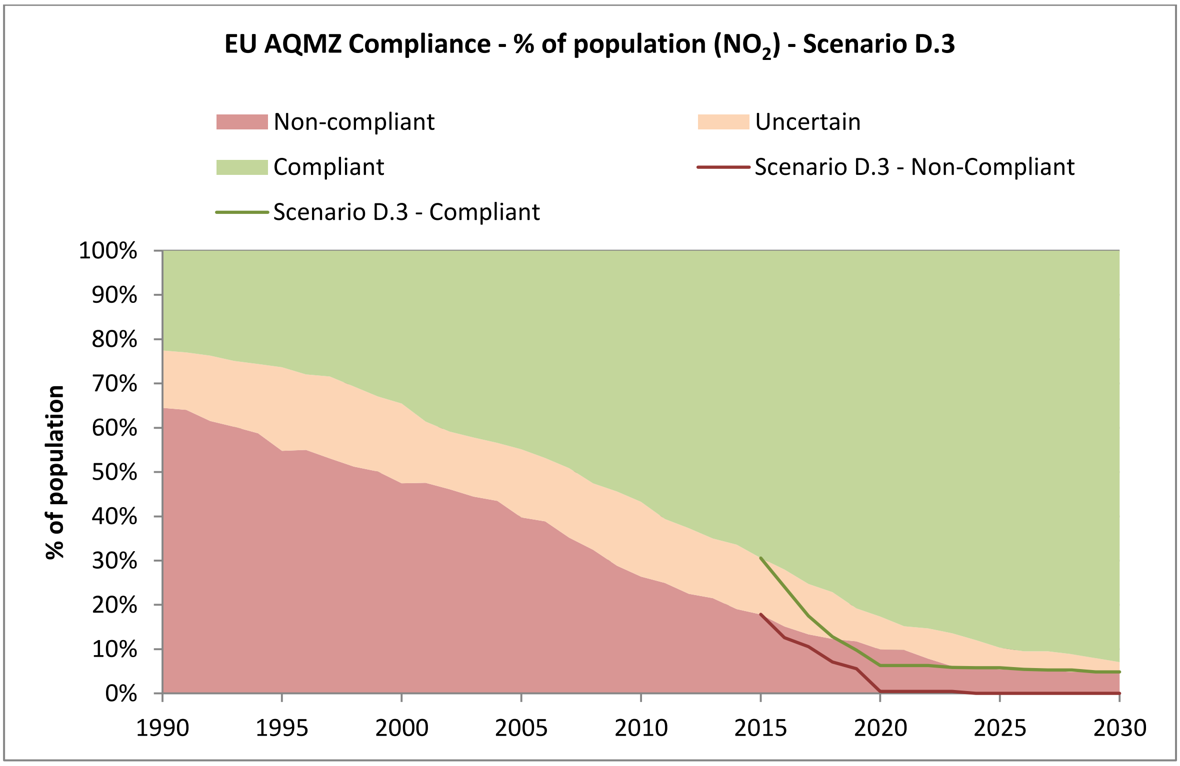
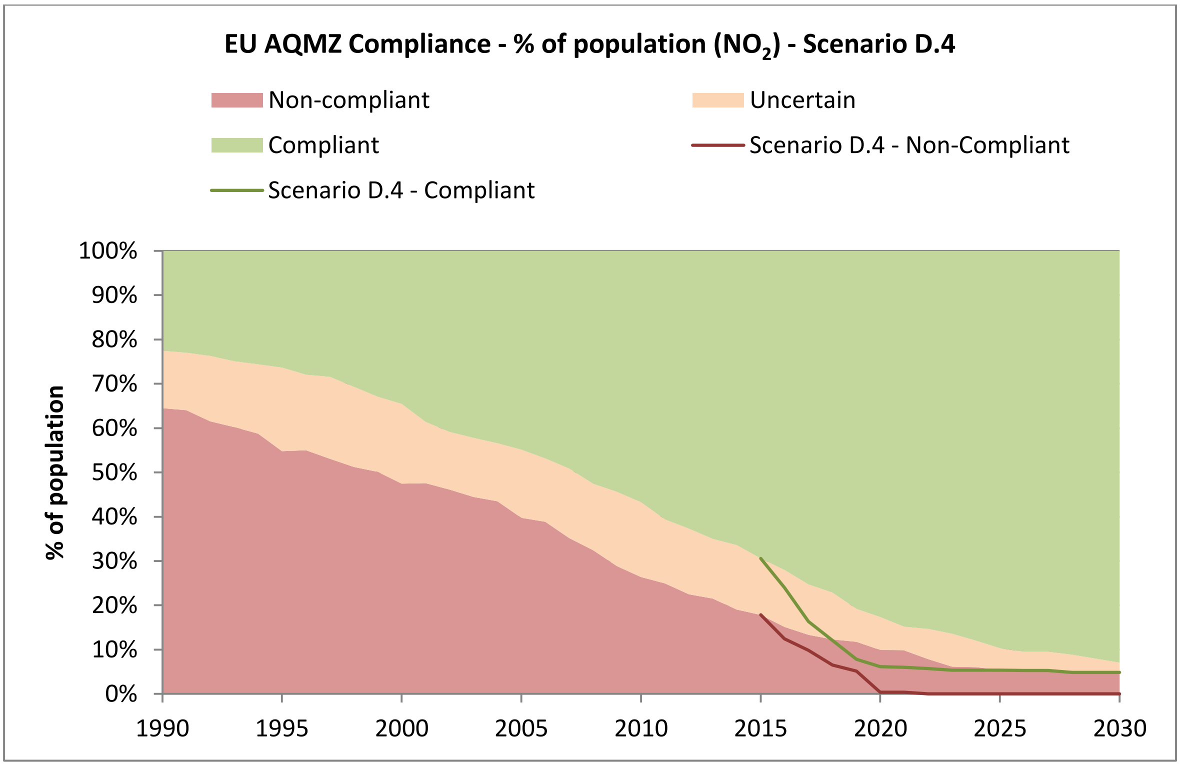


Figure 7.19 - NO_2 compliance by percentage of AQ zone population. Scenario D.4 (Removal of PCD + LDV + HDV + BUS Exhaust Emissions)



7.5 SCENARIO E - COMPARISON OF A RANGE OF EURO 6 REAL DRIVING EMISSION PERFORMANCE SCENARIOS

In "Phase 2" scenarios that attempt to reflect potentially more realistic real-world driving situations are explored. The real-world emissions are simulated using Conformity Factors (CF) that reflect a range of real driving emissions (RDE) based on available studies, these factors act as multipliers of the legislation limit value (LLV). For Euro 6 Diesel Passenger Cars (PCD) the LLV is 0.08g/km NO_X.

Diesel NO_X **Euro 6 performance cases:**

BC0 - This is the standard Base Case and represents a PCD emissions uplift of 2.8 times LLV

SN1a - 2015 to 2020 the uplift coefficient is 7 times the LLV; this is reduced to 2.8 times the LLV from 2020 (Figure 7.21)

SN1b - 2015 to 2020 the uplift coefficient is 7 times the LLV; this is reduced to 1.5 times the LLV from 2020 (Figure 7.22)

SN1c - 2015 to 2017 the uplift coefficient is 7 times the LLV; this is reduced to 1.5 times the LLV from 2017 (Figure 7.23)

7xLLV - From 2015 onwards the uplift coefficient is 7 times the LLV (Figure 7.24)

The zero emissions scenario used for comparison purposes:

ZEPCD - All diesel passenger cars registered from Jan 1, 2015 produce zero NO_X emissions (Figure 7.25)

The scenarios used in this study were defined prior to the recently proposed conformity factors agreed by the Member States Representatives at the "Technical Committee - Motor Vehicles" on the 28 October 2015 [5]. However it is worth noting that the range of scenarios explored in this study, with the exception of the most extreme and persistent Euro 6 under-delivery scenario (seven times the legislated limit), appropriately bound the proposed values with the closest ones being BC0 for the period up to 2020 and SN1b thereafter. The proposed conformity factors specify:

1. In a first step, car manufacturers will have to bring down the discrepancy to a conformity factor of maximum 2.1 (110%) for new models by September 2017 (for new vehicles by September 2019);
2. In a second step, this discrepancy will be brought down to a factor of 1.5 (50%), taking account of technical margins of error, by January 2020 for all new models (by January 2021 for all new diesel passenger cars).

At the time of writing this report, the above values have not yet cleared the regulatory scrutiny of the European Parliament and Council.

Table 7.2 - Summary of the Euro 6 conformity factors used in each scenario

	Conformity Factor		
Scenario	**2015**	**2020**	**2030**
BC0	2.8	2.8	2.8
SN1a	7	2.8	2.8
SN1b	7	1.5	1.5
SN1c	7 (to 2017)	1.5 (from 2017)	1.5
7xLLV	7	7	7

NO_2 Compliance

As described above, the SN1b scenario, while erring on the conservative side for the period 2015-2020, most closely matches the conformity factors agreed by the Member State Representatives at the recent meeting of their "Technical Committee - Motor Vehicles". Table 7.3 and Table 7.4 show the results of the "SN1b scenario" compared with the results of the "zero NO_X emissions from new diesel passenger cars scenario" (ZEPCD).

Table 7.3 - Percentage of EU 27 zone population living in compliance with ambient air quality standards for NO_2 in the Base Case, for a Euro 6 "central conformity" scenario (SN1b) and removing diesel vehicles from sale (ZEPCD)

NO_2	EU population living in likely compliant zones			EU population living in likely non-compliant zones		
	Base case	SN1b	ZEPCD	Base case	SN1b	ZEPCD
2015	69%	69%	69%	18%	18%	18%
2020	83%	80%	85%	10%	12%	9%
2025	90%	89%	92%	5%	6%	5%
2030	93%	93%	94%	5%	5%	0%

Table 7.4 - Percentage of EU air quality measuring stations in compliance with ambient air quality standards for NO_2 in the Base Case, for a Euro 6 "central conformity" scenario (SN1b) and removing diesel vehicles from sale (ZEPCD)

NO_2	Compliant air quality measuring stations			Non-compliant air quality measuring stations		
	Base case	SN1b	ZEPCD	Base case	SN1b	ZEPCD
2015	92%	92%	92%	8%	8%	8%
2020	97%	96%	98%	3%	4%	2%
2025	99%	99%	99%	1%	1%	1%
2030	99%	99%	100%	1%	1%	0%

These results show that although short term improvements in NO_2 compliance are possible, the effect reduces over time. The most marked improvement is the 5% of the population that will no longer be in living "likely non-compliant" zones in 2030 in the ZEPCD scenario, this population is concentrated in densely populated urban areas and represented by only 4 monitoring stations so it is probable that the same improvement should be possible using local measures in both the SN1b scenario and the Base Case. This diminishing improvement is a result of the near-full penetration of legislatively compliant Euro 6 vehicles in the fleet.

The high level of compliance observed in the SN1b scenario is consistent with the recent assessment work undertaken in the UK by the Department for Environment, Food and Rural Affairs (DEFRA) [6]. Based on modelling roughly 2000 individual road links in Greater London, this work indicates that by 2025 any residual NO_2 compliance issues will be confined to very small areas within a largely compliant urban agglomeration. Such small islands of non-compliance lend themselves to local, tailored strategies rather than significantly more costly and potentially disruptive city or country-wide responses.

The following chart (Figure 7.20) provides an overall view of the number of stations (all station types) that are predicted to remain out of compliance with the NO_2 40µg/m^3 annual mean air quality limit value from 2015 for each of the Conformity Factor scenarios described above. The impact of the ZEPCD scenario is also shown. To provide this overall compliance perspective, the uncertainty buffer has been removed in accordance with the procedure described in Section 5.5.

Figure 7.21 - Figure 7.37 show the results for each of the scenario E performance cases defined above.

Figure 7.20 - NO_2 Non-Compliance by AQ Monitoring Station - Scenarios: BC0, SN1a, SN1b, SN1c, 7xLLV and ZEPCD - All Stations

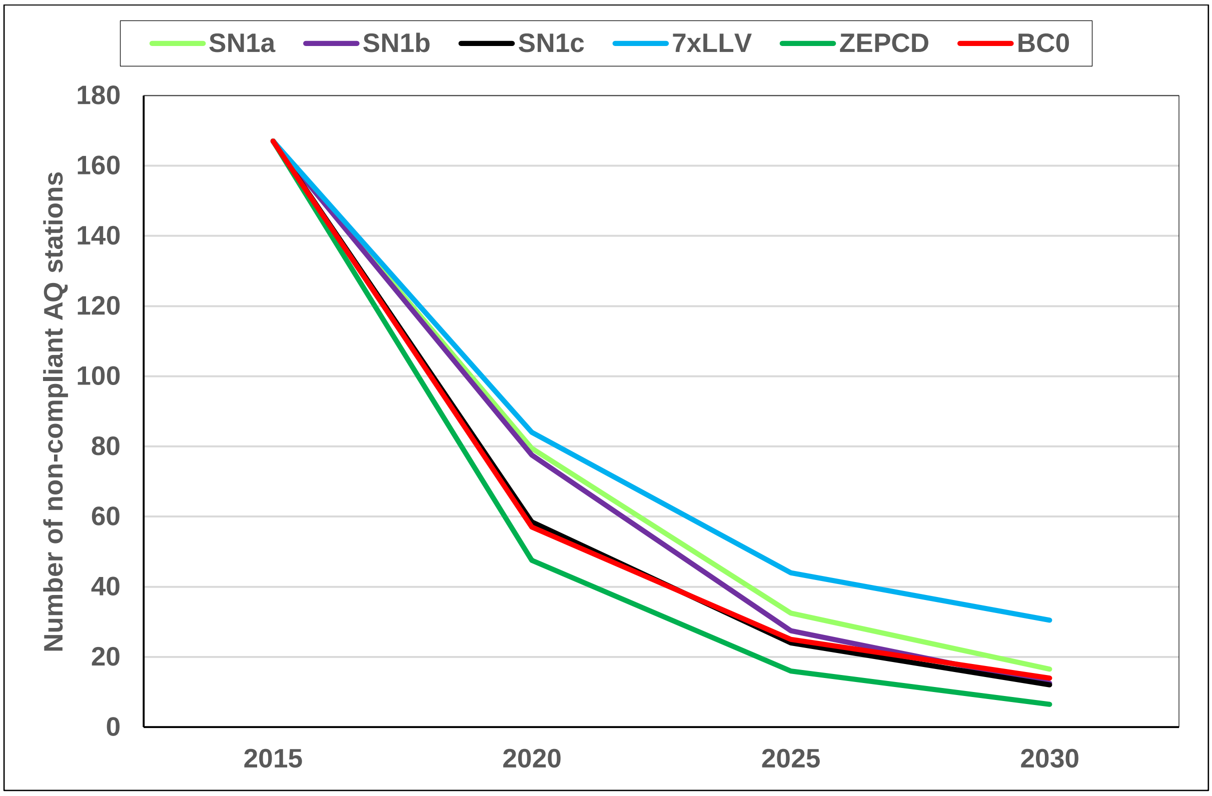


Figure 7.21 - NO_2 compliance by percentage of AQ zone population - Scenario SN1a - LLV Conformity Factors: 7 to 2020, 2.8 from 2020

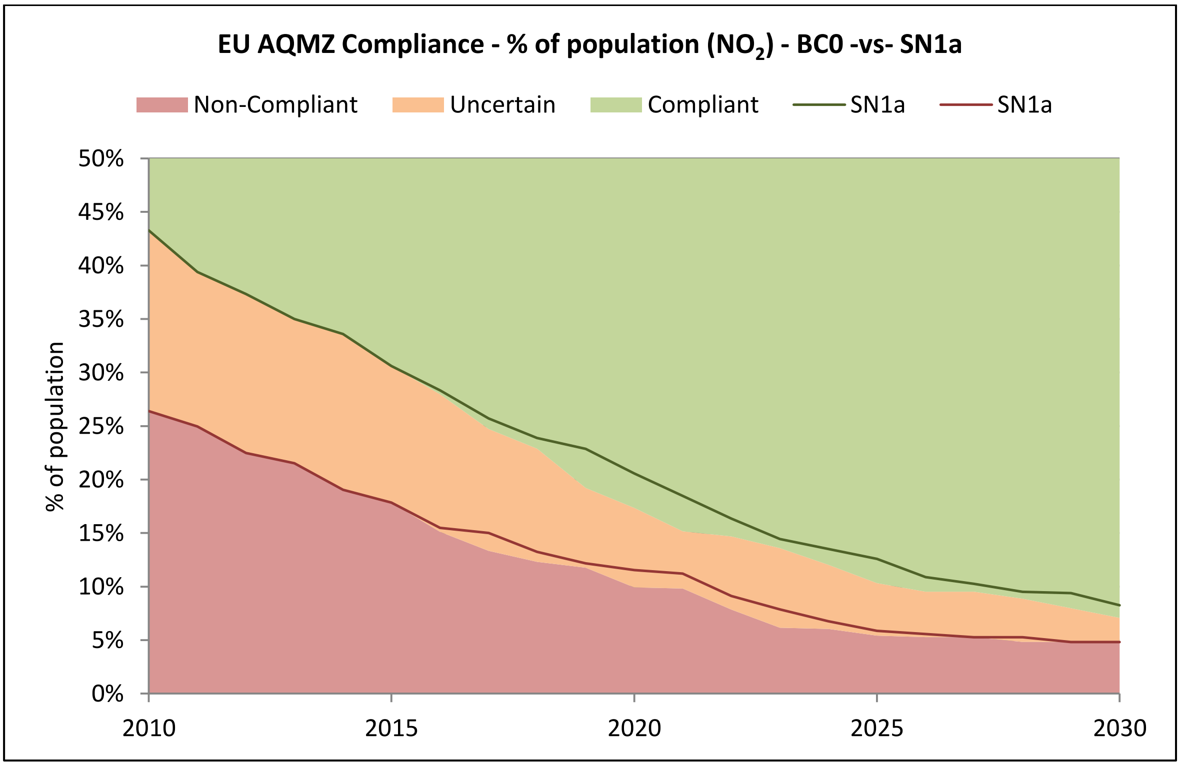


Figure 7.22 - NO_2 compliance by percentage of AQ zone population - Scenario SN1b - LLV Conformity Factors: 7 to 2020, 1.5 from 2020

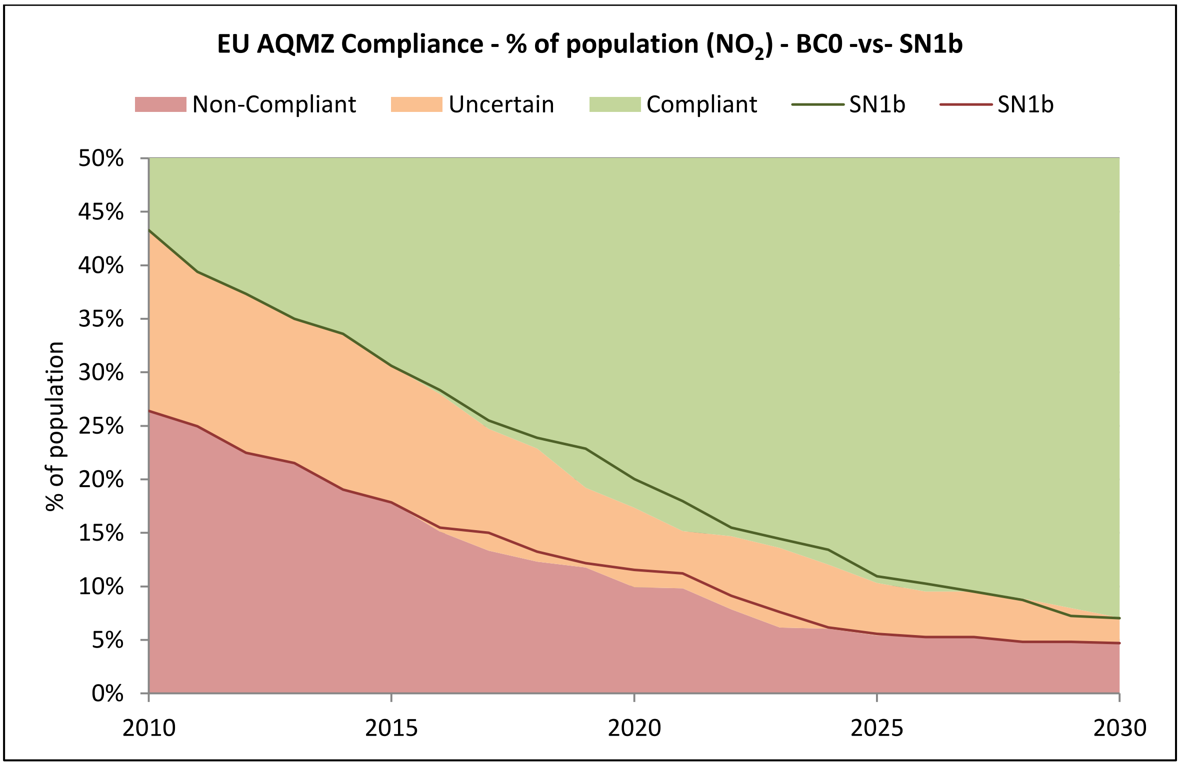


Figure 7.23 - NO_2 compliance by percentage of AQ zone population - Scenario SN1c - LLV Conformity Factors: 7 to 2017, 1.5 from 2017

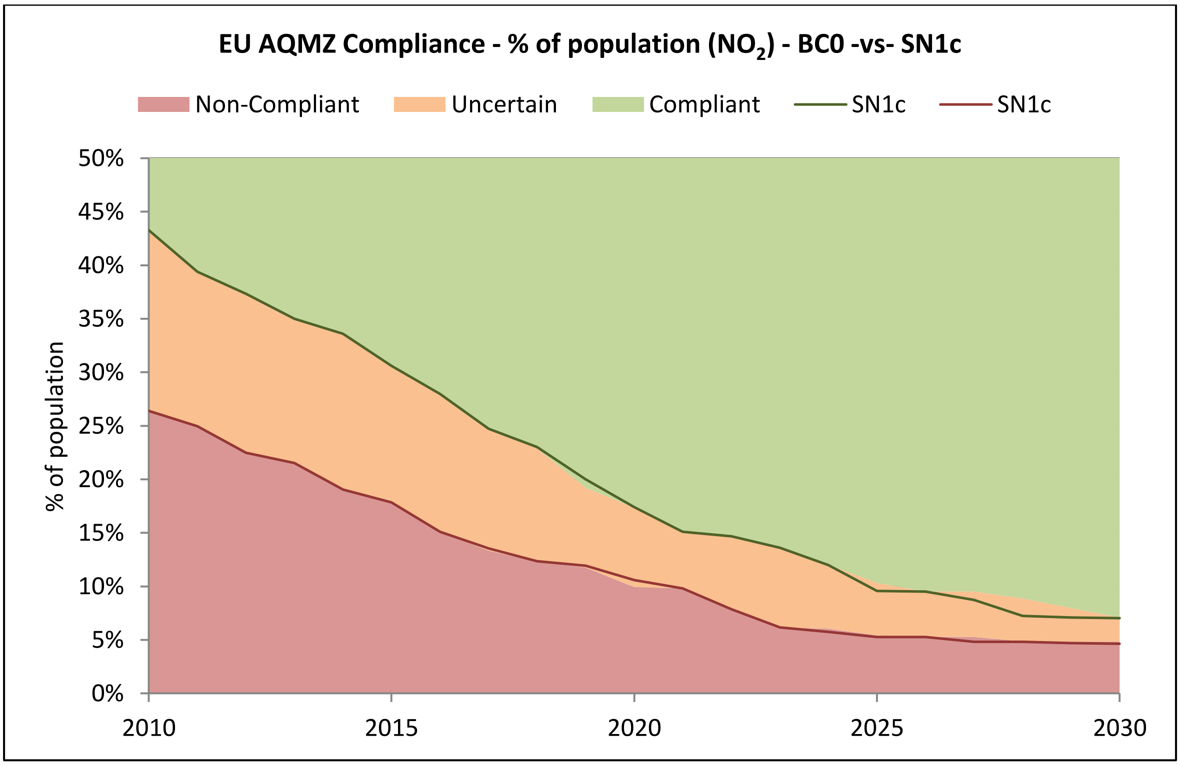


Figure 7.24 - NO_2 compliance by percentage of AQ zone population - Scenario 7xLLV

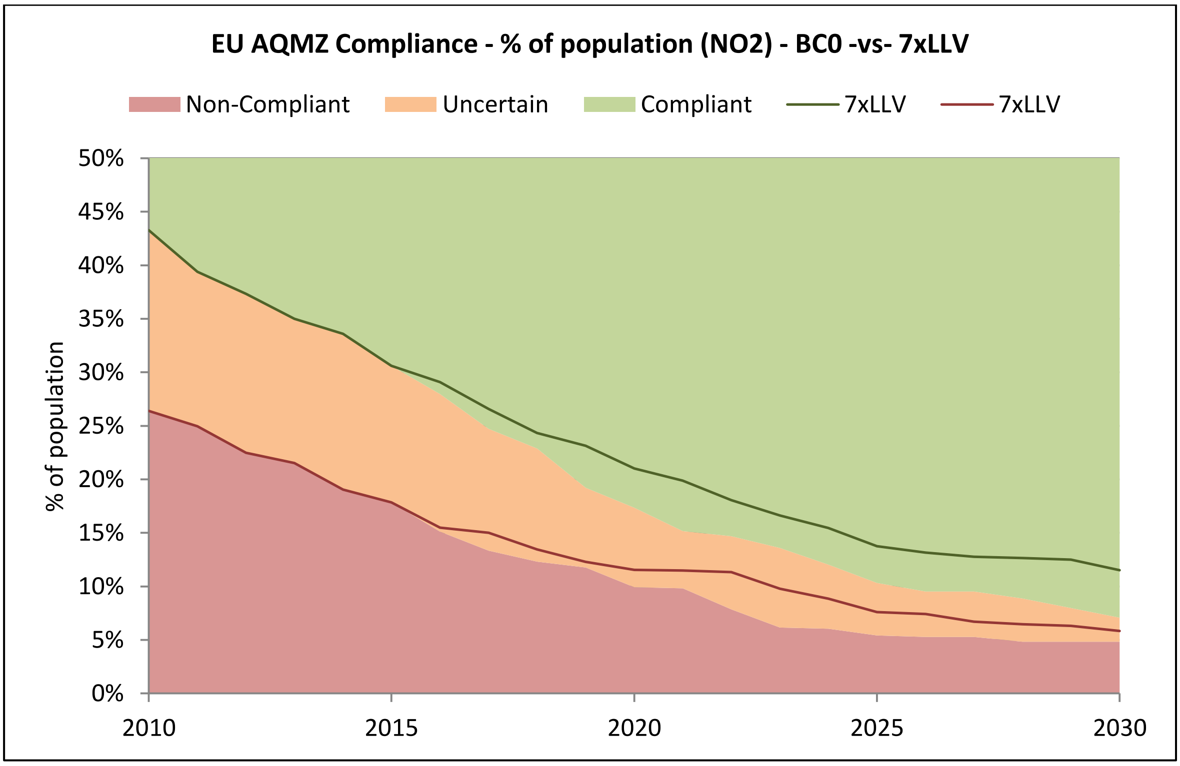


Figure 7.25 - NO_2 compliance by percentage of AQ zone population - Scenario ZEPCD

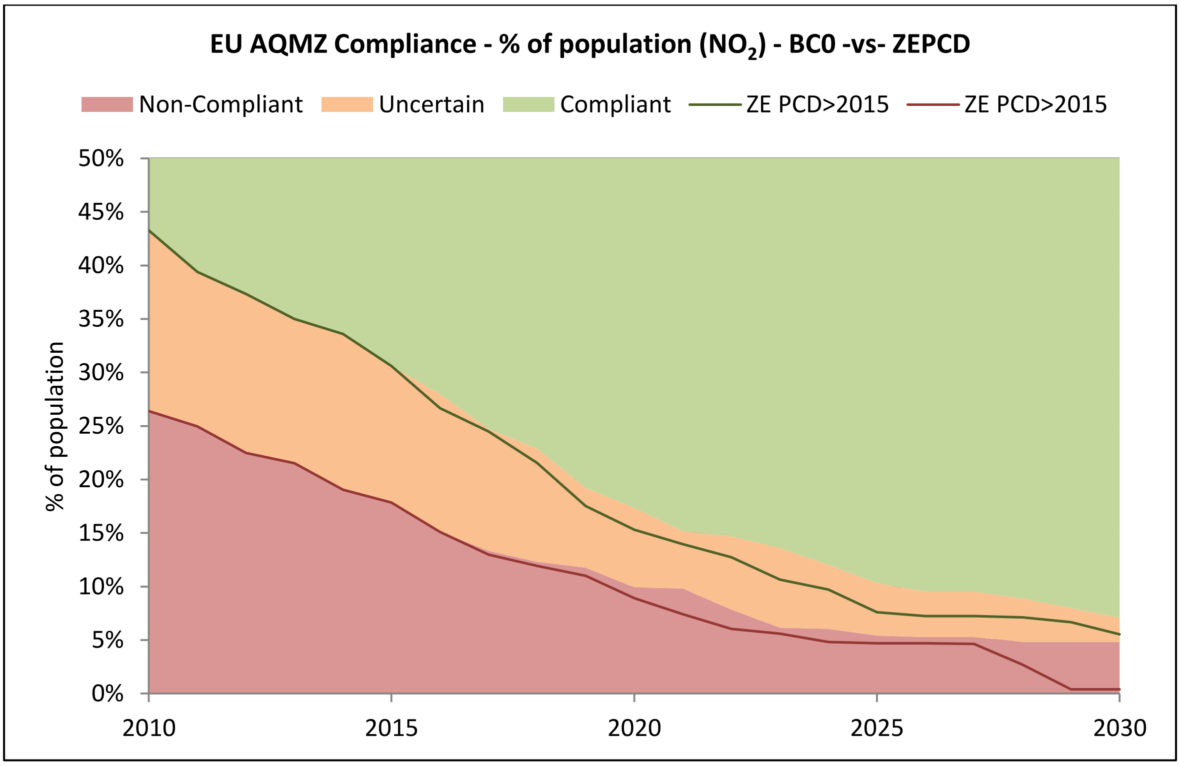


Figure 7.26 - Base Case - NO_2 - Air Quality Management Zone Compliance - 2020

Figure 7.27 - SN1a - NO_2 - Air Quality Management Zone Compliance - 2020

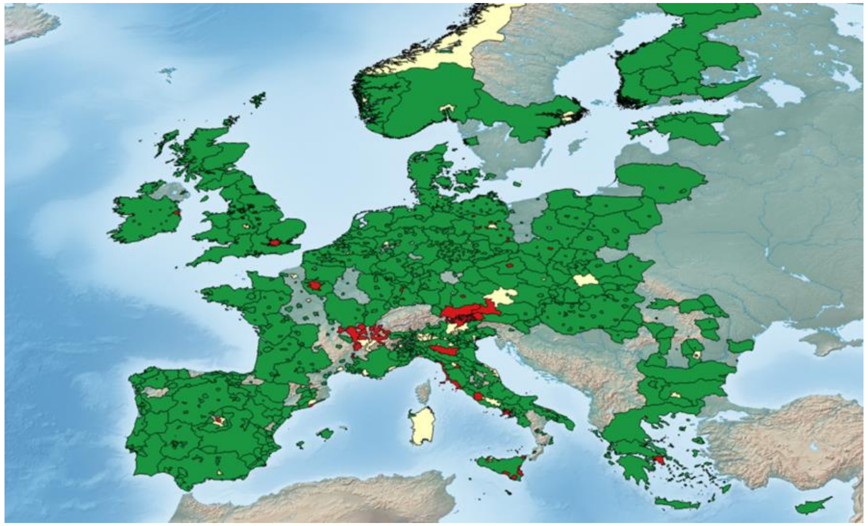


Figure 7.28 - SN1b - NO_2 - Air Quality Management Zone Compliance - 2020

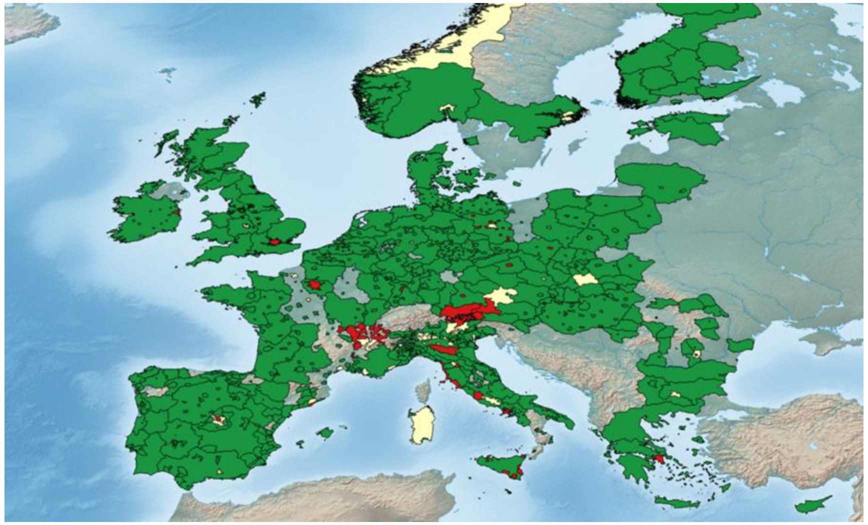


Figure 7.29 - SN1c - NO_2 - Air Quality Management Zone Compliance - 2020

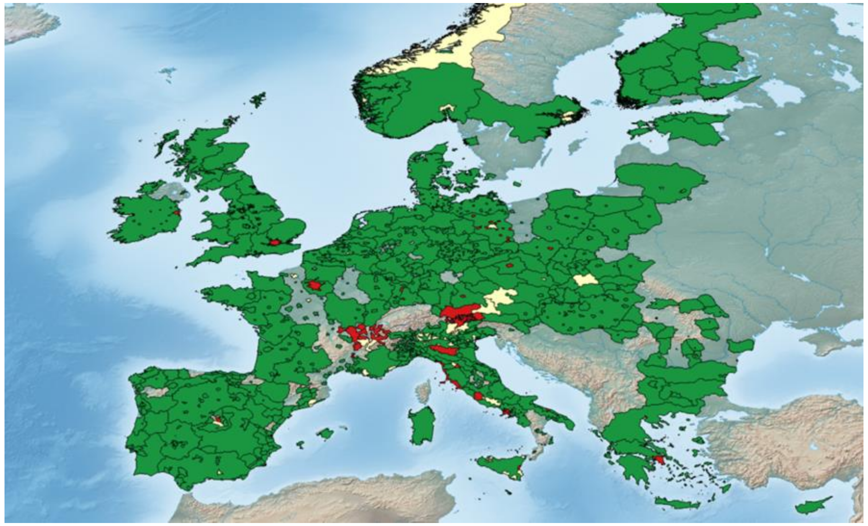


Figure 7.30 - Base Case - NO_2 - Air Quality Management Zone Compliance - 2030

Figure 7.31 - SN1a - NO_2 - Air Quality Management Zone Compliance - 2030

Figure 7.32 - SN1b - NO_2 - Air Quality Management Zone Compliance - 2030

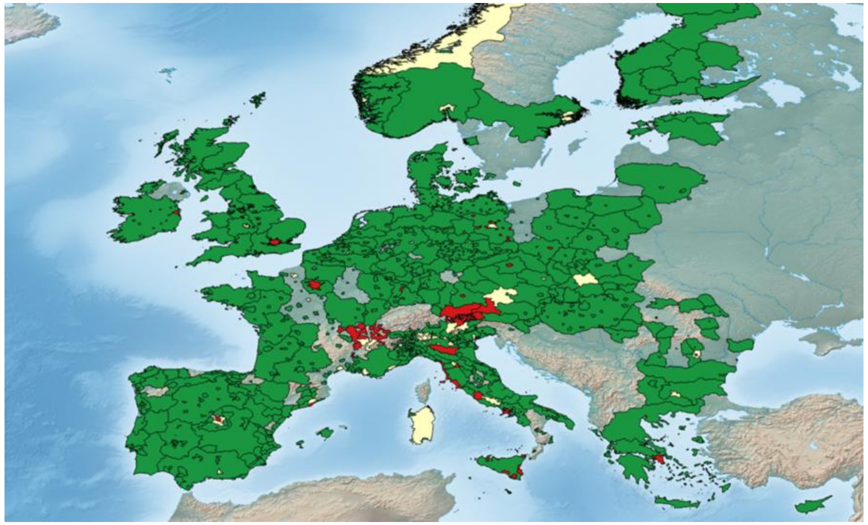


Figure 7.33 - SN1c - NO_2 - Air Quality Management Zone Compliance - 2030

Figure 7.34 - 7xLLV - NO_2 - Air Quality Management Zone Compliance - 2020

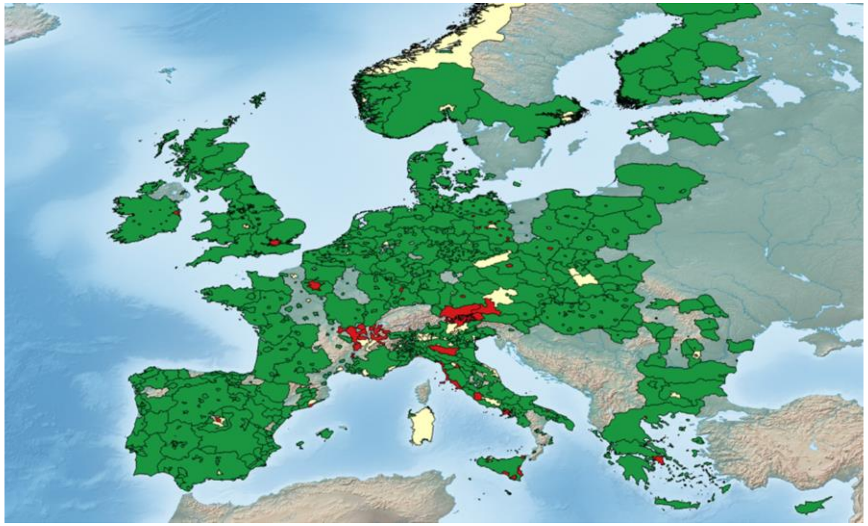


Figure 7.35 - ZEPCD - NO_2 - Air Quality Management Zone Compliance - 2020

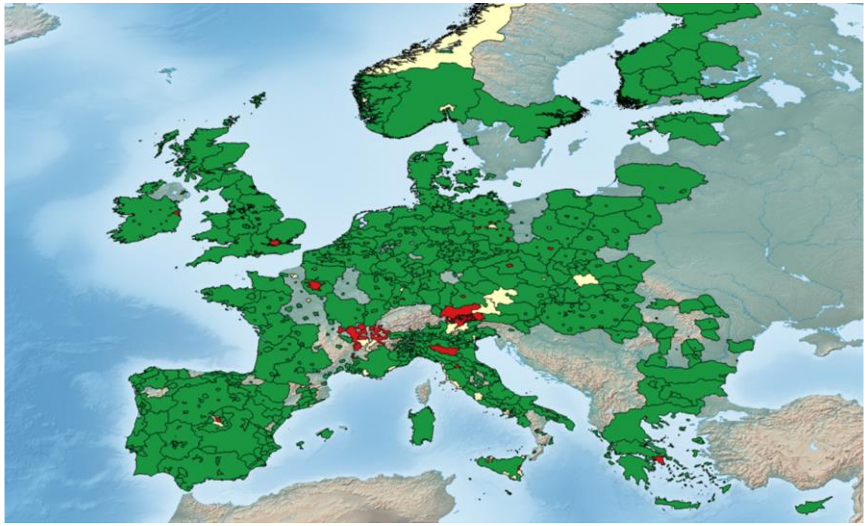


Figure 7.36 - 7xLLV - NO_2 - Air Quality Management Zone Compliance - 2030

Figure 7.37 - ZEPCD - NO_2 - Air Quality Management Zone Compliance - 2030

CITY FOCUS - BASE CASE

Berlin, London and Paris have been chosen as representative of European cities to explore the NO_2 compliance situation within the confines of specific urban environments. By modelling each measuring station individually we can access the compliance situation within each city and to what extent this is related to road transport. This is using the previously defined Base Case (BC0).

BERLIN - BASE CASE

Berlin has a limited compliance issue in 2015, with a single non-compliant station and six uncertain stations. By 2020 there is only a single 'uncertain compliance' station and by 2030 there is likely full compliance.

Table 7.5 - Berlin station compliance counts, Base Case (BC0)

Year	Compliant	Uncertain	Non-Compliant
2015	10	6	1
2020	16	1	0
2025	16	1	0
2030	17	0	0

LONDON - BASE CASE

London experienced a significant compliance issue in 2015 however by 2020 these issues are predicted to reduce significantly and by 2030 almost disappear. This picture is consistent with the London NO_2 air quality modelling study undertaken by DEFRA [6] in which some 50% of the modelled road links in London in 2015 exceeded the annual limit value; by 2020 this is predicted to reduce to 19%, by 2025 to 3% and to zero by 2030. [1]

Table 7.6 - London station compliance counts, Base Case (BC0)

Year	Compliant	Uncertain	Non-Compliant
2015	8	9	7
2020	16	5	3
2025	17	5	2
2030	20	3	1

PARIS - BASE CASE

Paris has limited but persistent compliance issues: In 2015 four non-compliant stations, by 2020 there are still four non-compliant stations and even by 2030 there are still two non-compliant stations.

Table 7.7 - Paris station compliance counts, Base Case (BC0)

Year	Compliant	Uncertain	Non-Compliant
2015	19	1	4
2020	20	0	4
2025	20	1	3
2030	20	2	2

[1] In September 2015 the UK Government Department for the Environment, Food and Rural Affairs (DEFRA) launched a major consultation regarding its plans for achieving NO_2 compliance with the Ambient Air Quality Directive 2008 (AAQD). Finalised plans were published in December 2015 and in addition to proposed policy measures substantial supporting technical data were released. These are available in a single Technical Report with a detailed Air Quality Plan for each of the 38 (out of 43) UK air quality zones identified as having NO_2 compliance issues. The report used DEFRA's Pollution and Climate Mapping (PCM) model to generate fully source apportioned concentrations of individual road links.

Figure 7.38 - Base Case - Berlin - NO_2 - AQ Measuring Station Compliance - 2015

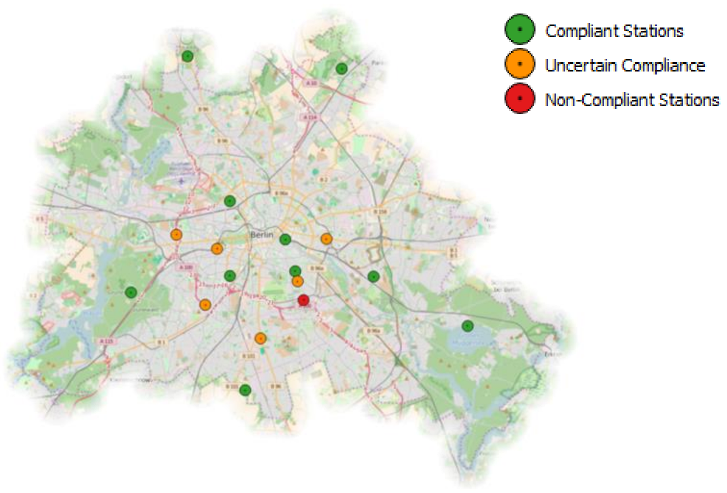


Figure 7.39 - Base Case - Berlin - NO_2 - AQ Measuring Station Compliance - 2020

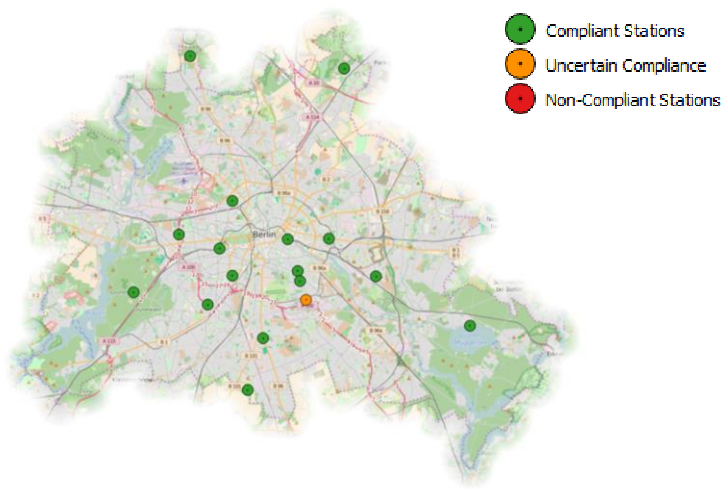


Figure 7.40 - Base Case - Berlin - NO_2 - AQ Measuring Station Compliance - 2025

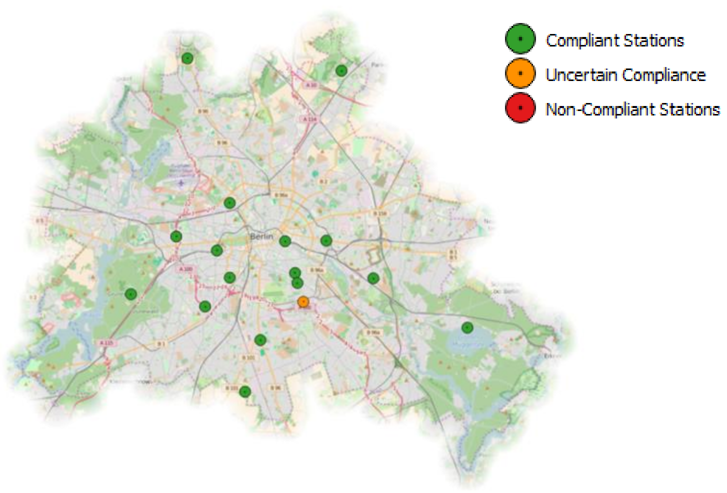


Figure 7.41 - Base Case - Berlin - NO_2 - AQ Measuring Station Compliance - 2030

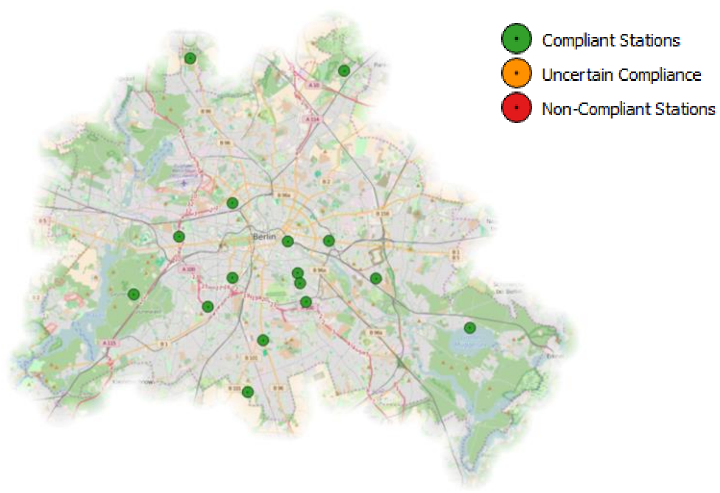


Figure 7.42 - Base Case - London - NO_2 - AQ Measuring Station Compliance - 2015

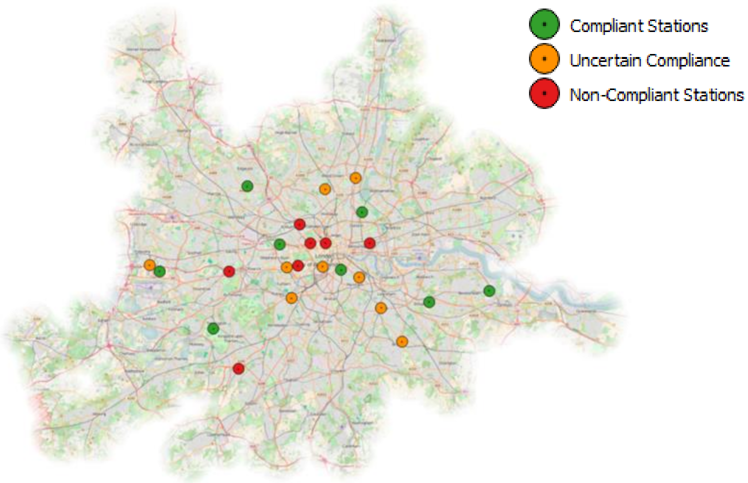


Figure 7.43 - Base Case - London - NO_2 - AQ Measuring Station Compliance - 2020

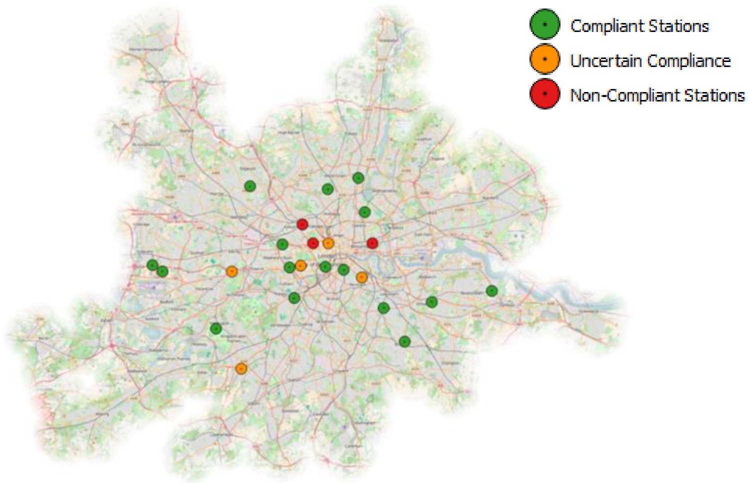


Figure 7.44 - Base Case - London - NO_2 - AQ Measuring Station Compliance - 2025

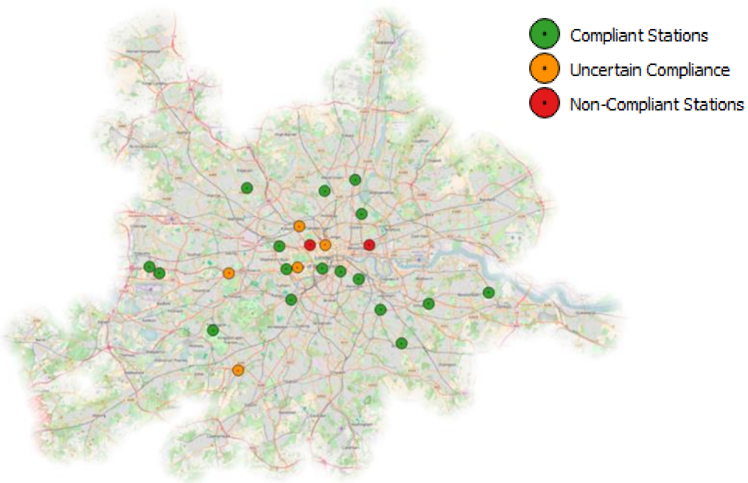
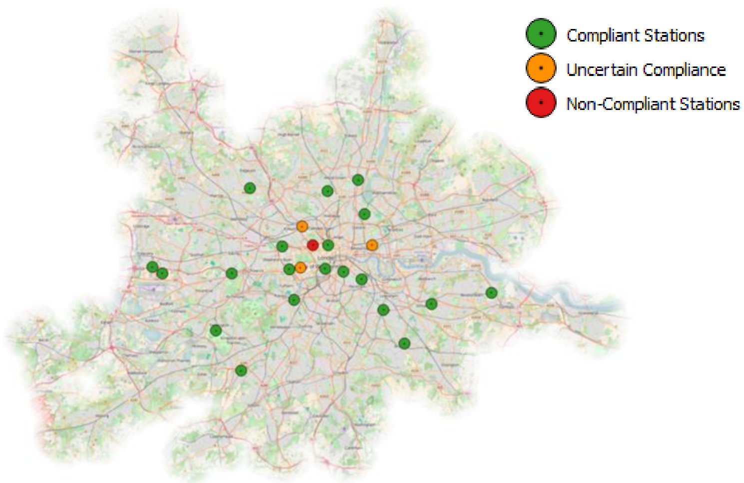


Figure 7.45 - Base Case - London - NO_2 - AQ Measuring Station Compliance - 2030



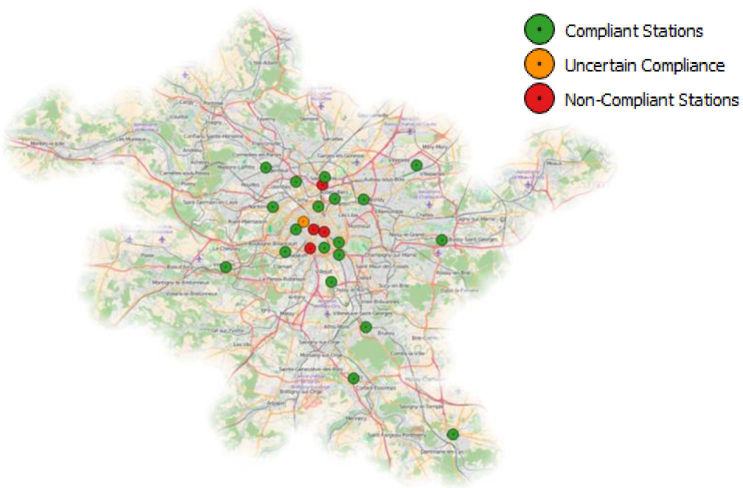


Figure 7.46 - Base Case - Paris - NO_2 - AQ Measuring Station Compliance - 2015

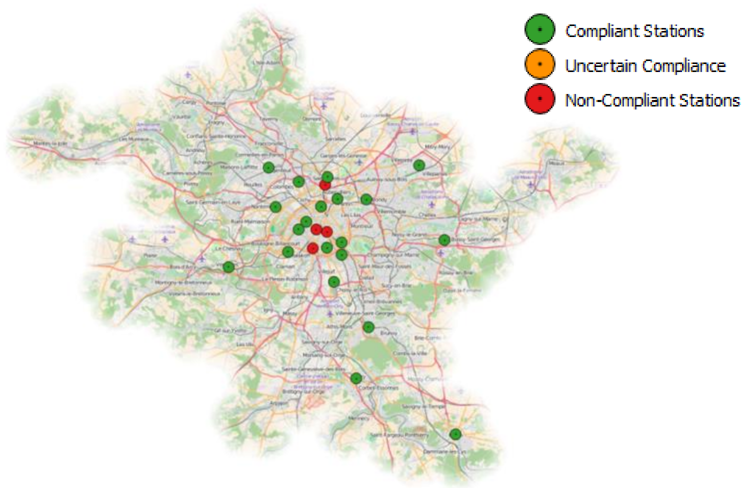


Figure 7.47 - Base Case - Paris - NO_2 - AQ Measuring Station Compliance - 2020

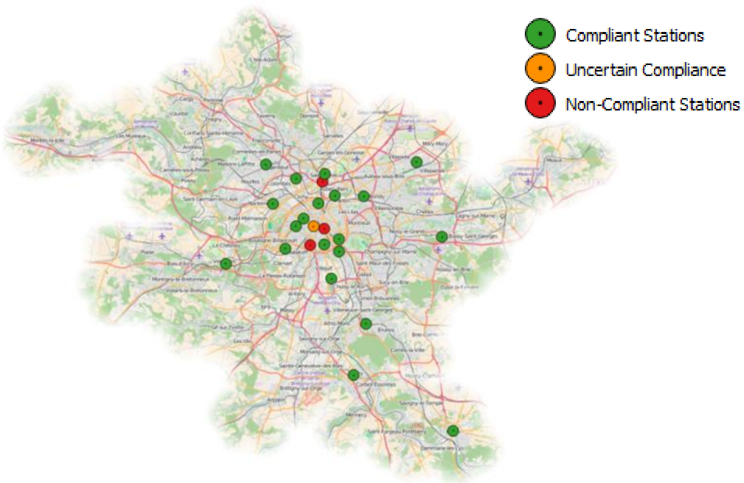


Figure 7.48 - Base Case - Paris - NO_2 - AQ Measuring Station Compliance - 2025

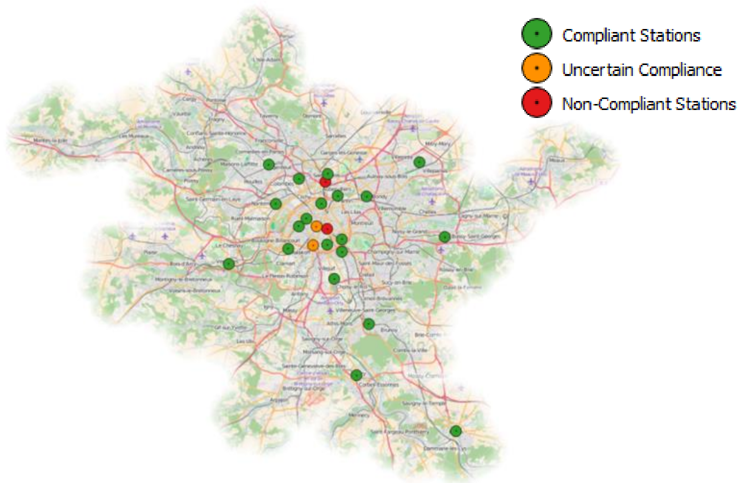


Figure 7.49 - Base Case - Paris - NO_2 - AQ Measuring Station Compliance - 2030

CITY FOCUS - SCENARIO SN1B

Scenario SN1b closely mirrors the RDE conformity factors from 2020 as decided by the "Technical Committee - Motor Vehicles" on the 28 October 2015 [5]. As this scenario is closest to the real world emissions produced by diesel passenger cars this city-scale assessment should provide a good overview of what the future holds barring other NO_X reduction measures being introduced. This scenario indicates marginal improvement in each city from 2020.

BERLIN - SN1B

Table 7.8 - Berlin station compliance counts, SN1b scenario

Year	Compliant	Uncertain	Non-Compliant
2015	(10)	(6)	(1)
2020	13 (16)	4 (1)	0 (0)
2025	16 (16)	1 (1)	0 (0)
2030	17 (17)	0 (0)	0 (0)

LONDON - SN1B

Table 7.9 - London station compliance counts, SN1b scenario

Year	Compliant	Uncertain	Non-Compliant
2015	(8)	(9)	(7)
2020	16 (16)	5 (5)	3 (3)
2025	17 (17)	5 (5)	2 (2)
2030	21 (20)	2 (3)	1 (1)

PARIS - SN1B

Table 7.10 - Paris station compliance counts, SN1b scenario

Year	Compliant	Uncertain	Non-Compliant
2015	(19)	(1)	(4)
2020	20 (20)	0 (0)	4 (4)
2025	20 (20)	1 (1)	3 (3)
2030	20 (20)	2 (2)	2 (2)

CITY FOCUS - ZERO EMISSIONS FROM NEW DIESEL PASSENGER CAR REGISTRATIONS

To ascertain what effect the "best" emissions case would have on compliance in these cities the ZEPCD scenario has been applied. In the following tables the number in brackets refers to the Base Case (BC0).

This example shows improvements in compliance for both Paris and London however there is no improvement in compliance for Berlin as this city is able to achieve compliance in the Base Case from 2020. The overall improvement is somewhat limited due to the high compliance level achieved in the Base Case.

BERLIN - ZEPCD

Table 7.11 - Berlin station compliance counts, ZEPCD scenario

Year	Compliant	Uncertain	Non-Compliant
2015	(10)	(6)	(1)
2020	16 (16)	1 (1)	0 (0)
2025	17 (16)	0 (1)	0 (0)
2030	17 (17)	0 (0)	0 (0)

LONDON - ZEPCD

Table 7.12 - London station compliance counts, ZEPCD scenario

Year	Compliant	Uncertain	Non-Compliant
2015	(8)	(9)	(7)
2020	16 (16)	5 (5)	3 (3)
2025	20 (17)	3 (5)	1 (2)
2030	21 (20)	3 (3)	0 (1)

PARIS - ZEPCD

Table 7.13 - Paris station compliance counts, ZEPCD scenario

Year	Compliant	Uncertain	Non-Compliant
2015	(19)	(1)	(4)
2020	20 (20)	1 (0)	3 (4)
2025	20 (20)	2 (1)	2 (3)
2030	20 (20)	3 (2)	0 (2)

7.6 $PM_{2.5}$ AIR QUALITY LIMIT VALUE SENSITIVITY ANALYSIS (20µg/m^3)

Annex XIV, Section E of the Ambient Air Quality Directive (2008/50/EC) sets forth $PM_{2.5}$ annual mean Limit Values in two Stages. The 'Stage 1' limit of 25µg/m^3 requires full compliance by January 1, 2015. The 'Stage 2' limit of 20µg/m^3 is noted as: *'indicative limit value to be reviewed by the Commission in 2013 in the light of further information on health and environmental effects, technical feasibility and experience of the target value in Member States*'. Although such a review has not yet been published by the Commission, this sensitivity scenario explores the effect this 'Stage 2' Limit Value would have on compliance versus the 'Stage 1' limit explored in the Base Case.

The effect of this reduction in 2020 (summarised in Table 7.14 and Table 7.15) would be an increase in the percentage of "likely non-compliant" (predicted concentrations >25µg/m^3) air quality measuring stations from 3% to 5%, these stations are concentrated within urban areas. The change in compliance picture is more marked for those stations that are predicted to be of "uncertain compliance" in 2020, where the percentage increases from 8% to 24%. The equivalent increase in 2030 would be from 5% to 17%.

Figure 7.50 compares the 25µg/m^3 limit (left chart) to the reduced 20µg/m^3 limit (right chart) for "all" stations and for "urban" stations.

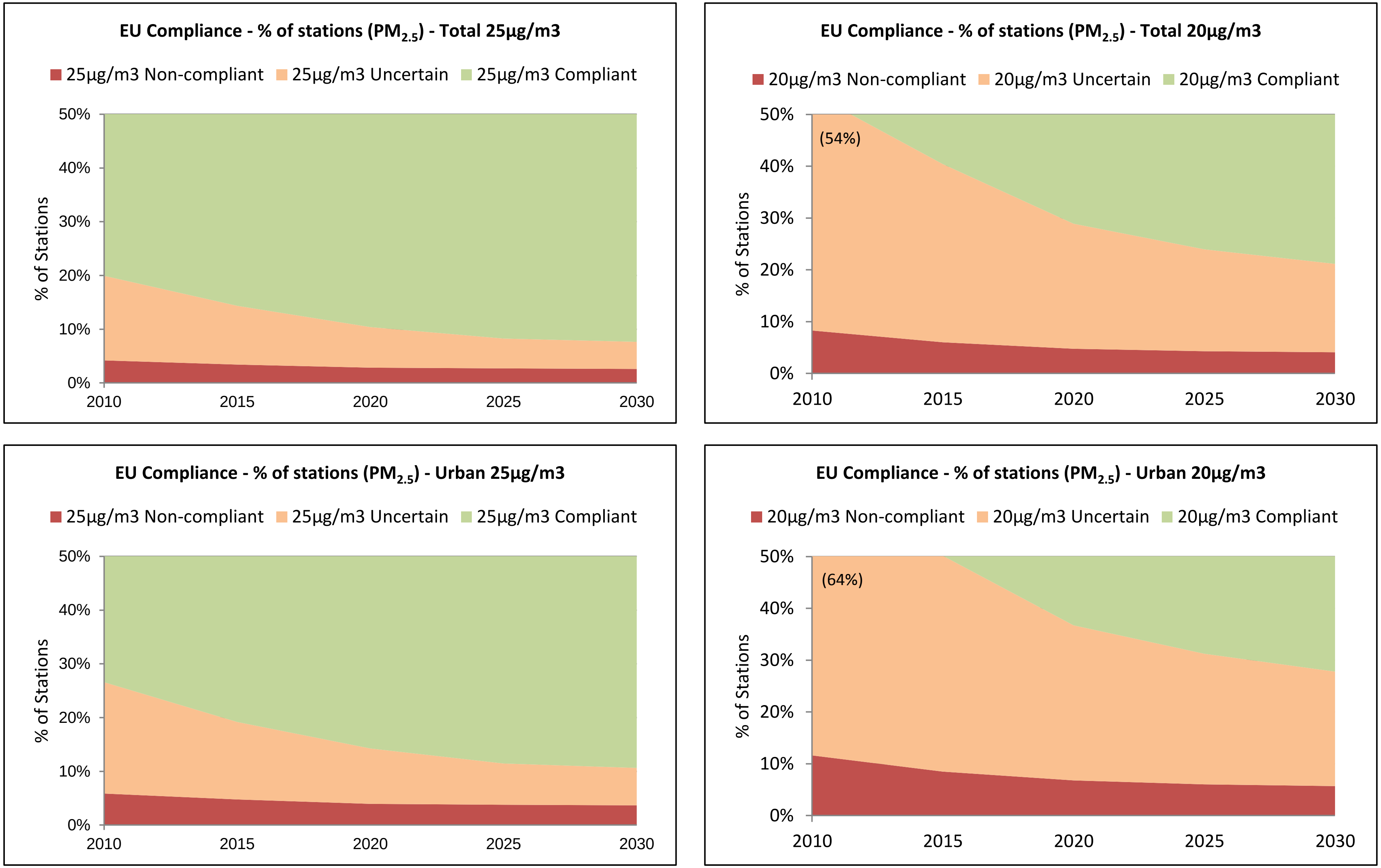
Table 7.14 - The number of compliant, uncertain and non-compliant stations for $PM_{2.5}$: 25 and 20µg/m^3 Limit Values - All stations

Scenario	(Current) 25µg/m3			(From 2020) 20µg/m3		
Year	Compliant (<20)	Uncertain (20-30)	Non-Compliant (>30)	Compliant (<15)	Uncertain (15-25)	Non-Compliant (>25)
2020	2647	223	84	2100	713	141
2025	2710	164	80	2246	581	127
2030	2728	149	77	2329	504	121

Table 7.15 - The number of compliant, uncertain and non-compliant stations for $PM_{2.5}$: 25 and 20µg/m^3 Limit Values - Urban stations

Scenario	(Current) 25µg/m3			(From 2020) 20µg/m3		
Year	Compliant (<20)	Uncertain (20-30)	Non-Compliant (>30)	Compliant (<15)	Uncertain (15-25)	Non-Compliant (>25)
2020	1564	188	72	1154	546	124
2025	1615	140	69	1254	460	110
2030	1630	127	67	1317	403	104

Figure 7.50 - The effect on EU air quality monitoring station $PM_{2.5}$ compliance of reducing the annual mean AQLV to 20µg/m[3]



8 GLOSSARY

AQLV - Air quality limit value

AQMZ - Air quality management zone

AQUIReS - Air Quality Universal Information and Reporting System

AQUIReS+ - The forecasting component of AQUIReS

CF - Conformity Factor - A coefficient applied to a legislative limit value to reflect non-conformance

CHIMERE - A chemical transport model developed by INERIS

CLE - Current legislation

COPERT - A road transport emissions tool

EEA AirBase - A database of European air quality measuring station data

EF - Emission factor

EMEP - The European Monitoring and Evaluation Programme

Emission Attenuation Profile - A method of converting emissions changes over time into a coefficient, with a coefficient of 1 in a "base-year" and values above or below this in subsequent years related to the proportional change in emissions in each year.

EU - European Union

GAINS - Greenhouse Gas and Air Pollution Interactions and Synergies Model

IIASA - International Institute for Applied Systems Analysis

INERIS - Institut national de l'environnement industriel et des risques

LEZ - Low Emission Zone

LLV - Legislated Limit Value

MCPD - Medium Combustion Plants Directive

NECD - National Emissions Ceiling Directive

NO_2 - Nitrogen Dioxide

NO_X - Oxides of Nitrogen (NO_2 + NO)

NH_3 - Ammonia

PM - Particulate Matter

PM_{10} - Particulate Matter smaller than 10µm in diameter

$PM_{2.5}$ - Particulate Matter smaller than 2.5µm in diameter

PPM - Primary Particulate Matter - particulates produced at source, e.g. abrasion

PRIMES - Energy Systems Model of the National Technical University of Athens

RDE - Real driving emissions

RMS - Root Mean Square

SNAP - Selected Nomenclature for Air Pollutants

SO_X - Oxides of Sulphur

SPM - Secondary Particulate Matter - particulates produced chemically after emission, e.g. from NO_X, SO_X, VOC and NH_3 emissions.

STEERS - Strategic Toolkit for Evaluating Emissions Reduction Scenarios

TREMOVE - A transport policy assessment model

TSAP - Thematic Strategy on Air Pollution

VOC - Volatile Organic Compounds

WPE - Working party on Environment

9 MODEL DESCRIPTIONS

9.1 AQUIRES

"Air Quality Universal Information and Reporting System". Designed and built by Aeris Europe this tool allows fast and customisable access to the entire catalogue of air quality measurement data across Europe.

9.2 AQUIRES+

This tool - another Aeris Europe product - incorporates source attribution data from European wide-modelling of air quality at gridded (down to 7x7km scale for the whole EU), AQMZ and measuring station levels and provides unique air quality forecasting capabilities at a screening level, based on historical measurement data. The modelling approach is semi-empirical, drawing on detailed historical measurements from more than three thousand monitoring stations in AirBase together with other available exogenous inputs currently used to support air policy development in Europe e.g. emissions inventories and source-receptor data.

9.3 CHIMERE MODEL

The CHIMERE multi-scale model is primarily designed to produce daily forecasts of ozone, aerosols and other pollutants and make long-term simulations (entire seasons or years) for emission control scenarios. CHIMERE runs over a range of spatial scales from the regional scale (several thousand kilometres) to the urban scale (100-200 Km) with resolutions from 1-2 Km to 100 Km.

9.4 COPERT

COPERT is a software tool developed in a European context but now used world-wide to calculate air pollutant and greenhouse gas emissions from road transport. The development of COPERT is undertaken by EMISIA SA under the coordination of the European Environment Agency (EEA), in the framework of the activities of the European Topic Centre for Air Pollution and Climate Change Mitigation. COPERT has been developed for official road transport emission inventory preparation in EEA member countries. The COPERT 4 methodology is part of the EMEP/EEA air pollutant emission inventory guidebook for the calculation of air pollutant emissions and the emission factors it produces are refined over time in response to real world data and experience reflecting the true performance of each technology standard.

The COPERT calculations are consistent with the "Detailed Methodology (Tier 3)" of the "EMEP/CORINAIR Atmospheric Emissions Inventory Guidebook" [7] chapter on exhaust emissions from road transport, which covers hot and cold-start exhaust emissions from passenger cars, light duty vehicles, heavy duty vehicles, mopeds and motorcycles.

9.5 EMEP MODEL

The European Monitoring and Evaluation Programme (EMEP) is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution (CLRTAP) for international co-operation to solve transboundary air pollution problems. The EMEP MSC-W chemical transport model is one of the key tools within European air pollution policy assessments.

9.6 GAINS MODEL

The Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)-Model provides a consistent framework for the analysis of reduction strategies from air pollution and greenhouse gas sources.

9.7 STRATEGIC TOOLKIT FOR EVALUATING EMISSION REDUCTION SCENARIOS (STEERS)

STEERS is capable of generating road transport emission forecasts based on a Member State specific, vintage segregated, vehicle fleet model that incorporates technology specific emissions factors, national vehicle fleet turnover functions and time-driven fleet composition changes. Also included is vehicle activity (annual distance driven) and a time-based dimension to reflect the reality that as vehicles age they are driven less. STEERS was originally developed for the "Auto Oil" project and has been periodically updated to provide additional functions and versions based on the evolving COPERT emissions factors. The STEERS vehicle fleet model structure is compatible with TREMOVE.

9.8 TREMOVE

TREMOVE is a mature transport policy assessment model which covers all inland urban and inter-urban transport modes. [8] To provide consistency and compatibility with other major policy tools, STEERS is populated with the TREMOVE 3.3.2 vehicle fleets. The 3.3.2 version of TREMOVE was developed for the iTren 2030 project [9] as part of the European Commission's 6th Framework Programme and it has two implementations: the reference fleet and the alternative fleet.

For this project the Base Case road transport emissions calculation utilised the TREMOVE 3.3.2 Alternative dataset and the COPERT 4 v11.8.5 emission factors. The alternative fleet corresponds to the iTren 2030 Integrated Scenario which predicts a capped diesel fleet evolution from 2015. The integrated iTren 2030 scenario also accounts for the economic and financial crisis of 2008/2009 including the economic recovery programmes implemented by the EU and the Member States as well as ambitious climate, energy and transport policies that are to be implemented between 2009 and 2025. This base dataset was also used in a previous study that CONCAWE participated in: "EU renewable energy targets in 2020: Revised analysis of scenarios for transport fuels" [10]

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11 APPENDICES

11.1 BASE CASE RESULTS

PARTICULATE MATTER ($PM_{2.5}$)

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	433	117	21	68%	28%	4%
2020	474	79	18	77%	19%	4%
2025	489	65	17	80%	16%	4%
2030	495	59	17	81%	15%	4%
	All AQ Stations			Urban AQ Stations		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	2530	323	101	1474	263	87
2020	2647	223	84	1564	188	72
2025	2710	164	80	1615	140	69
2030	2728	149	77	1630	127	67

PARTICULATE MATTER (PM_{10})

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	384	158	31	66%	27%	7%
2020	446	107	20	77%	19%	4%
2025	469	89	15	81%	16%	3%
2030	480	78	15	83%	13%	3%
	All AQ Stations			Urban AQ Stations		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	1605	752	265	845	559	227
2020	1861	555	206	1022	435	174
2025	1978	464	180	1108	373	150
2030	2046	404	172	1164	322	145

NITROGEN DIOXIDE (NO_2)

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	425	63	57	69%	13%	18%
2020	435	62	48	83%	7%	10%
2025	449	57	39	90%	5%	5%
2030	460	53	32	93%	2%	5%
	All AQ Stations			Urban AQ Stations		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	1828	166	84	960	145	73
2020	1994	54	30	1105	46	27
2025	2038	30	10	1141	27	10
2030	2056	16	6	1159	13	6

11.2 SCENARIO RESULTS

COMPLIANCE: SCENARIO A - $PM_{2.5}$

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	417	112	21	68%	28%	4%
2020	484	53	13	85%	12%	3%
2025	493	47	10	88%	9%	3%
2030	499	41	10	89%	9%	3%

COMPLIANCE: SCENARIO A - PM_{10}

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	371	152	31	66%	27%	7%
2020	484	61	9	89%	10%	2%
2025	505	44	5	92%	7%	1%
2030	510	39	5	93%	7%	1%

COMPLIANCE: SCENARIO B - $PM_{2.5}$

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	433	117	21	68%	28%	4%
2020	474	79	18	77%	19%	4%
2025	490	64	17	80%	16%	4%
2030	495	59	17	81%	15%	4%

COMPLIANCE: SCENARIO B - PM_{10}

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	384	158	31	66%	27%	7%
2020	446	107	20	78%	19%	4%
2025	469	89	15	81%	16%	3%
2030	481	77	15	83%	13%	3%

COMPLIANCE: SCENARIO B - NO_2

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426	61	57	69%	13%	18%
2020	456	53	35	94%	6%	0%
2025	489	32	23	95%	5%	0%
2030	511	20	13	95%	5%	0%

COMPLIANCE: SCENARIO C.1 - NO_2

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426	61	57	69%	13%	18%
2020	510	24	10	88%	6%	6%
2025	523	15	6	91%	4%	5%
2030	530	10	4	93%	2%	5%

COMPLIANCE: SCENARIO C.2 - NO_2

	AQ Zones			AQMZ Population %		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426	61	57	69%	13%	18%
2020	494	29	21	85%	6%	10%
2025	520	18	6	90%	5%	5%
2030	529	11	4	93%	2%	5%

COMPLIANCE BY ZONE COUNT: SCENARIOS D.1, D.2, D.3 & D.4 - NO_2

Scenario	D.1			D.2		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426	61	57	426	61	57
2020	513	22	9	516	20	8
2025	528	12	4	530	12	2
2030	535	8	1	538	6	0
Scenario	D.3			D.4		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426	61	57	426	61	57
2020	532	10	2	533	10	1
2025	535	9	0	537	7	0
2030	539	5	0	539	5	0

COMPLIANCE BY ZONE POPULATION: SCENARIOS D.1, D.2, D.3 & D.4 - NO_2

Scenario	D.1			D.2		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	69%	13%	18%	69%	13%	18%
2020	88%	6%	6%	89%	5%	6%
2025	93%	2%	5%	94%	6%	0%
2030	94%	5%	0%	95%	5%	0%
Scenario	D.3			D.4		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	69%	13%	18%	69%	13%	18%
2020	94%	6%	0%	94%	6%	0%
2025	94%	6%	0%	95%	5%	0%
2030	95%	5%	0%	95%	5%	0%

COMPLIANCE BY STATION COUNT: SCENARIOS BC0, SN1A, SN1B, SN1C, 7XLLV & ZEPCD - ALL STATIONS - NO_2

Scenario	BC0			SN1a			SN1b		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	1828 (88%)	166 (8%)	84 (4%)	1828 (88%)	166 (8%)	84 (4%)	1828 (88%)	166 (8%)	84 (4%)
2020	1994 (96%)	54 (3%)	30 (1%)	1958 (94%)	81 (4%)	39 (2%)	1961 (94%)	79 (4%)	38 (2%)
2025	2038 (98%)	30 (1%)	10 (0%)	2026 (97%)	39 (2%)	13 (1%)	2034 (97%)	33 (2%)	11 (1%)
2030	2056 (99%)	16 (1%)	6 (0%)	2053 (99%)	17 (1%)	8 (0%)	2058 (99%)	15 (1%)	5 (0%)
Scenario	SN1c			7xLLV			ZEPCD		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	1828 (88%)	166 (8%)	84 (4%)	1828 (88%)	166 (8%)	84 (4%)	1828 (88%)	166 (8%)	84 (4%)
2020	1992 (96%)	55 (3%)	31 (1%)	1949 (94%)	90 (4%)	39 (2%)	2006 (97%)	49 (2%)	23 (1%)
2025	2039 (98%)	30 (1%)	9 (1%)	2012 (97%)	44 (2%)	22 (1%)	2051 (99%)	22 (1%)	5 (0%)
2030	2058 (99%)	16 (1%)	4 (0%)	2030 (97%)	35 (2%)	13 (1%)	2066 (99%)	11 (1%)	1 (0%)

COMPLIANCE BY STATION COUNT: SCENARIOS BC0, SN1A, SN1B, SN1C, 7XLLV & ZEPCD - URBAN STATIONS - NO_2

Scenario	BC0			SN1a			SN1b		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	960 (82%)	145 (12%)	73 (6%)	960 (82%)	145 (12%)	73 (6%)	960 (82%)	145 (12%)	73 (6%)
2020	1105 (94%)	46 (4%)	27 (2%)	1071 (91%)	72 (6%)	35 (3%)	1073 (91%)	71 (6%)	34 (3%)
2025	1141 (97%)	27 (2%)	10 (1%)	1131 (96%)	35 (3%)	12 (1%)	1138 (96%)	30 (3%)	10 (1%)
2030	1159 (98%)	13 (1%)	6 (1%)	1156 (98%)	14 (1%)	8 (1%)	1161 (99%)	12 (1%)	5 (0%)
Scenario	SN1c			7xLLV			ZEPCD		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	960 (82%)	145 (12%)	73 (6%)	960 (82%)	145 (12%)	73 (6%)	960 (82%)	145 (12%)	73 (6%)
2020	1103 (94%)	47 (4%)	28 (2%)	1063 (90%)	80 (7%)	35 (3%)	1114 (94%)	43 (4%)	21 (2%)
2025	1142 (97%)	27 (2%)	9 (1%)	1118 (95%)	41 (3%)	19 (2%)	1154 (98%)	19 (2%)	5 (0%)
2030	1161 (99%)	13 (1%)	4 (0%)	1136 (96%)	31 (3%)	11 (1%)	1168 (99%)	9 (1%)	1 (0%)

COMPLIANCE BY ZONE COUNT: SCENARIOS BC0, SN1A, SN1B, SN1C, 7XLLV & ZEPCD - NO_2

Scenario	BC0			SN1a			SN1b		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426 (78%)	61 (11%)	57 (10%)	426 (78%)	61 (11%)	57 (10%)	426 (78%)	61 (11%)	57 (10%)
2020	486 (89%)	36 (7%)	22 (4%)	470 (86%)	47 (9%)	27 (5%)	473 (87%)	44 (8%)	27 (5%)
2025	520 (96%)	17 (3%)	7 (1%)	509 (94%)	26 (5%)	9 (2%)	516 (95%)	20 (4%)	8 (1%)
2030	529 (97%)	10 (2%)	5 (1%)	526 (97%)	13 (2%)	5 (1%)	530 (97%)	10 (2%)	4(1%)
Scenario	SN1c			7xLLV			ZEPCD		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	426 (78%)	61 (11%)	57 (10%)	426 (78%)	61 (11%)	57 (10%)	426 (78%)	61 (11%)	57 (10%)
2020	485 (89%)	36 (7%)	23 (4%)	467 (86%)	50 (9%)	27 (5%)	495 (91%)	30 (6%)	19 (3%)
2025	521 (96%)	17 (3%)	6 (1%)	499 (92%)	29 (5%)	16 (3%)	526 (97%)	14 (3%)	4 (1%)
2030	530 (97%)	11 (2%)	3 (1%)	512 (94%)	23 (4%)	9 (2%)	536 (99%)	7 (1%)	1 (0%)

COMPLIANCE BY ZONE POPULATION PERCENTAGE: SCENARIOS BC0, SN1A, SN1B, SN1C, 7XLLV & ZEPCD - NO_2

Scenario	BC0			SN1a			SN1b		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	69%	13%	18%	69%	13%	18%	69%	13%	18%
2020	83%	7%	10%	79%	9%	12%	80%	8%	12%
2025	90%	5%	5%	87%	7%	6%	89%	5%	6%
2030	93%	2%	5%	92%	3%	5%	93%	2%	5%
Scenario	SN1c			7xLLV			ZEPCD		
Year	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant	Compliant	Uncertain	Non-Compliant
2015	69%	13%	18%	69%	13%	18%	69%	13%	18%
2020	83%	7%	10%	79%	9%	12%	85%	6%	9%
2025	90%	5%	5%	86%	6%	8%	92%	3%	5%
2030	93%	2%	5%	88%	6%	6%	95%	5%	0%

11.3 NO_X ROAD TRANSPORT ATTENUATION FACTORS FOR ALTERNATIVE BASE CASES AS CO-EFFICIENTS OF 2010 BASELINE EMISSIONS

Country	BC0			SN1a			SN1b			SN1c			7xLLV			ZEPCD		
Year	2020	2025	2030	2020	2025	2030	2020	2025	2030	2020	2025	2030	2020	2025	2030	2020	2025	2030
Austria	0.38	0.22	0.18	0.46	0.28	0.20	0.46	0.25	0.15	0.39	0.20	0.13	0.48	0.37	0.36	0.32	0.12	0.06
Belgium	0.51	0.32	0.23	0.60	0.37	0.25	0.60	0.33	0.19	0.52	0.29	0.17	0.63	0.49	0.42	0.43	0.21	0.10
Bulgaria	0.49	0.34	0.29	0.60	0.41	0.31	0.59	0.37	0.24	0.50	0.30	0.21	0.62	0.56	0.55	0.40	0.19	0.11
Cyprus	0.69	0.49	0.37	0.69	0.50	0.37	0.69	0.50	0.37	0.69	0.49	0.37	0.69	0.50	0.37	0.69	0.49	0.37
Czech Republic	0.55	0.38	0.27	0.59	0.41	0.29	0.59	0.39	0.27	0.56	0.37	0.25	0.60	0.45	0.37	0.52	0.33	0.20
Denmark	0.46	0.29	0.22	0.50	0.32	0.24	0.49	0.31	0.22	0.46	0.28	0.20	0.51	0.36	0.31	0.42	0.24	0.15
Estonia	0.45	0.29	0.18	0.45	0.29	0.18	0.45	0.29	0.18	0.45	0.29	0.18	0.46	0.29	0.19	0.45	0.28	0.18
Finland	0.49	0.33	0.25	0.54	0.36	0.27	0.53	0.34	0.24	0.49	0.31	0.23	0.55	0.41	0.35	0.45	0.27	0.19
France	0.57	0.39	0.32	0.69	0.48	0.37	0.68	0.44	0.30	0.58	0.36	0.26	0.71	0.62	0.59	0.47	0.24	0.14
Germany	0.38	0.22	0.19	0.47	0.27	0.19	0.46	0.23	0.15	0.38	0.19	0.14	0.50	0.37	0.33	0.30	0.13	0.09
Greece	0.44	0.26	0.17	0.45	0.27	0.17	0.45	0.26	0.17	0.44	0.26	0.16	0.45	0.28	0.18	0.44	0.25	0.16
Hungary	0.39	0.22	0.15	0.41	0.23	0.16	0.41	0.22	0.15	0.39	0.21	0.14	0.41	0.25	0.20	0.38	0.20	0.12
Ireland	0.32	0.21	0.21	0.35	0.23	0.22	0.35	0.21	0.19	0.32	0.20	0.18	0.37	0.28	0.29	0.28	0.16	0.15
Italy	0.54	0.34	0.24	0.62	0.39	0.27	0.61	0.36	0.22	0.55	0.32	0.20	0.64	0.48	0.41	0.48	0.24	0.13
Latvia	0.49	0.29	0.21	0.52	0.31	0.22	0.52	0.30	0.20	0.49	0.28	0.19	0.53	0.34	0.27	0.46	0.25	0.17
Lithuania	0.61	0.44	0.35	0.68	0.50	0.38	0.68	0.47	0.34	0.62	0.43	0.31	0.70	0.58	0.52	0.55	0.36	0.24
Luxembourg	0.43	0.25	0.18	0.46	0.27	0.19	0.46	0.25	0.17	0.43	0.24	0.16	0.47	0.31	0.24	0.41	0.22	0.14
Malta	0.37	0.20	0.13	0.38	0.21	0.14	0.38	0.21	0.13	0.37	0.20	0.13	0.39	0.23	0.16	0.36	0.19	0.11
Netherlands	0.41	0.23	0.17	0.47	0.27	0.18	0.46	0.24	0.15	0.41	0.21	0.14	0.48	0.33	0.29	0.35	0.16	0.09
Poland	0.53	0.31	0.21	0.56	0.33	0.21	0.56	0.31	0.19	0.53	0.30	0.19	0.57	0.37	0.28	0.49	0.27	0.17
Portugal	0.56	0.35	0.20	0.62	0.39	0.22	0.62	0.37	0.19	0.57	0.34	0.17	0.64	0.45	0.32	0.52	0.28	0.12
Romania	0.55	0.39	0.25	0.57	0.41	0.25	0.57	0.40	0.24	0.55	0.38	0.23	0.58	0.44	0.30	0.53	0.36	0.21
Slovakia	0.39	0.26	0.17	0.41	0.28	0.18	0.41	0.27	0.17	0.40	0.26	0.16	0.42	0.30	0.23	0.38	0.24	0.14
Slovenia	0.54	0.39	0.35	0.67	0.48	0.39	0.66	0.43	0.31	0.56	0.35	0.27	0.70	0.64	0.66	0.44	0.23	0.15
Spain	0.64	0.45	0.33	0.74	0.52	0.38	0.73	0.49	0.33	0.65	0.43	0.29	0.76	0.62	0.54	0.55	0.33	0.20
Sweden	0.35	0.20	0.17	0.41	0.22	0.18	0.40	0.20	0.15	0.35	0.18	0.14	0.42	0.29	0.26	0.31	0.14	0.10
United Kingdom	0.49	0.28	0.25	0.59	0.34	0.25	0.58	0.31	0.20	0.50	0.25	0.19	0.61	0.45	0.42	0.41	0.17	0.13
EU27	**0.50**	**0.32**	**0.24**	**0.58**	**0.36**	**0.26**	**0.57**	**0.34**	**0.22**	**0.51**	**0.29**	**0.20**	**0.60**	**0.45**	**0.40**	**0.43**	**0.22**	**0.14**

12 LIST OF FIGURES

Concawe
Boulevard du Souverain 165
B-1160 Brussels
Belgium

Tel: +32-2-566 91 60
Fax: +32-2-566 91 81
e-mail: info@concawe.org
website: http://www.concawe.org

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