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Further vehicle exhaust emission controls and their impact on NO_2 air quality in Europe

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More information on the Internet

More information is available on the internet:

- on the GAINS methodology,

- on air quality calculations in support of the review of the Thematic Strategy on Air Pollution

- interactive access to input data and results.

http://www.iiasa.ac.at/web/home/research/researchPrograms/air/Program-Overview.en.html

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1 Introduction

About 8% of the urban population in the European Union (EU28) is exposed to ambient NO_2 concentrations in excess of the annual air quality limit value of 40 µg/m^3 (Guerreiro et al. 2014, 56f.). In addition, eleven Member States have not met their 2010 NO_x emissions cap under the EU Directive on Emission Ceilings, and six countries continue failing still in 2013 (EEA 2015b). High on-road NO_x emissions notably from diesel cars are made responsible for the persistent exceedance of the NO_2 air quality limit value, in particular along urban roads (EEA 2015a). NO_x emissions from all sectors are expected to decrease by more than 40% between 2015 and 2030 if legislation is implemented as planned in EU28. NO_x emissions from diesel heavy duty and light duty vehicles are expected to decline by 80% and 60%, respectively, in the same period (Markus Amann et al. 2014). In consequence, exceedances of the NO_2 ambient limit values are expected to decrease. However, there is particular uncertainty about the on-road emissions from future light duty diesel vehicles. Therefore, how many stations will still remain in excess of the ambient air quality limit value does crucially depend on the real-world NO_x emissions of Euro 6 light duty diesel vehicles (Borken-Kleefeld and Ntziachristos 2012) (Fig. 1). In case of high on-road NO_x emissions from Euro 6 diesel cars and light commercial vehicles there might be a need for further emission controls.

Stations in non-compliance as a function of Euro 6 LDV emissions

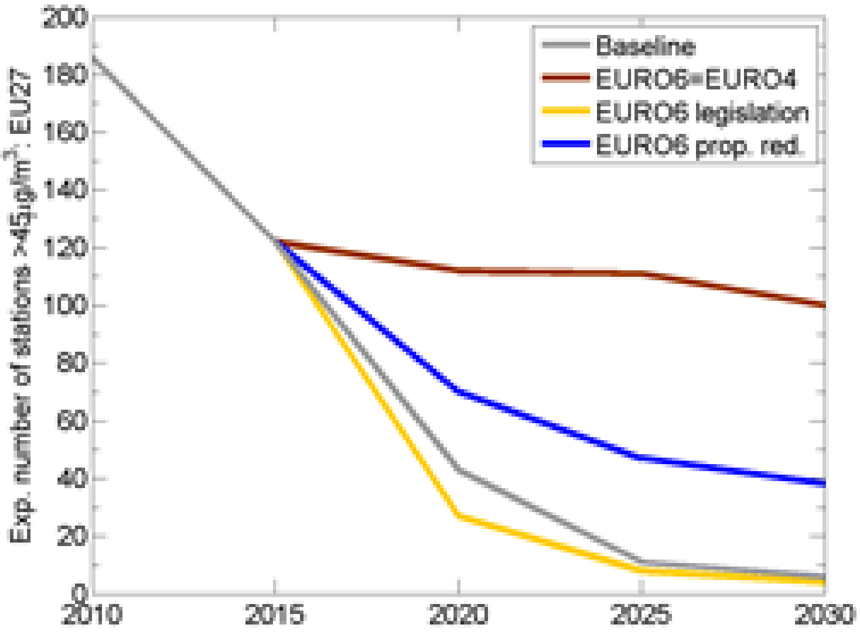

Fig. 1: Number of European monitoring stations in non-compliance with the annual NO_2 air quality limit value as a function of the on-road emissions of the Euro 6 diesel cars and light commercial vehicles. Non-compliance will be eliminated in the next decades only if Euro 6 cars emit in real-driving close to the legislative limit value (Markus Amann et al. 2012).

This study explores how much an additional hypothetical emission control stage (called Euro 7/VII) for light- and heavy-duty diesel vehicles could help to reduce further or quicker the NO_2 ambient concentrations.

2 Approach

To answer the question we

i) model the introduction of the hypothetical new vehicle emission control stage into the vehicle fleet,

ii) calculate the resulting NO_x emissions from road transport, while emissions from all other sectors remain unchanged, and finally

iii) calculate the resulting ambient NO_2 concentrations.

We employ the GAINS model for this analysis. It is the basis for the European Commission's Impact Assessment for the proposed 'Directive on the reduction of national emissions of certain atmospheric pollutants'[1]. The respective emission scenarios include all relevant emission sources from all European countries. The data have been thoroughly discussed and validated with national representatives. The atmospheric model includes cross-boundary transport so that the background pollution is properly captured. The chemical interactions of the nitrogen oxides with ozone are modelled, which is particularly relevant for the ambient NO_2 concentrations. The simulated values are calibrated to Europe's official air quality monitoring network (AirBase). Annual average ambient NO_2 concentrations are calculated as a function of the emission scenarios for background, urban and roadside stations. For further information on the approach refer to (G. Kiesewetter et al. 2014; M. Amann et al. 2011), on specific applications for the impact assessment of the proposed revised New Emission Ceilings (NEC) Directive refer to the extensive on-line documentation[2].

2.1 Calculating road vehicles' emissions

In general, emissions are calculated for each country in Europe by vehicle category and fuel type. Age or Euro norm respectively is the main determinant for the exhaust emission characteristics reflected in the average emission factor employed. Each new emission control stage gradually penetrates the fleet in the rate of fleet turnover. The fleet average emission factor decreases as younger, generally less polluting vehicles replace older, generally higher emitting vehicles.. Infamously this has not been the case for NO_x emissions from light duty diesel vehicles.

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[1] http://www.iiasa.ac.at/web/home/research/researchPrograms/air/policy/TSAP-reports.html

[2] http://www.iiasa.ac.at/web/home/research/researchPrograms/air/Program-Overview.en.html

Total resulting emissions depend also on the growth in activity. The GAINS model covers all relevant air pollutants but here we focus on emissions of NO_x.

Total national emissions from vehicles in a given year are calculated according to the following formula

$$Em_p = \sum_{fc} (FC_{fc} * EF_{fcp})$$

with:

Em_p	total national emission of pollutant *p*. [Unit: kt]
FC_{fc}	fuel consumption of vehicle category *c,* powered with fuel *f* [Unit: PJ]
EF_{fcp}	average emission factor of pollutant *p* for vehicle category *c*, powered with fuel *f*. [Unit: g per MJ, equivalent to kt per PJ].

The emission calculation in GAINS is based on the fuel consumption per vehicle category, as reported in national statistics. Many national traffic emission models are based on the national traffic volume, which in turn is calibrated to the total fuel consumed nationally, the same figure that we use. Our emission factors are expressed per energy unit consumed, the other emission factors are expressed per distance travelled. Both are related by the average fuel economy of the vehicle category. During extensive consultations with EU Member States the approach, data and assumptions were cross-checked and adapted where appropriate. We therefore calculate the same emissions from road traffic as Member States report for historic years, with a similar distribution between vehicle categories. Remaining differences relate mostly to intrinsic uncertainties (Amann, M. et al. 2015).

Input data for historic years are extracted from national statistics. Fuel consumption data are taken from EUROSTAT, and refer by convention to the fuel sold in a country. Hence, emissions resulting from that fuel use are allocated also to this country, irrespective of cross-border traffic. Projections of the future transport activity and transport's fuel consumption are taken the European Union's official trend outlook – the PRIMES 2013 Reference scenario in this case (Capros et al. 2013). From the same report energy and activity data for all other sectors are taken, so that the whole range of emission sources is covered in a consistent and EU-wide accepted manner. Further details for road transport projections are given in section 2.2.1.

The average emission factor EF_{fcp} is calculated as the weighted sum of the emission factors per technology or emission concept *t*, identified by their Euro exhaust emission standard for each combination of vehicle category *c* and fuel *f*:

$$EF_{p\,fc} = \sum_t (share_t * EF_{tp})_{fc}$$

with:

$EF_{p\,fc}$ average emission factor of pollutant *p* for vehicle category c, powered with fuel *f* [Unit: g per MJ];

$Share_t$ share of this technology *t* in total fuel consumption for vehicle category *c*, powered with fuel *f* [Unit: %], in GAINS also called control share;

EF_{tp} average emission factor of pollutant *p* for technology *t*, vehicle category *c*, powered with fuel *f* [Unit: g per MJ].

Emission factors were calculated specifically for the EU's review with the COPERT 4 database[3]. The figures are representative for real-world driving in the respective countries as established in the ARTEMIS project and follow-up research. Particular attention is devoted to accurately represent real-driving NO_x emissions from light and heavy duty diesel vehicles. The specific assumptions on Euro 6 emission factors are discussed in section 2.2.3; the assumptions on the hypothetical Euro 7/VII emission factors are presented in section 2.3.

2.2 The Reference emission scenario

The Reference scenario reflects the future trend assuming current legislation for emission controls. It is thus the backdrop against which all further scenarios are evaluated. We use the same scenario as used for the impact assessment of the EU's Thematic Strategy on Air Pollution (Markus Amann et al. 2014), but extend notably

- for developments up to 2040, based on activity projections from the PRIMES 2013 Reference scenario (Capros et al. 2013), and
- account for the second package of the real driving emission (RDE) tests for Euro 6 light duty diesel vehicles (Consilium 2016a).

The scenario does not yet account for measures to be implemented when the proposed Thematic Strategy on Air Pollution is adopted. This case is presented as a sensitivity scenario below (sect. 3.5); we can already note here that this package, if adopted as proposed, would only have a small impact on the resulting NO_x emissions. All conclusions drawn for the Reference scenario are therefore robust. Likewise, the recently adopted Stage V controls for Non-Road Mobile Machinery are not included (Consilium 2016b). They do not have a significant impact on the development of NO_x emissions because the emission share of land based Non-Road Mobile Machines is only about 10% and the new Stage V mostly addresses PM and PN emissions but has only few additional requirements on NO_x emissions.

2.2.1 Road traffic's activity

Traffic volume is projected to increase by some 40% in EU28 between years 2015 and 2040, according to the PRIMES Reference scenario (Fig. 2, left). This growth is

[3] http://emisia.com/products/copert-4

driven by the increase in car traffic. Diesel cars' traffic volume is assumed to grow particularly strong (+69%) in that period while the traffic volume of gasoline cars is projected to decrease slightly (-8%). In consequence, the mileage share of diesel cars is expected to increase continuously from about 60% in 2015 to more than 70% in 2040. Battery electric cars are assumed to attain 1% share in the car fleet's total mileage in 2030, growing to 1.6% in 2040. Trucks are expected to increase their mileage by 35% between 2015 and 2040, thus maintaining their share of about 9% in road traffic's mileage throughout the period.

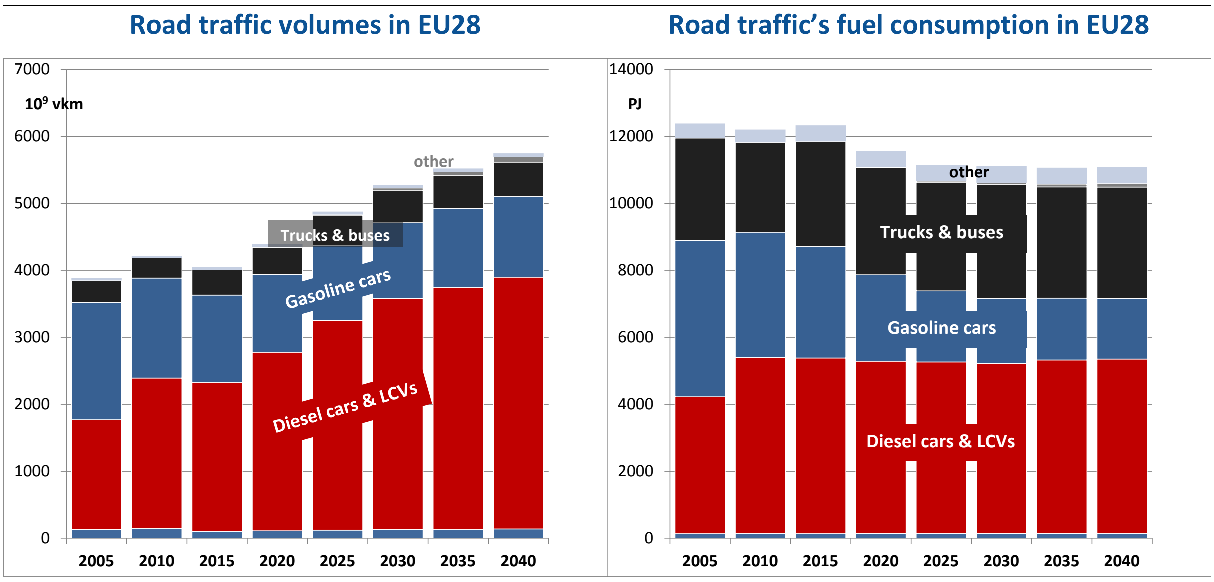

Fig. 2: Development of traffic volume (left, in 10^9 vehicle-km) and fuel consumption (right, in PJ) by vehicle category aggregated for EU28 according to the Reference scenario (PRIMES 2013). Other: Vehicles powered by LPG, CNG, H_2 or (battery) electricity.

Total petroleum consumption is expected to decline slightly, but shifting very much to diesel fuel: Consumption of gasoline is projected to decrease by 46% between 2015 and 2040: Less traffic and strongly increased fuel efficiency from cars mean much less gasoline demand. The efficiency of diesel cars and light commercial vehicles as well as truck is projected to increase by 40% and 20% respectively, offsetting the increase in traffic volume. Thus, overall diesel consumption is expected to increase by +2% between 2015 and 2040.

2.2.2 Age distribution and turnover of vehicle fleet

The vehicle fleet is disaggregated by their legislative emission certification class, the Euro norm. This classification is based on the vehicles' first registration; it serves as proxy for the emission factors assigned to each vehicle category and age class. New emission limit penetrate the fleet through uptake of new vehicles and phasing-out of older vehicles.

The age composition of the fleet is taken from registration/holding statistics for historic years for each EU Member States (Ntziachristos et al. 2008). The future fleet turnover is simulated by the COPERT model over the projection period. Newer vehicles are driven significantly more miles annually than older vehicles (Andre, Hammarstrom, and Reynaud 1999; Bundesamt für Raumentwicklung 2002; Boulter 2009, 20f.). The mileage shares are weighted with the respective average fuel consumption per emission control stage. They can then be multiplied with the fuel consumption based emission factors used in GAINS (their unit is gram pollutant per MJ fuel consumed). As result, we obtain the share of fuel consumed by each vehicle category and emission class. Fig. 3 shows the fleet distribution for light and heavy duty diesel vehicles in EU28 by emission control stage. Every new emission control stage is gradually introduced, while older vehicles retire from the fleet. Euro 6/VI vehicles attain an average share of 90% or more by 2030, and consume almost 100% of the fuel by 2040 in this Reference scenario.

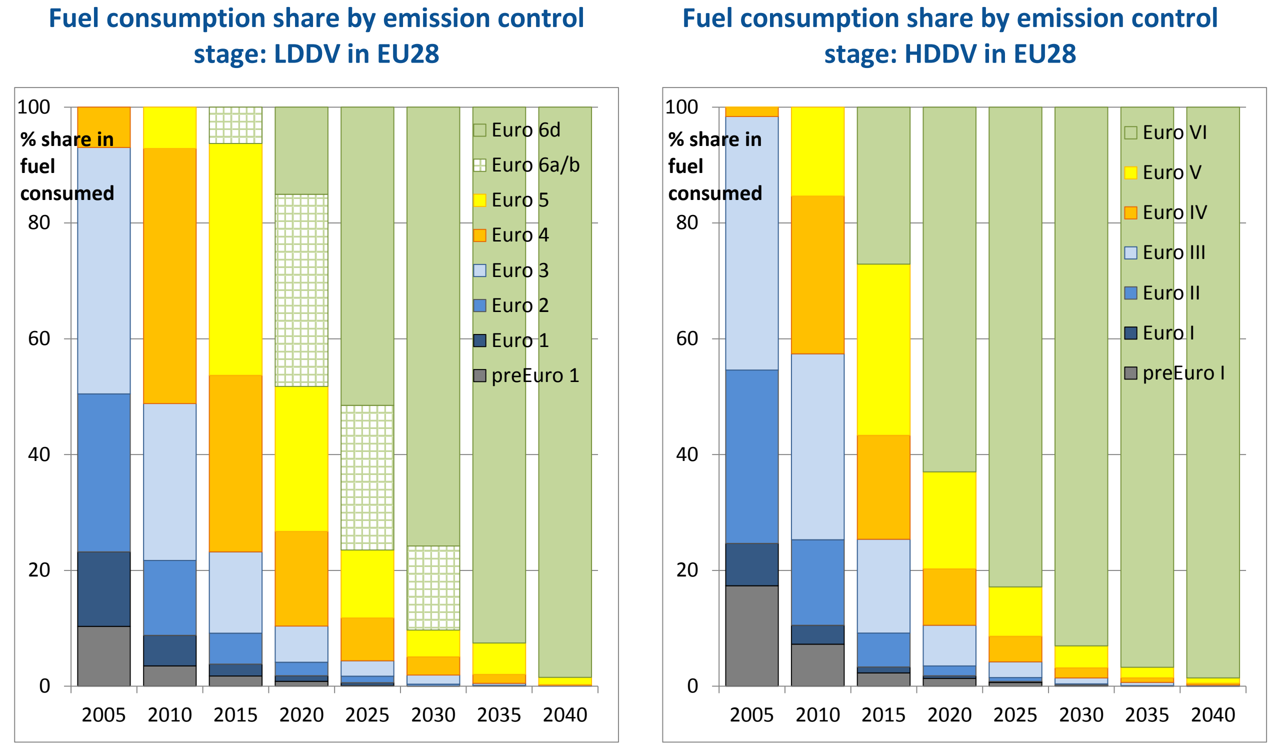

Fig. 3: Distribution of fuel consumption by emission control stages for light duty diesel vehicles (left) and heavy duty diesel vehicles (right) in EU28 between 2005 and 2040.

2.2.3 Vehicle emission factors

The exhaust emission factor of a vehicle is largely determined by its propulsion type (gasoline or diesel) and the emission limit it is certified to at the time of production. Average emission rates for regulated pollutants under real driving conditions are taken from the COPERT model (v 9.1), differentiated by Euro norm (Katsis, Ntziachristos, and Mellios 2012). Because of both, their uncertainty as well as their importance for the analysis here NO_x emission rates from diesel passenger cars and light commercial vehicles have been thoroughly reviewed based on recent on-road measurements (Weiss et al. 2011; Carslaw and Rhys-Tyler 2013; Chen and Borken-Kleefeld 2014). The NO_x emissions from Euro 6 diesel cars and light commercial vehicles are modelled in three stages depending on their production date and the provisions of the respective RDE (real-driving emissions) package (Consilium 2016a). For Euro 6 diesel cars the assumption is notably that average RDE emissions equal average emission in annual driving, also in urban areas. Tab. 1 summarizes our assumptions for the NO_x emission rate of diesel cars and their share in primary NO_2 emissions. Similar assumptions are taken for diesel light commercial vehicles.

	average NO_x emission rate in on-road driving [mg/km]	share of primary NO_2
Euro 4 and older	~600	range: 7% to 49%
Euro 5 – until 09/2015	~750	37%
Euro 6a,b – 09/2015-08/2019	~350 (CF:4.4)	32%
Euro 6c – 09/2019-12/2020*	~168 (CF:2.1)	32%
Euro 6d – 01/2021ff	~120 (CF:1.5)	32%

Tab. 1: Average NO_x emission rate and share of primary NO_2 for diesel passenger cars by emission control stage in the reference scenario.
***: In GAINS we do not represent explicitly the intermediate Euro 6c stage. Its effect is modelled through a linear combination of Euro 6a and Euro 6d.**

The average emission factors for heavy duty trucks are given in Tab. 2. From Euro III to Euro VI the emission rate decreases by a factor 20, and thus much more than for light duty vehicles.

	average NO_x emission rate in on-road driving [mg/km]	share of primary NO_2
Euro III	~5000	7%
Euro IV	~3500	9%
Euro V	~2000	20%
Euro VI	~250	36%

Tab. 2: Average NO_x emission rate and share of primary NO_2 for diesel heavy duty trucks by emission control stage in the reference scenario (Sources: Katsis, Ntziachristos, and Mellios 2012; HBEFA 3.1 2010 for primary NO_2 shares)

2.3 Assumptions for the Euro 7/VII emission scenarios

The purpose of this study is to analyse the impact of an additional emission control stage for diesel light- and heavy duty vehicles on the resulting ambient NO_2 concentration. For simplicity we call this hypothetical emission control stage "Euro 7/VII". Emission rate and application times were suggested by AECC and the Steering Committee. The new limit is about one third of the Euro 6d/VI RDE NO_x emission rate. The Euro VII limit for heavy-duty vehicles is equivalent to the CARB optional low NO_x standard of 0.10 g/bhp.hr. Three different variants for the introduction and uptake of the new emission control standards are designed as follows (Tab. 3):

- The "Central" scenario assumes an introduction of the new emission control stage from 2020 onwards for heavy-duty vehicles and from 2023 onwards for light duty vehicles.

- The “Accelerated” scenario assumes the same introduction times as the “Central” plus in addition an early replacement of vehicles older than 10 years in more affluent EU Member States and of vehicles older than 15 years in less affluent EU Member States from 2030 onwards.
- The “Later” scenario assumes the first application of the new emission control stage from 2025 and 2028 onwards.

Euro 7 / VII for	**average NO_x emission rate in on-road driving**	**Application date for Euro 7/VII controls by scenario**		
		“Central”	“Accelerated”	“Later”
Passenger cars & light commercial vehicles (N1-I)	40 mg/km	2023	„Central“ plus phase-out of vehicles older than 10 (or 15*) years by 2030	2028
Heavy duty trucks, coaches & buses	134 mg/kWh	2020		2025

Tab. 3: Assumptions about emission rate and introduction time for the Euro 7 scenarios. *) The following countries with slower fleet turnover, older fleet or high share of used vehicles are assumed to retire vehicles only when older than 15 years: Bulgaria, Cyprus, Czech Republic, Estonia, Greece, Ireland, Latvia, Lithuania, Malta, Poland, Romania, Slovak Republic.

The effect of the different introduction times and turn-over assumptions is illustrated in Fig. 4 and Fig. 5: Differences affect the distribution of the newest cars i.e. Euro 6 and Euro 7 as well as the share of older cars in the “Accelerated” scenario, which are phased-out by 2030. Differences between scenarios are biggest in the year 2030, with Euro 7 cars having either 0% or 10% as in the Reference and the “Later” Euro 7 scenario, or more than 80% in the “Accelerated” scenario. Differences due to the Euro 7 timing become small again by 2040 as the fleet has been almost completely renewed in all three scenarios.

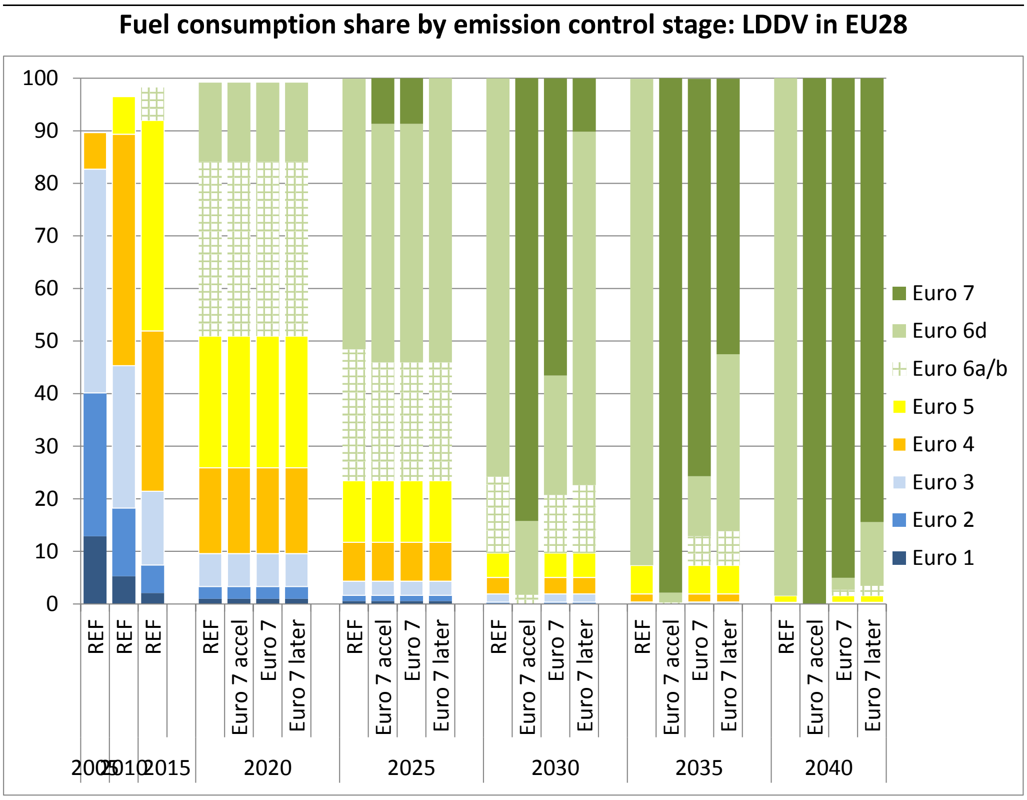

Fig. 4: Distribution of light duty diesel vehicles activity (measured in fuel consumption) in the Reference and the different Euro 7/VII scenarios.

The same is true for heavy duty diesel vehicles (Fig. 5). Effects are however more pronounced as the introduction of Euro VII was assumed three years earlier than for light duty diesel vehicles: The Euro VII shares range between 30% and almost 100% of total activity in 2030, but differences between the Euro VII shares are small by 2040.

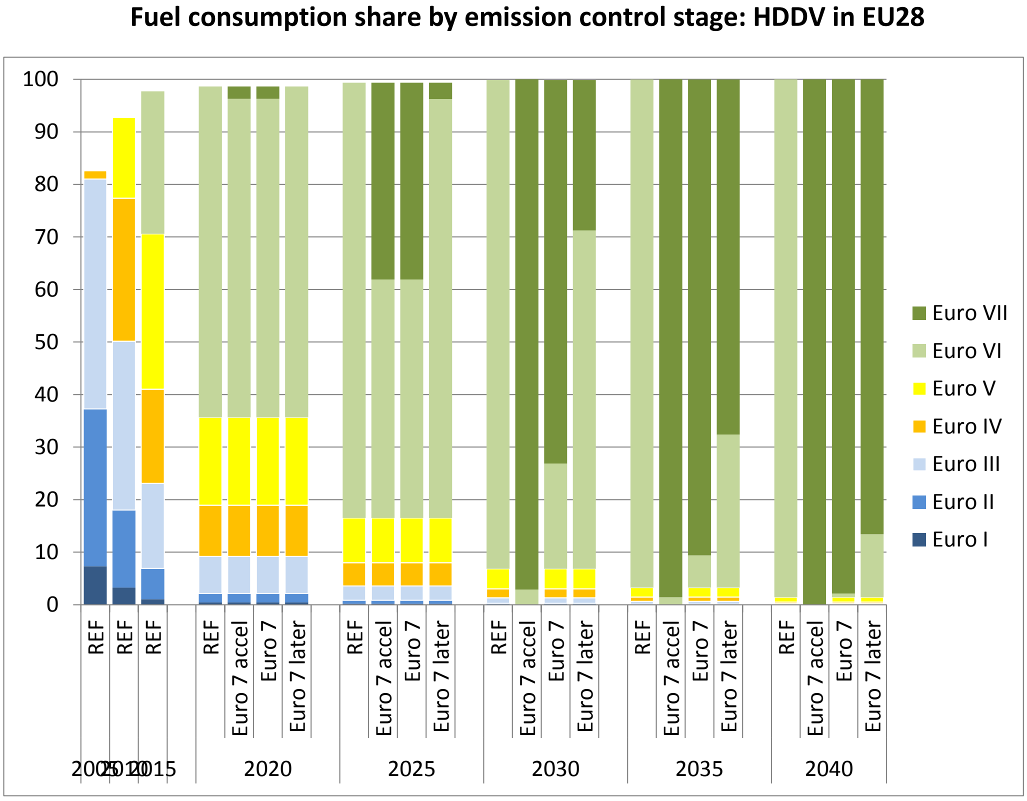

Fig. 5: Distribution of heavy duty diesel vehicles activity (measured in fuel consumption) in the Reference and the different Euro 7/VII scenarios.

2.4 Calculation of ambient NO_2 concentrations

The NO_x emissions from all anthropogenic sources, i.e. industry, power plants, road and non-road transport, residential heating etc. are modelled spatially explicit in GAINS for all European countries. They are input to the meteorological and chemical transport models (EMEP and CHIMERE) calculating the large scale and urban ambient NO_2 concentrations across Europe. Incremental roadside NO_2 concentrations are computed based on road traffic's emissions and accounting for the interaction with ambient ozone. All simulations have been calibrated to the NO_2 concentrations measured at about 2000 European air quality monitoring stations (Fig. 6).

The whole calculation chain has been developed and used for the EU's Impact Assessment of its revised Thematic Strategy on Air Pollution. Full details are presented in the associated reports and peer reviewed publication (G. Kiesewetter et al. 2014; Gregor Kiesewetter et al. 2013).

We calculate the ambient NO_2 concentrations as a function of the NO_x emissions in the Euro 7 scenarios for the about 2000 air quality monitoring stations across Europe. These stations are categorized into regional and urban background sites, industrial sites and road traffic sites. Exceedances of the ambient annual limit value of 40 µg NO_2 per m^3 are usually (only) found for traffic stations in major cities and/or along major roads. We can expect them to be problematic also in future. Fig. 6 shows the location and classification of the European air quality monitoring stations to which our model is calibrated to. Most NO_2 exceedances are found in Germany, Northern Italy, France and the UK where the density of monitoring stations is also high. There is a relative scarcity of stations (satisfying the quality criteria for a reliable air quality modelling) in Central and Eastern Europe, the Baltic countries and Scandinavia. This does not mean clean air but ignorance about the situation on the ground.

European air quality monitoring stations

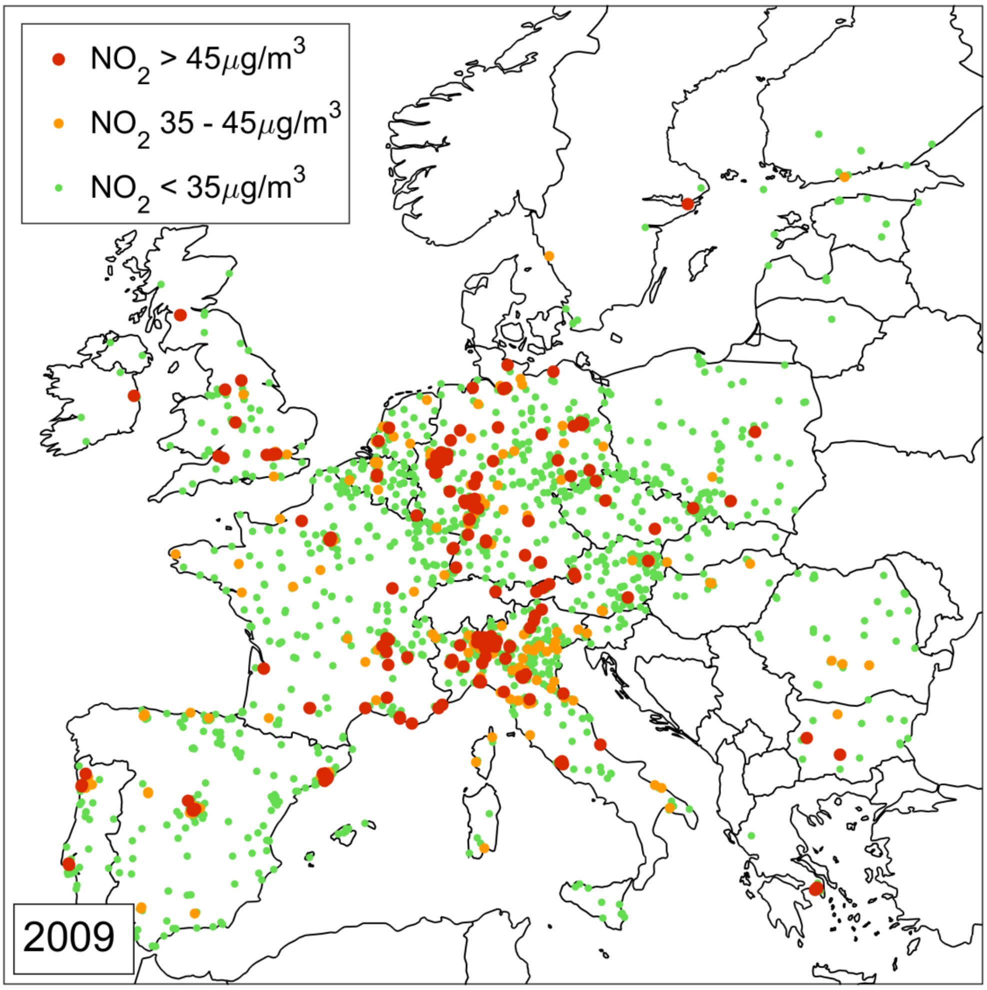

Fig. 6: Distribution of the 1974 European air quality monitoring stations used for this analysis. Colours indicate the annual average NO_2 concentration in the year 2009.

2.5 Uncertainties

The underlying PRIMES 2013 Reference scenario assumed a continuously increasing share of diesel cars (cf. section 2.2.1). From today's perspective this may seem questionable. However if there eventually come less diesel cars then this would mean less NO_x emissions from road traffic and consequently lower ambient NO_2 concentrations. In other words, NO_x emissions and NO_2 concentrations calculated here might be biased high, hence it is a precautionary approach not to underestimate a potential risk.

2.5.1 Contingent on RDE performance from Euro 6 diesel cars

Emission factors used here are largely based on European measurement programs and thus only subject to a usual measurement uncertainty. However, given past experience, it remains to be seen how well Euro 6 RDE provisions will actually reflect emissions in average annual driving. Here we have taken the assumption that RDE tested NO_x emissions are actually equal to average annual emissions. But as noted above, if Euro 6 NO_x emissions turned out to be higher, ambient NO_2 concentrations in the Reference scenario could be much higher. Then the reduction potential by an additional emission control stage would also be higher.

2.5.2 Uncertainties in modelling

Calculated NO_2 concentrations for individual stations underlie considerable uncertainty for a number of reasons:

- General limitations of the steady state model for roadside NO_2 increments using annual mean concentrations, with background concentrations calculated from linear transfer coefficients.
- Reliance on the quality of monitoring data and meta-information (e.g. correct classification and positioning of monitoring sites) in the AirBase database for the model parameter calibration for each monitoring site.
- Assumptions taken on the representativeness of country wide emission trends for individual stations: The physical parameters of traffic stations like average mixing time, representativeness of the background stations used, and the like are estimated in a calibration step for the year 2009 based on measured concentrations and are therefore characteristic for each station. Emission trends are however not calculated for individual stations; the country trends of NO_2 and NO_x emissions are applied to the whole ensemble of stations in each country. The specifics of fleet composition and its changes, and possibly changes to the traffic flow at each individual station cannot be represented Europe-wide. Therefore, results are also only valid for the statistical ensemble and not for individual stations.
- The ozone background concentrations are assumed constant over time.
- Non-modelled NO_2 residual: Our air quality model can explain on average 92% of the observed NO_2 concentrations at roadsides, though individual stations can have substantially higher uncertainties. The unexplained remainder is treated as a constant residual in all future scenarios. In all future scenarios the NO_x emissions from known sources will decrease and consequently the roadside NO_2 concentrations; therefore the constant residual attains a bigger weight. For instance for traffic stations with still elevated NO_2 concentrations in 2030 the unexplained residual contributes about 7 µg per m^3. It might be that the effect of emission reductions are not

fully captured for these sites and hence the resulting ambient concentrations are somewhat biased to the high.

All these factors are of increasing importance for monitoring stations with higher concentrations, which are projected to still have compliance gaps despite strong emission reductions in the future. Ideally such stations should be scrutinized individually, which is however beyond the scope of this project.

As a consequence, results need to be interpreted in a statistical context. We analyse stations aggregated into compliance classes according to their modelled concentrations and do not provide forecasts for individual stations.

2.5.3 Limitations in spatial coverage of stations

The NO_2 modelling is based on a total of 1974 European air quality monitoring stations (AirBase[4]), 434 of which are traffic stations. They have been chosen from a sample of more than 3000 stations after filtering for data coverage and completeness. However, the distribution of stations across countries is not even, and more so the distribution of traffic stations (European Environment Agency 2011). Generally, old EU Member States have a higher density of monitoring stations than new Member States: For instance, 110 traffic stations are located in Germany, whereas only one traffic station is used in Slovakia. Therefore, absolute numbers of stations in different compliance classes may be dominated by a few countries with high station densities.

[4] http://acm.eionet.europa.eu/databases/airbase/

3 Results

3.1 Presentation of results

NO_x emissions are calculated for every European country individually for every 5 years up to 2040. Emission results are presented for EU28 aggregated in the different scenarios. Emissions for individual countries by sector are provided in electronic format.

Ambient NO_2 concentrations are presented as annual averages at the air quality monitoring stations. Because of the inherent uncertainties in the model we apply an uncertainty margin of ±5 µg NO_2 per m^3 and group results for future years in four concentrations bands:

- Above 45 µg NO_2 per m^3, i.e. with high certainty above the annual ambient air quality limit value of 40 µg per m^3;
- between 35 and 45 µg NO_2 per m^3, i.e. within the uncertainty around the annual ambient air quality limit value;
- below 35 but above 20 µg NO_2 per m^3, i.e. with high certainty below the annual ambient air quality limit value, yet possibly still health relevant;
- below 20 µg NO_2 per m^3.

Health impacts from long-term exposure to ambient NO_2 have been under intensive discussion until today. For the protection of human health the World Health Organisation suggests an annual average concentration of 40 µg NO_2 per m^3 (WHO 2006). This value has been adopted in the European Union as annual ambient air quality limit value. An annual value of 30 µg NO_2 per m^3 is recommended for ecosystem protection. There are indications that long-term exposure to NO_2 concentrations above 20 µg per m^3 are detrimental to human health (Héroux et al. 2015) but that is under intensive discussion. Therefore we also display NO_2 concentrations above 20 µg per m^3.

Results are presented as average annual NO_2 concentration for these stations, and can thus be directly compared with legislative limits or recommended values. Results are reported in aggregates and not for individual stations because of the statistical nature of the model.

3.2 Emissions and ambient NO_2 concentrations in the Reference scenario

First we report NO_x emissions and resulting ambient NO_2 concentrations in the Reference scenario. This scenario reflects the current legislation including Euro 6 RDE (in the case of road vehicles). Thus, the Reference scenario constitutes the backdrop against which any further measures are to be evaluated.

NO_x emissions by sector are plotted in Fig. 7 (left) for EU28 in the Reference scenario: Total emissions are expected to decrease continuously by about 50% between 2015 and 2040, continuing the decline from the earlier years. Emissions from industry will remain about constant at their 2015 level, while emissions from residential combustion are expected to decrease only by 20% over the period. All other sectors' will see significant emissions' decrease.

With the regulations already on the books, road transport is expected to decrease its NO_x emissions by 80% in that period (Fig. 7, right). In consequence the share of road to total emissions will decrease from some 40% in 2015 to less than 20% by 2040. This means also that the relative importance of vehicle emissions on the resulting ambient NO_2 concentration will decrease over the next decades.

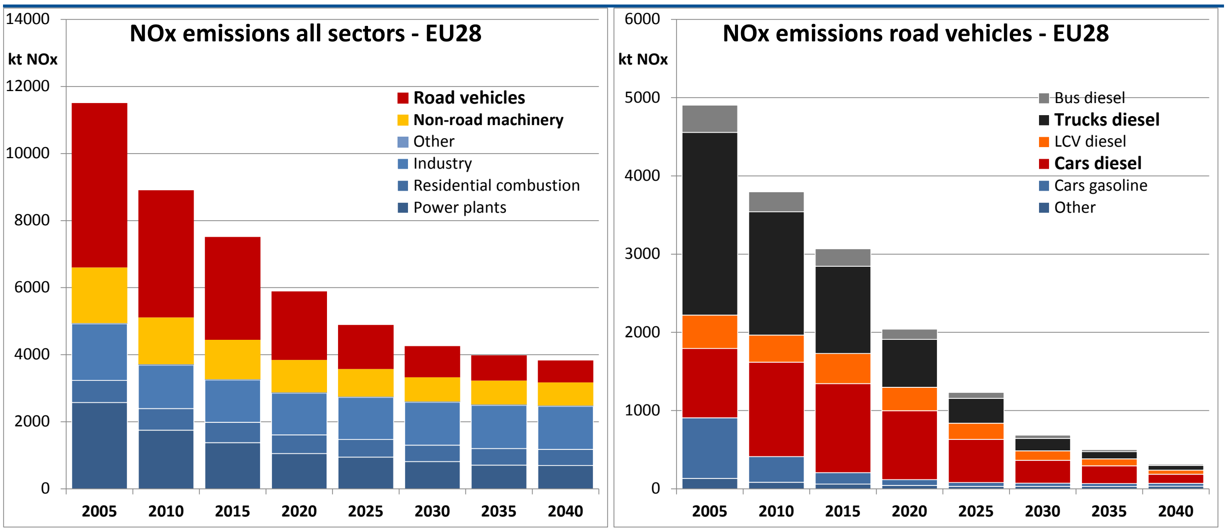

Fig. 7: Development of NO_x emissions from all sectors in EU28 (left) and from road vehicles only (right) according to the Reference scenario. For more details on the non-road machinery: See appendix.

NO_x emissions from road transport result to more than 90% from diesel powered vehicles, with diesel cars and trucks each contributing about 36% in 2015. Light commercial vehicles have a share of 13%, buses and coaches 7%. Gasoline cars have only 5% share in road transport's NO_x emissions despite their abundance; the three-way catalyst effectively cleans the exhaust gas. All vehicles are expected to decrease their NO_x emissions as a consequence notably of the Euro VI/6 emission controls. Emissions from trucks and buses are expected to decrease strongest by 85%. Thus their share in total emissions declines to 22% and 5% in 2040, while the share in emissions from diesel cars and light commercial vehicles will increase – at a much lower absolute level – to 43% and 22% respectively.

Almost 10% of stations have ambient NO_2 concentrations above 45 µg per m^3 in the year 2015 and thus clearly above the air quality limit value (Fig. 8, left). Another 10% of stations are in the range between 35 and 45 µg per m^3, thus risking exceedance of the limit value. More than one third of stations (36%) have concentrations between 20 and 35 µg per m^3 and less than half are below 20 µg per m^3.

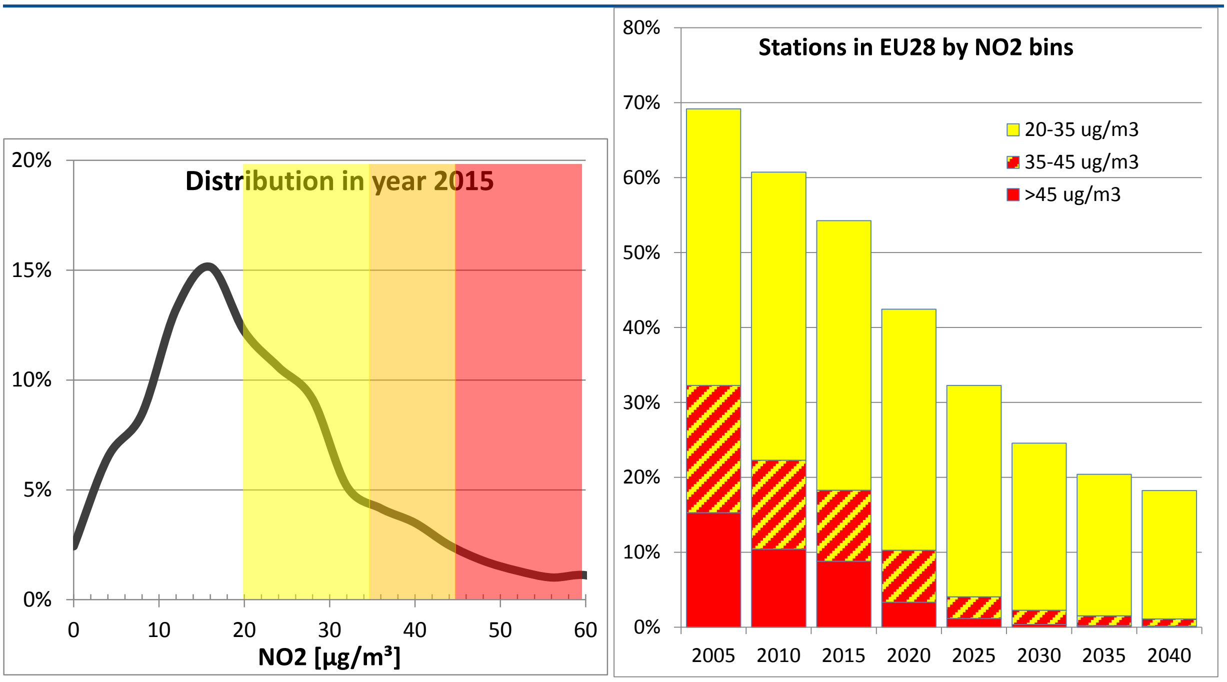

Fig. 8: NO_2 ambient concentrations at European monitoring stations. Left: Distribution in the year 2015. Right: Development by concentration bin in the Reference scenario.

In the Reference scenario ambient annual NO_2 concentrations are expected to decrease continuously: By 2030 some 2% of stations risk exceeding the air quality limit value (i.e. having a modelled value of 35 µg per m^3 or more). By 2040 this share is expected to become 1%. The projected decrease in precursor emissions will also be felt at intermediate concentrations: Stations registering between 20 and 35 µg NO_2 per m^3 on annual average are expected to drop to 22% and 17% in years 2030 and 2040 respectively.

3.3 Emissions and ambient NO_2 concentrations in the central Euro 7/VII scenario

In the following we present results for the “Central” Euro 7/VII scenario that assumes that the new emission control stage is applied to heavy and light duty vehicles from 2020 and 2023 onwards, respectively. Results are shown relative to the Reference scenario so that the difference can be immediately seen (Fig. 9): Total NO_x emission in the “Central” scenario would be 6% and 9% lower in 2030 and 2040 respectively. These result from significantly lower NO_x emissions in the road transport sector alone: Emissions would be 26% and 52% lower than in the Reference scenario by 2030 and 2040 respectively. Reductions come from light and heavy duty diesel vehicles in roughly same proportions.

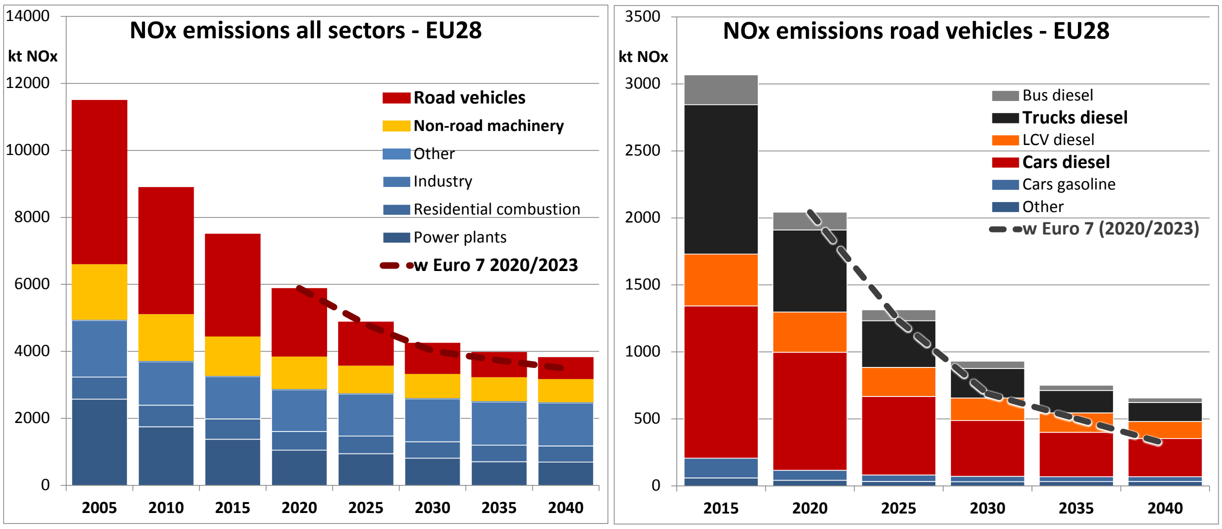

Fig. 9: Development of NO_x emissions from all sectors in EU28 (left) and from road vehicles only (right) according to the "central" Euro 7/VII scenario.

Lower emissions from road vehicles will result in lower ambient NO_2 concentrations notably at traffic stations. Differences can be seen from the year 2025 onwards, as the Euro 7/VII emission control stage has begun to replace some shares of older vehicles (Fig. 10, left). The full effect can be seen in the year 2040 when more than 95% of vehicle activity is by Euro 7/VII vehicles (Fig. 10, right):

By 2030 the number of stations risking exceedance of the ambient air quality limit value could be reduced from 2% to 1% in the Euro 7/VII scenario, the number of stations between 20 and 35 µg per m^3 could be reduced from 22% to 16% relative to the Reference scenario. In other words, the air quality of Reference scenario in 2040 could be attained with this additional emission control stage already 10 years earlier. Similarly, by 2040 the share of stations in excess of 35 µg per m^3 could also be halved from 1% to 0.5%, and stations above 20 µg per m^3 could be reduced from 17% to 11%.

The frequency distribution of ambient NO_2 concentrations in the year 2040 shows that the absolute majority of stations covered in the modelling has concentrations below 9 µg per m^3, compared to 11 µg per m^3 in the Reference scenario. At the upper end of the distribution, there will be only very few stations left with annual average concentrations above 30 µg per m^3. Their concentrations can also be reduced if a Euro 7/VII vehicle emission control stage would be introduced. These stations are typically along busy roads or highways in urban agglomerations (like Paris or London) or in industrialised regions with adverse meteorological conditions for the dispersion of pollutants (like Northern Italy).

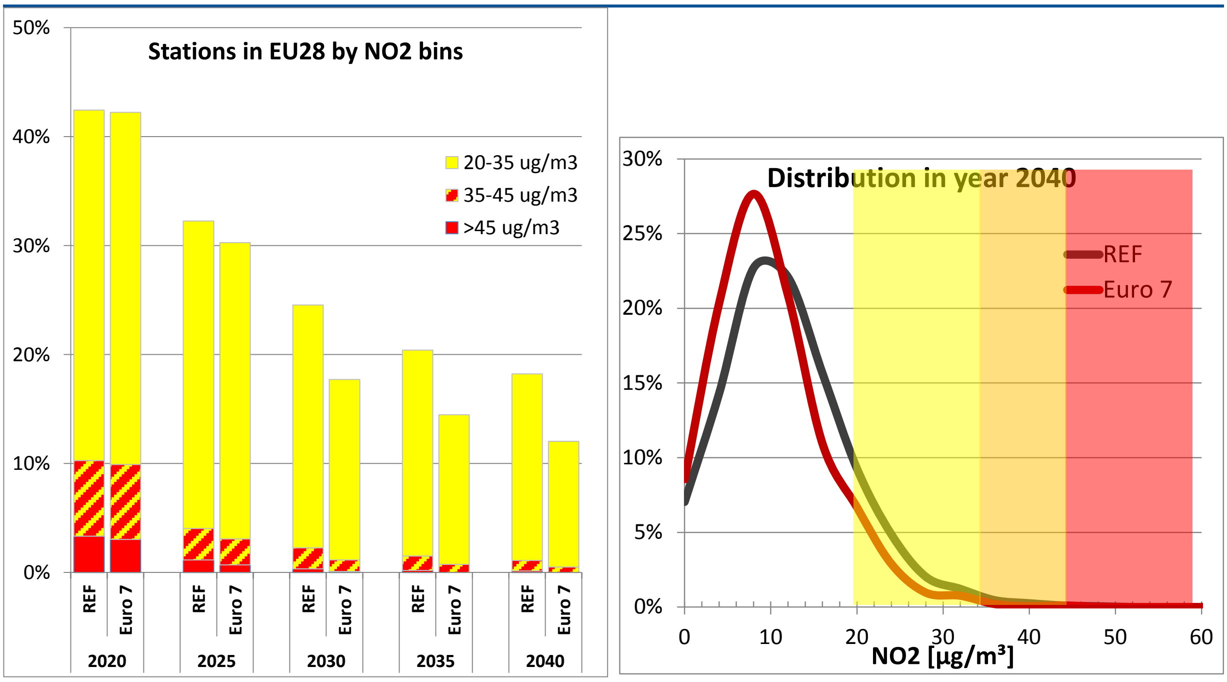

Fig. 10: NO_2 ambient concentrations at European monitoring stations, comparing the Reference scenario with the "Central" Euro 7/VII scenario. Left: Development by bins. Right: Distribution of station values in the year 2040 (other years in the Appendix).

3.4 Emissions and ambient NO_2 concentrations at different Euro 7/VII introduction timing: "Accelerated" and "Later" scenarios

Two other scenarios modulate the timing and uptake rate for a potential new emission control stage. The "Accelerated" scenario assumes an additional phase-out of vehicles older than 10 years in more affluent EU Member States or older than 15 years in less affluent EU Member States respectively; they are replaced with younger (Euro 6/VI) or new (Euro 7/VII) vehicles. The "Later" scenario assumes introduction of the new emission control stage by 2025 for HDDV and 2028 for LDDV, i.e. five years later than in the "Central" scenario. Thus these scenarios differ essentially in the turnover rate of the fleet.

Road vehicles contribute 35% of NO_x emissions from all sectors in the EU28 in the year 2020, declining to 17% until 2040. With a hypothetical Euro 7/VII emission control stage total emissions could be 6% to 9% lower in 2030 and 2040 respectively ("Central" Euro 7/VII scenario). If in addition older vehicles were phased-out (the "Accelerated" scenario) total NO_x emissions could be 15% or 11% lower in 2030 and 2040 respectively (Fig. 11). In the "Later" scenario the reduction on totals is up to 8% in 2040.

Total NO_x emissions from road vehicles as a function of the different uptake speed of Euro 7/VII vehicles are shown in Fig. 11: In the year 2030 the accelerated phase-out of older diesel vehicles results in emissions less than half of the "Central" scenario; this would be one third of NO_x emissions in the Reference scenario without Euro

7/VII vehicles. With older vehicles phased-out, NO_x emissions in 2030 would already almost be at the 2040 level. Vice versa, with "Later" introduction of a potential Euro 7/VII emission control stage NO_x emissions from road vehicles would be in 2030 about the same as in the Reference scenario and about half their value in 2040. While differences between the three Euro 7/VII variants are significant in 2030, they all converge for 2040 with reduction rates of about 90% relative to the 2015 emission level.

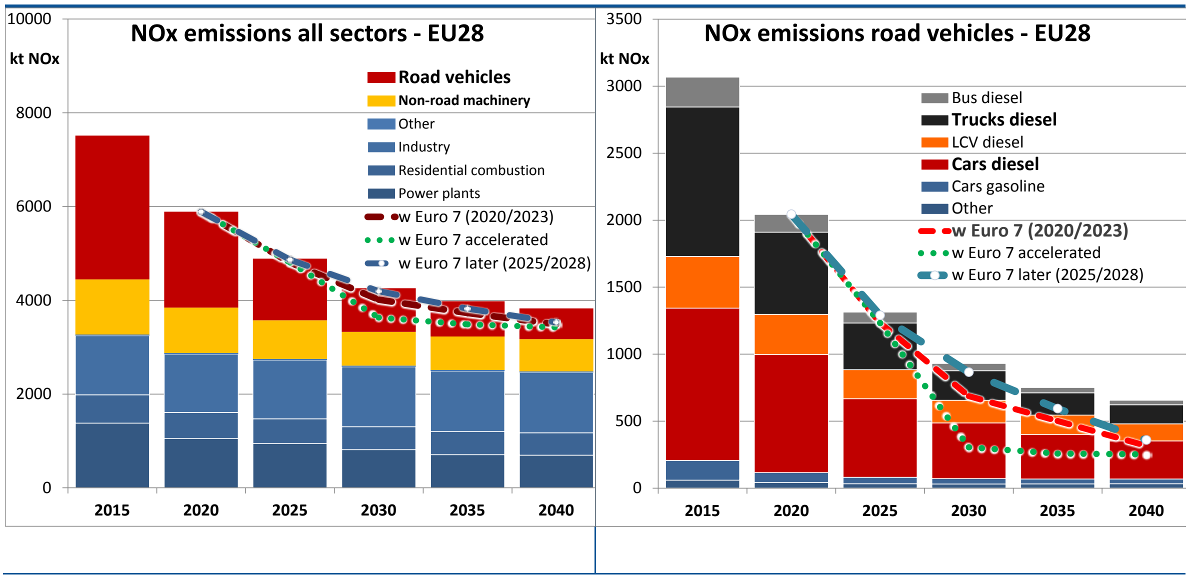

Fig. 11: Development of NO_x emissions from all sectors in EU28 (left) and from road vehicles only (right) according to the Reference scenario (the stacked columns), the "Central" Euro 7/VII scenario and the "Accelerated" and "Later" Euro 7/VII scenarios.

Ambient NO_2 concentrations reflect the development of road vehicles NO_x emissions. Differences between the Euro 7/VII scenarios are insignificant for the year 2040 (Fig. 12): The share of NO_2 concentrations risking exceedance of the ambient air quality limit value is half the value in the Reference scenario in all three Euro 7/VII variants (0.5% compared to 1.1%), and stations in the range of 20 to 35 µg per m^3 could be reduced by one quarter from a share of 22% to 16%.

The difference in NO_2 concentrations is biggest for the year 2030: With phase-out of older vehicles the share of stations above 35 µg per m^3 could be as low as 0.5% (compared to 2.3% in the Reference and 1.1% in the Central scenarios). The share of stations in the range of 20 to 35 µg per m^3 could be halved to 11%. However, NO_2 concentrations might also be close to the Reference scenario with later introduction of Euro 7/VII vehicles. In case of the "Later" introduction, the benefits of an additional emission control stage would only fully be reaped in the year 2040.

NO₂ ambient concentration bins: Reference vs. Euro 7/VII scenarios

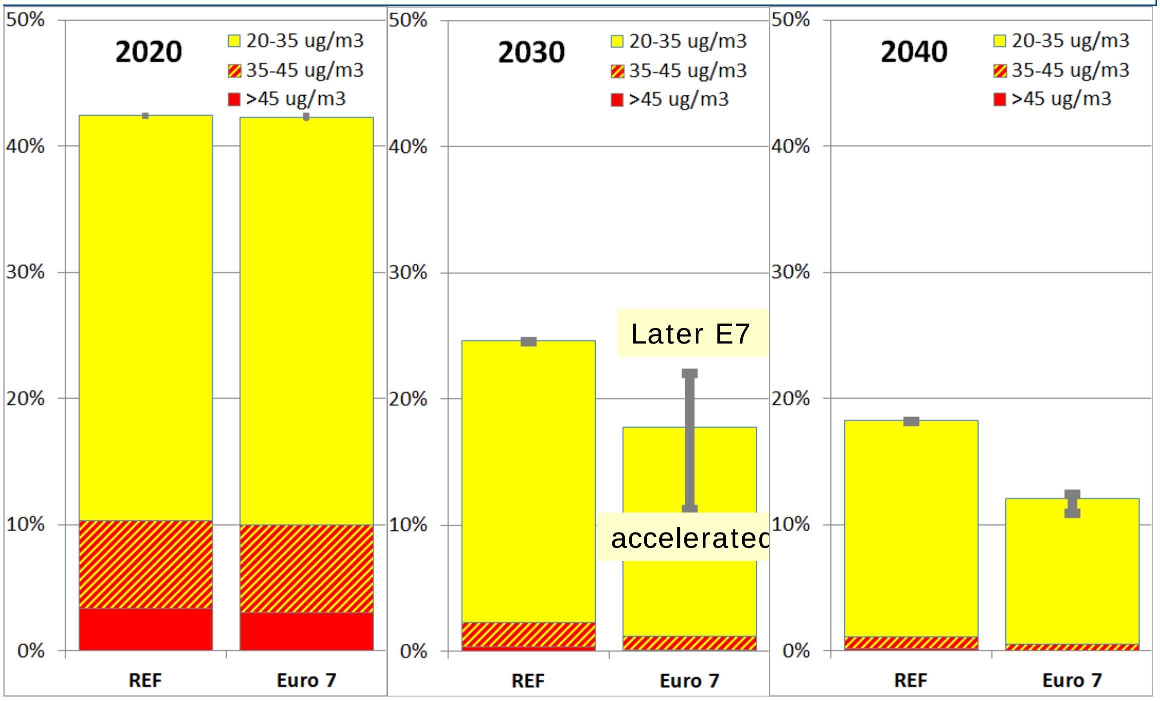

Fig. 12: Comparison of NO_2 ambient concentrations by bin between the Reference scenario and the different variants of the Euro 7/VII scenarios: The "Central" Euro 7/VII scenario is plotted as stacked column, the "Later" and "Accelerated" scenarios are indicated by the range of the error bar.

3.5 Sensitivity: Emissions and ambient NO_2 concentrations in the proposed NEC emissions scenario

The Reference scenario includes all EU-wide legislation adopted until Dec 2013, plus the provisions of the 2nd RDE package. Further emission control policies have been under intensive discussions since the European Commission proposed its new NEC Directive (CEC 2103). Here we compare NO_x emissions and resulting ambient NO_2 concentrations between the two scenarios (Fig. 13). Measures in the NEC proposal would address NO_x emissions only to a smaller extent, and notably concern power plants and industry. Emissions from road transport are the same as vehicle emission control policies are outside the NEC package. Total emissions in the NEC scenario would be 7% lower than in the Reference scenario in EU28 by 2030, if all measures will be implemented as proposed.

Ambient NO_2 concentrations in the proposed NEC scenario are slightly lower than in the Reference scenario, with 1% less stations in the range between 20 and 35 µg per m^3 (21% instead of 22%) and 1.9% stations with higher concentrations (instead of 2.3%). Differences are however insignificant and all messages derived for the Reference scenario without measures from the NEC proposal hold true.

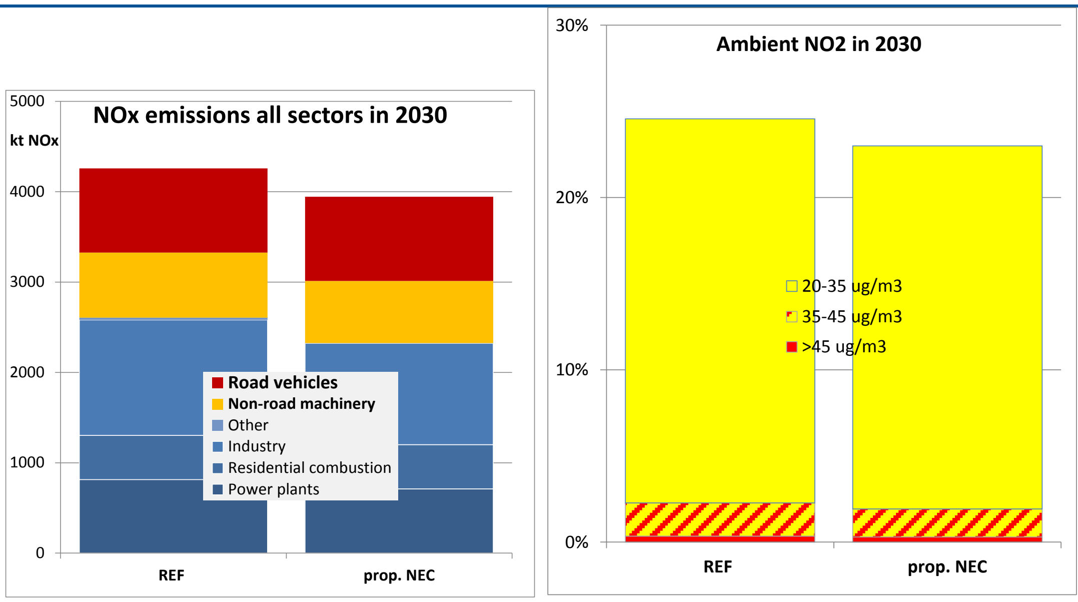

Fig. 13: Comparison of the Reference scenario with the proposed NEC scenario for EU28 in the year 2030.
Left: Total NO_x emissions; right: Resulting ambient NO_2 concentrations.

Thus we can conclude that the Reference scenario taken here is a valid baseline. Future emission controls in other sectors, as to be expected as a consequence from a New Emission Ceilings (NEC) Directive, do not affect the conclusions on the impact of a potential further vehicle emission control stage. In fact, we are conservative in the approach and may (slightly) overestimate the expected NO_2 concentrations.

4 Summary

Ambient NO_2 concentrations will decrease significantly until the year 2030 and beyond if the Euro 6 RDE provisions for diesel cars lead to equally low NO_x emissions in annual average driving and if developments in other sectors are along the lines assumed in the current legislation scenario. The air quality limit value of 40 µg NO_2 per m^3 on annual average may be exceeded by only 2% of the stations analysed in 2030 and only 1% in the year 2040. By far the majority of stations can be expected to have no more than 30 µg NO_2 per m^3 on annual average.

The number of stations risking exceedance of the air quality limit value could cut by half from 2030 onwards if an additional vehicle emission control stage would soon be introduced, with on-road NO_x emissions of about one third of the (prospective) Euro 6d/VI RDE values for light and heavy duty diesel vehicles. Their effect could be accelerated if vehicles certified to Euro 5/V or older would be phased out. An introduction later than 2025/2028 would delay benefits to the year 2040.

Additional NO_x emission control measures could reduce the ambient NO_2 concentrations e.g. in the range of 20 to 30 µg per m^3 by about 25%. There are indications that NO_2 concentrations at this level are health relevant – but this is subject to intense discussion within the WHO community.

Whether air quality problems in a limited number of places justify Europe-wide action like a general emission control stage appears questionable from a cost-effectiveness criterion. If needed, potential measures should be compared across sectors to find the most suitable and cost-effective set.

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6 Appendix

6.1 Disaggregation of non-road mobile machines

Several machine categories are summarized (in GAINS) under the heading of "non-road mobile machines". The following tables (Tab. 4 and Tab. 5) provide fuel consumption and NO_x emissions by subcategory. The biggest sector are ships (excluding international marine shipping), following by agricultural machines and construction machinery.

PJ fuel consumed per year	***2005***	***2010***	***2015***	***2020***	***2025***	***2030***	***2035***	***2040***
Construction & industry	389	327	304	296	288	310	266	264
Agriculture & forestry machines	577	497	476	460	457	483	415	402
Rail	129	118	114	109	100	95	74	56
Coastal & inland ships, fishing	539	539	574	624	637	582	659	662
Handheld & other engines	25	18	15	15	15	16	17	17
Sum	1660	1499	1483	1504	1498	1486	1432	1401

Tab. 4: Fuel consumption in the EU28 in the GAINS sector "non-road mobile machines" by subcategories.

kt NO_x per year	***2005***	***2010***	***2015***	***2020***	***2025***	***2030***	***2035***	***2040***
Construction & industry	347	265	171	123	96	99	72	68
Agriculture & forestry machines	569	436	333	208	130	107	71	53
Rail	137	121	109	89	69	52	29	21
Coastal & inland ships, fishing	372	364	365	378	367	317	339	339
Handheld & other engines	99	85	83	82	80	72	78	80
Sum	1524	1271	1060	880	742	647	590	561

Tab. 5: NO_x emissions in the EU28 in the GAINS sector "non-road mobile machines" by subcategories in the Reference Scenario.

6.2 Distribution of ambient NO_2 over stations in Europe

Stations with ambient concentrations >30 µg per m^3 will continuously become less while stations cluster at about 11 µg per m^3 in the Reference scenario (Fig. 14). This can be accelerated with an additional Euro 7/VII vehicle emission control stage.

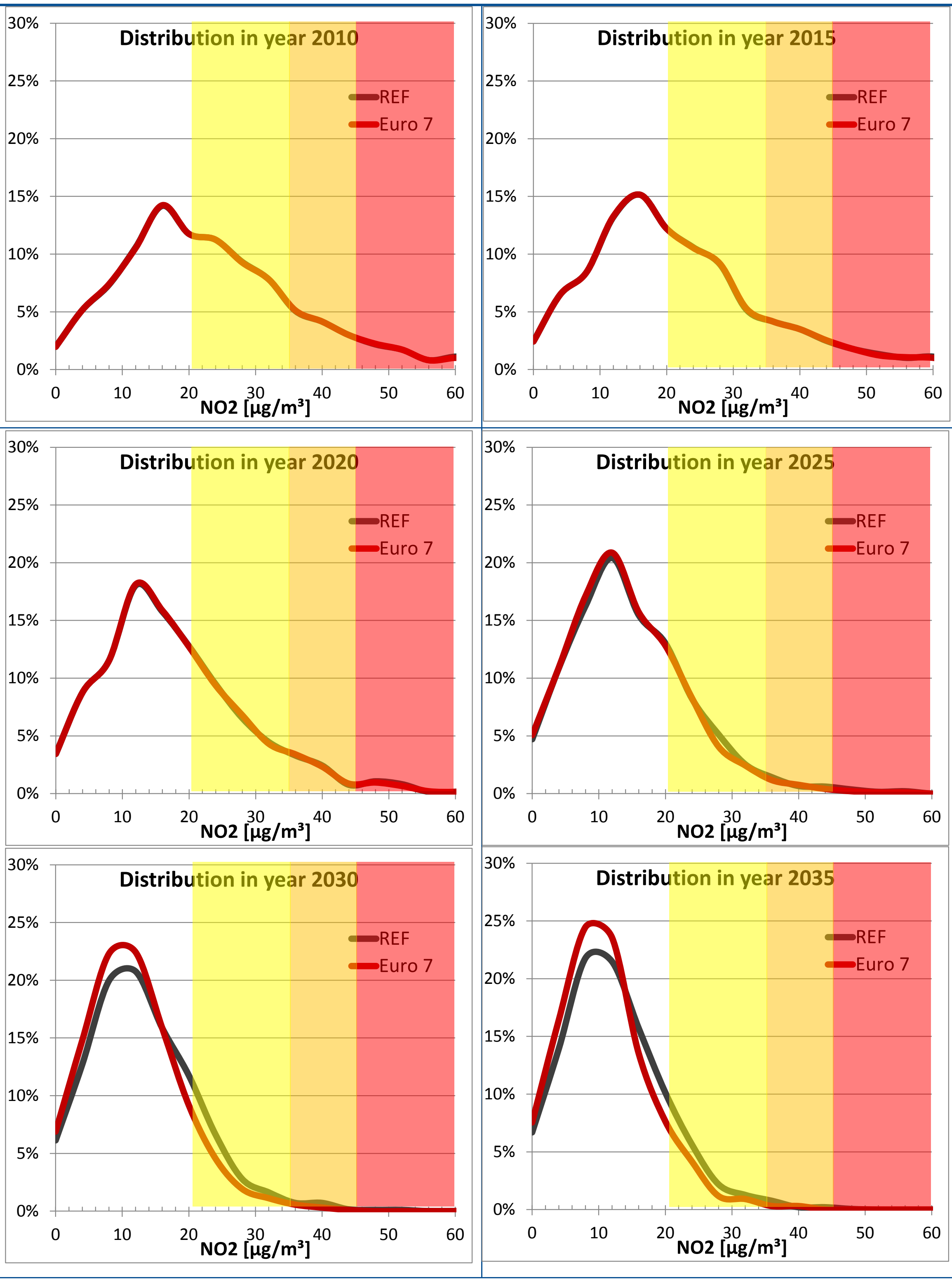

Fig. 14: Distribution of the NO_2 ambient concentrations at European monitoring stations, comparing the Reference scenario with the "Central" Euro 7/VII scenario.