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Factors determining **recent** changes of emissions **of air pollutants in Europe**

TSAP Report #2

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Executive Summary

To support the European Commission in the review of the 2005 Thematic Strategy on Air Pollution, this report revisits the baseline scenario that was presented in 2005 in view of today's knowledge, in particular taking into account the impacts of the economic crisis on economic and energy development, and real-life experience with newly implemented emission regulations.

It compares the final baseline emission projection developed in 2005 within the Clean Air For Europe (CAFE) programme for the Thematic Strategy on Air Pollution against the recent baseline projection prepared for the revision of the Thematic Strategy in 2012 (the TSAP-2012 baseline).

The report reviews the assumptions on main drivers of emission changes, i.e., demographic trends, economic growth, changes in the energy intensity of GDP, switches to other fuels, and application of dedicated emission control measures. For most of these drivers, reality has developed rather different compared to what has been assumed in 2005.

In reality, SO₂ emissions in the old Member States in 2010 were 5% lower than what was projected by CAFE. NH₃ was 10% and VOC 3% lower. NO_x exceeded the CAFE projection by 7%, and PM_{2.5} by 10%. Larger differences occurred for the new Member States, where SO₂ was 30% and NH₃ 16% below the levels suggest by CAFE. NO_x was 11% higher, and PM_{2.5} and VOC 21% higher than estimated earlier.

For 2020, the TSAP-2012 baseline projection expects for the EU-27 about 20% less SO₂ emissions than the earlier CAFE baseline, with application of dedicated emission controls as the dominating factor for lower emissions. NO_x would be 5-7% lower, depending on the assumptions on the effectiveness of the new vehicle emission standards. The PM projection is about 10% higher, while smaller differences emerge for VOC and NH₃.

Many of these changes are smaller than differences in the actual drivers. In many cases, higher effectiveness of dedicated emission controls compensated the lower than expected decline in total energy consumption as well as the delay in the phase-out of coal.

A re-analysis of air pollution control costs based on the actual statistics suggests for 2010 6% higher costs earlier estimated, mainly due to higher consumption of coal that required more emission control efforts.

For 2020, emissions of the new TSAP-2012 baseline (without additional measures) are substantially higher than the indicative targets for emission reductions established by the Thematic Strategy in 2005. As a consequence, the environmental targets established by the TSAP for the protection of human health, eutrophication and forest acidification would not be met by the TSAP-2012 baseline without additional measures.

More information on the Internet

More information about the GAINS methodology and interactive access to input data and results is available at the Internet at <http://gains.iiasa.ac.at>.

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List of acronyms

boe	Barrel of oil equivalent
CAFE	The 'Clean Air for Europe' programme of the European Commission
CAPRI	Common Agricultural Policy Regionalised Impact Model
EC	European Commission
EU-15	The 15 Member States of European Union before 2004
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies Model
GDP	Gross domestic product
IIASA	International Institute for Applied Systems Analysis
kt	kilotons
NEC	National Emission Ceilings
NH ₃	Ammonia
NMS-12	New Member States of European Union that joined after 2004
NO _x	Nitrogen oxides
PM2.5	Fine particulate matter
RAINS	Regional Acidification Information and Simulation Model
SO ₂	Sulphur dioxide
TSAP	Thematic Strategy on Air Pollution
US-\$	United States dollar
VOC	Volatile organic compounds
yr	Year

1 Introduction

In its 2005 Thematic Strategy on Air Pollution (TSAP), the European Commission outlined a road map to attain 'levels of air quality that do not give rise to significant negative impacts on, and risks to human health and environment' (CEC, 2005a). It established health and environmental objectives and outlined emission reduction pathways that would achieve these targets in a cost-effective way. These scenarios employed the best estimates of future economic development at that time, based on prevailing expectations on the implementation rates and effectiveness of existing and new policies (CEC, 2005b).

In 2011, the European Commission has launched a comprehensive review and revision of its air policy, in particular of the 2005 Thematic Strategy on Air Pollution and its related legal instruments.

To support the European Commission in the review, this report presents a re-analysis of the scenarios that were presented in 2005 in view of today's knowledge, in particular taking into account the impacts of the economic crisis on economic and energy development, and real-life experience with newly implemented emission regulations.

This report compares the final baseline emission projection developed in 2005 within the Clean Air For Europe (CAFE) programme for the Thematic Strategy on Air Pollution (Amann et al., 2005a) against the recent baseline projection prepared for the revision of the Thematic Strategy in 2012 (the TSAP-2012 baseline), which is presented in TSAP Report #1 (Amann et al., 2012). It addresses five air pollutants, i.e., SO₂, NO_x, PM2.5, NH₃ and VOC. The comparison includes the year 2010, for which actual statistical information is now available. Thereby, the report illustrates how over the last 10 years the European Union (EU) has moved along the foreseen trajectory towards achievement of the interim targets defined in the National Emission Ceilings (NEC) directive (CEC, 2001).

The report also addresses projections up to 2020, for which expectations have changed since 2005. The analysis examines assumptions taken in 2005 against the most recent developments and assumptions incorporated in the TSAP-2012 baseline.

This report presents a quantitative decomposition of the major factors that determine the development of air pollutant emissions. By comparing the actual trends and recent projections of the driving factors against the evolution that has been anticipated in 2005, the analysis reveals the degree to which the development materialized as foreseen, and quantifies the implications of the various factors that evolved in unexpected directions.

The analysis is carried out for each EU Member State; however, results are reported for groups of countries, i.e., the old Member States (EU-15) and the new Member States (NMS-12) that joined the EU after 2004.

Finally, the analysis compares costs for emission controls as estimated in 2005 by the Thematic Strategy with the recent estimates of the baseline projection for the 2012 revision of the Thematic Strategy.

This report is organized as follows. The following section provides a brief overview of the methods and data used for the study to lay the foundations for the subsequent quantitative analyses. Section 3 compares the actual development of emissions between 2000 and 2010 as well as the recent baseline projection up to 2020 against the earlier expectations. It highlights the most important factors that led to different development. The final section presents conclusions and discusses policy implications of the main findings.

This report presents draft findings from the first phase of the Service contract. It should provide a basis for consultations with experts from different stakeholders, whose feedbacks will be incorporated into the final version of the report to be presented by the end of 2012.

2 Methodology and data sources

The development of emission over time is influenced by a variety of factors. First, emissions are directly related to the level of emission generating activities (e.g., energy consumption or transport volumes), which in itself is influenced by the development in different sectors the economy, and the energy intensity of economic activities. Furthermore, the composition of fuel consumption has significant impacts on emissions, as different fuels emit different quantities of air pollutants. In addition, dedicated measures to control the release of emissions (e.g., through end-of-pipe emission control technologies) is a critical determinant of the final emission level (Rafaj et al., 2010). Some of these factors are subject to dedicated environmental policies (e.g., the application of end-of-pipe emission control measures), while others are usually not directly influenced by environmental policies (e.g., economic growth).

To quantify the importance of targeted abatement measures and autonomous developments such as changes in the energy structure, overall economic growth and technological advances, a decomposition analysis is performed. In a first step, the relationships between these factors are clarified. These equations are then applied to data for all Member States to quantify the importance of the different factors in different regions.

2.1 Determinants of emission changes

In a general form, total emissions in a region (*EMIS*) can be described as a product of three factors, i.e., population, per-capita income, and emissions per unit of GDP:

$$EMIS = POP * \left(\frac{GDP}{POP}\right) * \left(\frac{EMIS}{GDP}\right)$$

All these factors evolve over time, and influence the development of total emissions. The first two terms are usually beyond the direct impact of environmental policies, which affect mainly the third term (i.e., *EMIS/GDP*). This term includes autonomous technological progress, structural changes in the national economies, behavioural changes and dedicated environmental policies. To reveal the importance of these individual components that can lead to changes in the emission density of GDP, this identity is extended. We decompose it into three factors that relate to (i) changes in energy use per GDP, (ii) the share of different fuel types in total energy use, and (iii) emission rates of per unit of fuel type. Thereby, , emission changes relative to a selected base year can be described as:

$$\Delta EMIS = GDP * \Delta \left(\frac{ENE}{GDP}\right) * \Delta \eta * \Delta \left(\frac{EMIS}{ENE}\right) * (1 - eff) * \Delta X$$

where the following factors are distinguished:

Energy intensity (*ENE/GDP*), i.e., the energy requirement (*ENE*) for a unit of gross domestic product (*GDP*). Changes in energy intensities determine overall energy

consumption, and influence the resulting emission levels (*EMIS*). The time evolution of the differences in energy intensities across countries reflects variations in socio-economic structures as well as in behavioural patterns.

The **efficiency** of the energy system ($\Delta\eta$), i.e., the efficiency by which primary energy (e.g., coal, crude oil) is converted into different forms of final energy (e.g., electricity). Changes over time occur from improved efficiencies of converting primary fuels into electricity, of the combustion of final energy carriers in the industry, transport or household sectors, and finally from efficiency improvements of end-use devices such as vehicles or light bulbs. Efficiency improvements are either mandated by regulations or emerge in response to fuel availability and price signals.

The **fuel mix** of different energy forms affects emission intensities. Changes over time due occur from inter-fossil fuel switching and changes in the fraction of non-fossil fuels in the energy supply. Substitution of traditional fuels with electricity and heat belongs to this mitigation component too. Fuel switches can be triggered by environmental regulations, but more importantly by cost considerations and convenience.

Emission control measures reduce the amount of pollutants emitted per unit of energy through end-of-pipe measures, as well as through improved fuel quality due to, for example, lower sulphur contents of coal or heating oil. Changes in emission factors over time can also be influenced by modified import patterns and by exploration of resources with different characteristics. The resulting emission coefficient depends on the removal efficiency (*eff*) of an abatement measure adopted at a specific application rate (*X*).

With these factors, we capture the key reasons that can lead to different emissions, i.e., overall economic changes, changes in the energy structure, and dedicated application of emission control measures.

2.2 Factors that led to emission changes in the past

Our formulation is useful to isolate the impacts of dedicated environmental policy interventions from other driving forces. For this purpose, we compute four hypothetical emission scenarios in which we keep one or several of these factors at the level that has been observed for a selected base year:

1. First, a hypothetical upper limit for emissions is calculated assuming absence of any factors that change the emission intensities of GDP. Such an emission path would result from the growth in GDP with constant energy intensity of GDP, unchanged fuel mix, and no further emission control measures beyond what was implemented in the base year. This trajectory reflects only changes in GDP, and will be used as a reference against which the impacts of the other factors can be quantified.
2. In the following step, an emission trajectory is calculated for the actual development of total primary energy use, but keeping fuel mix and emission

factors for each fuel type constant at the base year level. By comparing to the first (GDP) trajectory, this path reveals the impacts of a decoupling between GDP growth and energy consumption on emissions. These changes in the energy intensities of GDP result from shifts in the sectorial composition of GDP as well as from efficiency improvements in the energy systems.

3. Third, a trajectory is calculated that accounts for the changes in fuel mix, while keeping emission factors for each fuel type unchanged compared to the base year value. Comparison to the second trajectory quantifies the impacts of fuel substitution (e.g., the replacement of coal by natural gas) on emissions. Fuel substitution occurred in some cases in response to environmental legislation, but most likely in many cases due to other factors.
4. Finally, the contribution of dedicated emission control measures to total emission changes is derived from a fourth trajectory, which calculates actual emissions by applying observed and projected trends to all factors, including the changes in emission factors for each fuel type.

A comparison of the differences between these trajectories, the impact of the following four drivers on emission can be quantified:

- Overall economic growth
- The decoupling between GDP and energy use
- Changes in the fuel mix of total energy composition
- Application of dedicated emission control measures.

2.3 Data sources

To calculate emissions from 2000 to 2020 in five-year intervals, this analysis employs information from different statistics, databases and models. While the assessment is conducted for all Member States individually, results are presented for two aggregated regions, i.e., the old Member States (EU-15), and the 12 new Member States that joined the EU after 2004.

As a basis, the analysis uses the final 2005 baseline scenario for the CAFE programme documented in the CAFE Report #6 (Amann et al. 2005a). This scenario incorporated the 'With climate measures' energy projection developed with the PRIMES energy model (Mantzou and Zeka-Paschou, 2004). Implemented in the GAINS/RAINS model (Amann et al., 2011), these detailed energy balances, macroeconomic projections, transport and industrial activities up to 2020 have been complemented with the GAINS emission factors for the decomposition analysis. Emission factors for the base year 2000 and consecutive years have been extracted from databases of RAINS and GAINS models that have been used for the original CAFE analyses (<http://www.iiasa.ac.at/web-apps/tap/RainsWeb/>).

The available data do not provide sufficient detail that would allow a full quantification of the role of efficiency improvements. While data on changes in conversion efficiencies are available for the power sector, they are lacking for end-use devices and appliances. Therefore, energy intensity and efficiency improvements had to be treated together in this analysis.

This CAFE projection is then compared against the recent baseline scenario for the 2012 revision of the Thematic Strategy on Air Pollution, that is presented in TSAP report #1 (Amann et al., 2012). Energy balances and macro-economic data such as GDP, energy intensity and population growth are harmonized with EUROSTAT statistics until the year 2010. Emissions for the period 2000-2005 match the official national estimates reported to European Monitoring and Evaluation Programme (EMEP) under CLRTAP (<http://www.ceip.at/webdab-emission-database/officially-reported-emission-data>). As official inventory data for 2010 are not yet available at the time of preparing this report, most recent GAINS estimates are used.

The analysis also includes changes in industrial process emissions based on PRIMES data on the relevant industrial activities. Statistics and projections of agricultural activities are derived from the most recent estimates of the CAPRI model (Witzke et al., 2009). Finally, it is noted that the decomposition analysis of energy-related emissions does not include fuel combustion of international marine bunkers.

3 Results

Anthropogenic emissions are determined by numerous factors, such as demographic changes, economic development, fuel prices, energy, transport, climate and agricultural policies, and by the application of dedicated emission control measures. A wide range of autonomous or intentional drivers influences these factors, and future projections of these drivers are loaded with uncertainties.

3.1 Comparison of assumptions on key drivers

This section compares the trends in the main driving forces that have been assumed in the final CAFE baseline scenario (with climate measures and current legislation, as of June 2005; Amann et al., 2005a) against the actual development to 2010 (derived from statistics) and the projections to 2020 of the recent TSAP-2012 baseline.

3.1.1 GDP and population

Because of the recent economic and financial crisis, economic growth in Europe was significantly slower than the expectations in 2005. The CAFE baseline assumed up to 2010 an annual growth rate of GDP of 1.9% for the EU-15 and of 3.7% for the new Member States. In reality, GDP in real terms increased by 1.0% and 3.4%, respectively.

For the period after 2010, the CAFE baseline assumed for the EU-15 an annual growth of 2.5% per year; the TSAP-2012 baseline reduces expectations to 2.1%, and the recent projection of DG-ECFIN to 1.4%. Expectations for the new Member States are in the TSAP baseline 3.2%/year instead of 3.9%, and 2.4% in the 2012 DG-ECFIN forecast (Figure 3.1).

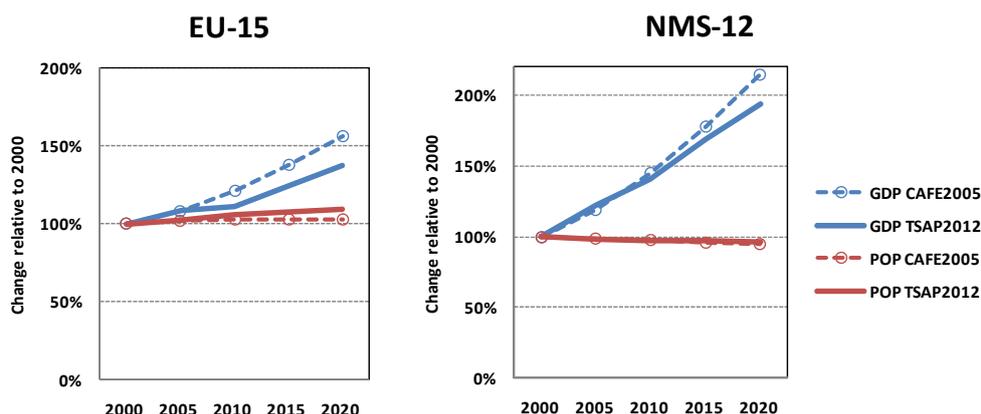


Figure 3.1: Evolution of GDP and population (POP) in the EU-15 and NMS-12. Assumptions for CAFE2005 and TSAP2012; for TSAP until 2010 current statistics are used. (Index: 2000 = 100%)

In contrast, European population grew faster than anticipated in 2005. In 2010, total population is 3% higher than assumed (mainly in the old Member States), while the new projection for 2020 exceeds the old estimate by 6%.

3.1.2 Fuel prices

Fossil fuel prices developed rather different compared to what has been assumed for the 2005 CAFE baseline. In 2010, international fuel prices for oil, gas and coal exceeded the CAFE-assumptions by a factor of three (Figure 3.2). The recent assumptions for oil and gas prices up to 2020 envisage similar relative growth rates as the 2005 CAFE baseline, however starting from substantially higher levels.

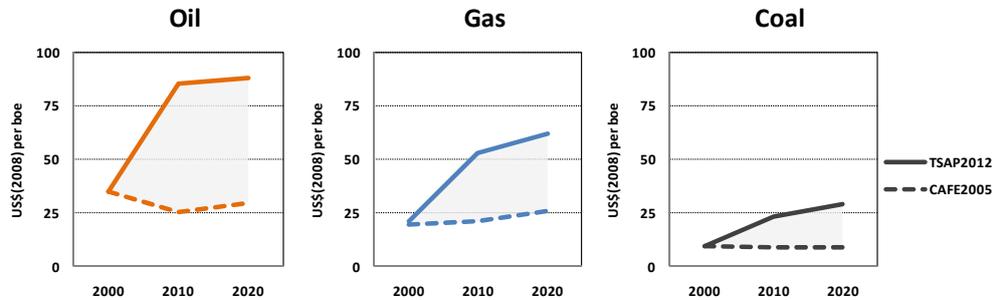


Figure 3.2: Evolution of international fossil fuel prices projected under CAFE2005; for TSAP until 2010 recent statistics are used (constant US-\$ of 2008 per boe).

3.1.3 Energy intensities

Change in energy intensities are influenced by many factors, such as progress in adoption of energy saving measures, structural changes in national economies, behavioural changes, etc. The resulting trajectory emerges from an interplay of all these determinants.

Energy intensity of GDP has declined relative to the year 2000 in the old and new Member States. By 2010, however, improvements have been by 10% less than what has been assumed in the CAFE baseline scenario. The recent TSAP-2012 projections are also less optimistic about future improvements in energy intensities, particularly for the new Member States, where the new assumptions are 20% lower than before (Figure 3.3).

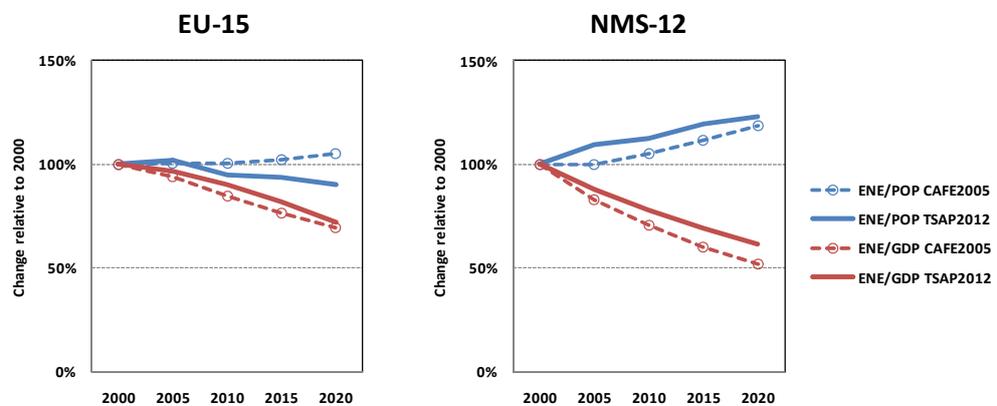


Figure 3.3: Evolution of energy consumption per capita (ENE/POP) and energy intensity (ENE/GDP) in EU-15 and NMS1-2 regions under CAFE and TSAP scenarios; for TSAP until 2010 current statistics are used. (Index: 2000 = 100%)

On a per-capita basis, energy intensity trends differ between the old and the new Member States, due to the sustained rapid increase in energy use for transport and household appliances in the new Member States.

3.1.4 Fuel mix

Among of the most important factors for changes in emissions are shifts in the composition of the fuel mix. In reality, substitution of coal by natural gas occurred at a significantly lower rate than assumed in the CAFE projections for 2010 (Figure 3.4). In contrast, the move from gasoline to diesel was significantly larger than anticipated.

For 2020, the TSAP-2012 baseline assumes higher shares of coal and lower shares of natural gas compared to the 2005 CAFE assumptions. For non-fossil fuels, including biomass, hydropower and other renewables, the new scenario assumes more rapid growth than the CAFE scenario in 2005.

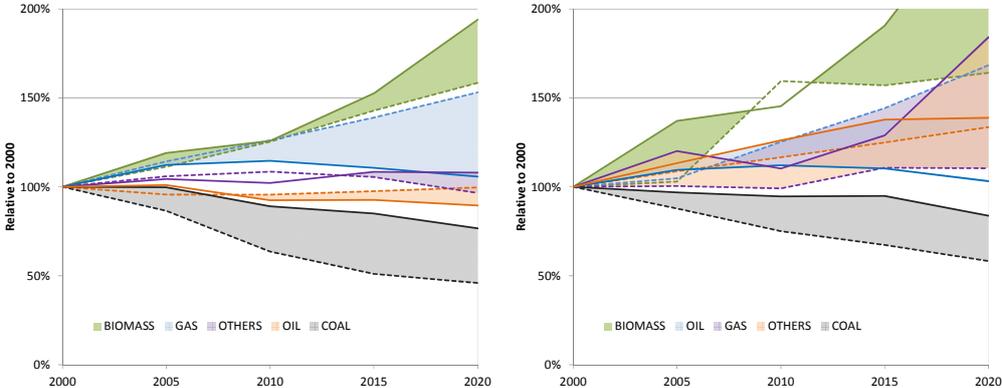


Figure 3.4: Differences between the fuel consumption of the CAFE-2005 projection (dashed lines), actual development up to 2010 (solid lines) and the TSAP-2012 baseline up t 2020 (solid line). Left panel: old Member States, right panel: new Member States

3.1.5 Changes in air quality legislation

Since the completion of the CAFE scenarios, new regulations and policy instruments for the control of air pollutant emissions have been introduced in the European Union. Table 3.1 summarises the recently introduced measures that were not included in the CAFE 2005 baseline, but are now part of the TSAP-2012 baseline.

Table 3.1: New emission control legislation and their impacts on emissions

Sector	CAFE2005	Change->	TSAP2012
Energy and Industry	<i>Large combustion plant directive</i>	<i>replaced with more stringent</i>	<i>Directive on Industrial Emissions for large combustion plants</i>
	<i>IPPC legislation on process sources</i>	<i>replaced with more stringent</i>	<i>BAT requirements for industrial processes according to the provisions of the Industrial Emissions directive</i>
	<i>Directive on the sulphur content in liquid fuels</i>	<i>replaced with more stringent</i>	<i>Directive on the sulphur content in liquid fuels</i>
Transport	<i>Directives on quality of petrol and diesel fuels</i>	<i>replaced with more stringent</i>	<i>Fuel Quality directive 2009/30/EC regarding quality Directives on quality of petrol and diesel fuels</i>
	<i>For light duty vehicles: All EURO-standards up to EURO-4</i>	<i>replaced with more stringent</i>	<i>All EURO-standards, including adopted EURO-5 and EURO-6</i>
	<i>For heavy duty vehicles: All EURO-standards up to EURO V</i>	<i>replaced with more stringent</i>	<i>All EURO-standards, including adopted EURO V and EURO VI</i>
	<i>For motorcycles and mopeds: All EURO-standards for motorcycles and mopeds up to Euro 3</i>	<i>Earlier adoption</i>	<i>All EURO- standards for motorcycles and mopeds up to Euro 3</i>
	<i>For non-road mobile machinery: All EU emission controls up to Stage IIIB</i>	<i>Earlier adoption and more stringent</i>	<i>All EU emission controls up to Stage IV</i>
Agriculture	<i>IPPC Directive for pigs and poultry production as interpreted in national legislation</i>		<i>The same control measures as in CAFE with:</i> <ul style="list-style-type: none"> <i>updates in national legislation</i>
	<i>National legislation including elements of EU law, i.e., Nitrates and Water Framework Directives</i>		<i>harmonisation of national legislation with EU-standards in the new Member States</i>
	<i>Current practice including the Code of Good Agricultural Practice</i>		
VOC	<i>Stage I directive (liquid fuel storage and distribution)</i>		<i>The same control measures as in CAFE with:</i> <ul style="list-style-type: none"> <i>updates in national legislation</i>
	<i>Directive 96/69/EC (carbon canisters)</i>		
	<i>Fuels directive (RVP of fuels) (EN 228 and EN 590)</i>		<i>harmonisation of national legislation with EU-standards in the new Member States</i>
	<i>Solvents directive</i>		
	<i>Products directive (paints)</i>		

3.2 Impacts on emissions

3.2.1 SO₂ emissions

Old Member States

By 2010, SO₂ emissions of the EU-27 were slightly lower (-5%) than suggested in the CAFE baseline projection (Figure 3.5, red lines). However, it is important to note that the additional policy measures listed in Table 3.1 were not considered the CAFE baseline. The lower emission projection of the recent TSAP baseline prevails for the coming decade, so that by 2020 the new TSAP-2012 baseline suggests 20% lower emissions than the CAFE baseline.

A number of factors explain these differences. First, GDP developed less favourable than foreseen in CAFE. By 2010, the increase in GDP was only 11% relative to 2000, instead of 21% assumed in CAFE. For 2020, the new projections of GDP-growth are 12% lower than before (black lines in Figure 3.5)

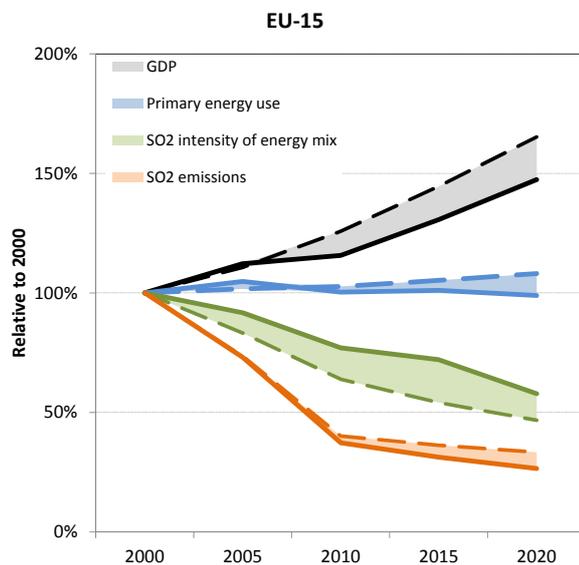


Figure 3.5: Old Member States: GDP, total energy consumption, SO₂ intensity of the fuel mix, and SO₂ emissions. Differences between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

Energy intensity of GDP declined less than assumed, so that in 2010 total energy consumption was close to the anticipated value (blue lines in Figure 3.5). For 2020, the TSAP-2012 scenario suggests now 8% lower energy consumption than the CAFE baseline. The largest impact on SO₂ emissions emerges from different developments in the fuel mix. The CAFE baseline projected a sharp decline in coal consumption, which did not yet materialize in practice. Beyond 2010, the TSAP-2012 baseline maintains the trend assumed for CAFE, although from a different starting point in 2010 (green lines in Figure 3.5). Although GDP, energy intensities and fuel mix developed rather differently, actual SO₂ emissions match rather well the anticipated trend as technical emission controls compensated the other factors. In particular,

higher coal use in 2010 was compensated by higher emission removals through end-of-pipe measures (red lines in Figure 3.5).

In summary, for 2010 the decline in SO₂ emissions anticipated by CAFE was slightly less optimistic than the actual development, mainly because the baseline did not consider the recently emission control legislation. For 2020, the TSAP-2012 baseline suggests 20% less SO₂ emissions than the earlier CAFE projection. There are, however, important differences in the factors that lead to relatively similar emission projections. First, CAFE was much more optimistic about the economic development, and assumed slightly faster penetration of energy efficiency measures. Most importantly, CAFE was quite optimistic about the phase-out of coal, which occurred at a much slower pace, although the current TSAP-2012 projections maintain the optimism for the coming decade. While with the emission factors of 2000 the higher coal use would have led to substantially higher SO₂ emissions, more stringent emission control legislation introduced after 2000 compensates much of this effect (Figure 3.6).

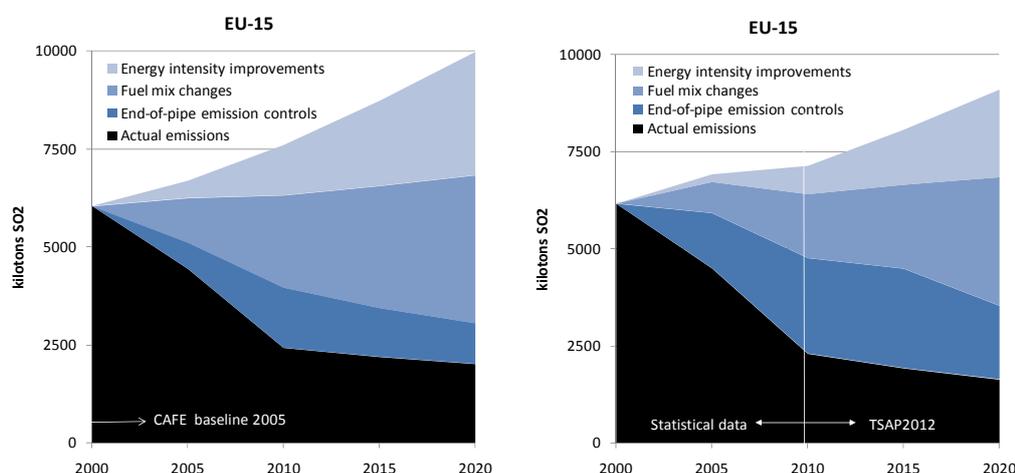


Figure 3.6: Impacts of the driving forces (GDP, energy use, fuel mix and end-of-pipe controls) on total SO₂ emission in the old Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

New Member States

A similar picture emerges for SO₂ emissions in the new Member States, and the recent perspective yields significantly lower total SO₂ emissions than before (Figure 3.6).

GDP developed less favourable than foreseen in CAFE, although the discrepancy is smaller than for the old Member States. CAFE was somehow too optimistic in the assumptions on the decline in energy intensities. Most critical is the underestimated persistence in coal use, which was, however, compensated by larger removal of emissions through end-of-pipe measures. Obviously, by 2010 the implementation of EU legislation in the new Member States was more effective than foreseen earlier, and for 2020 the new perspective suggests total SO₂ in these countries to be 54% lower than in the CAFE projection.

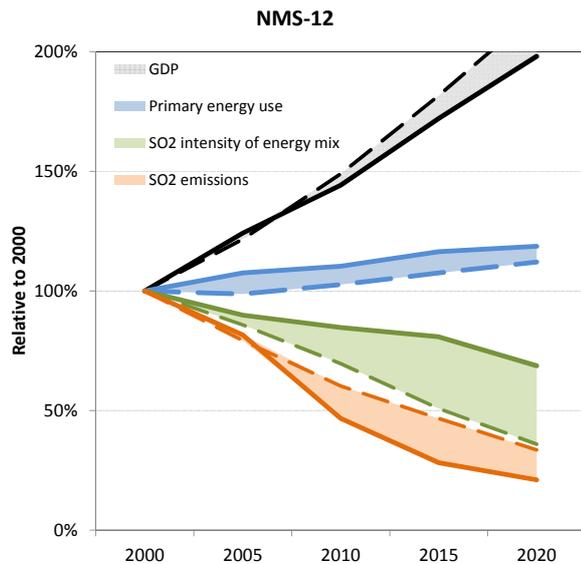


Figure 3.7: New Member States: Differences in the projections of GDP, total energy consumption, the SO₂ intensity of the fuel mix, and resulting SO₂ emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

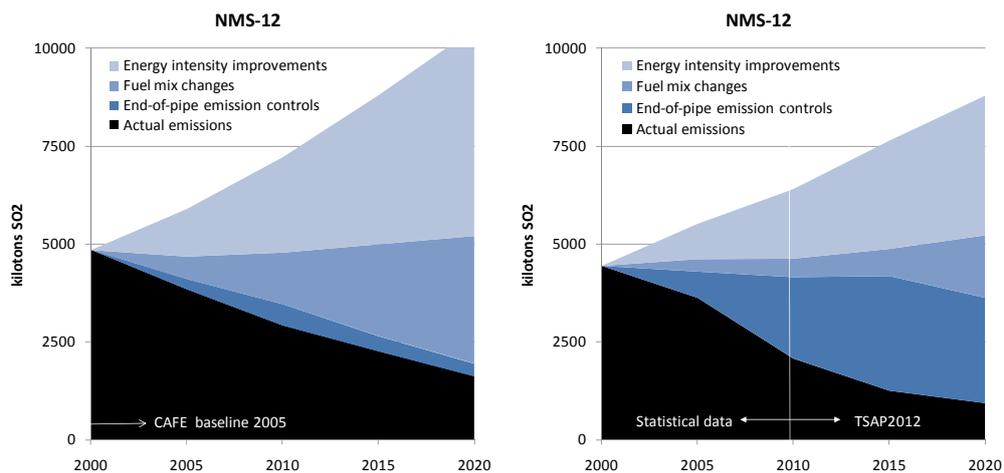


Figure 3.8: Impacts of the driving forces (GDP, energy use, fuel mix and end-of-pipe controls) on total SO₂ emission in the new Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

Comparison to international commitments for sulphur emissions

The aggregated 2010 emissions caps of the NEC directive (NEC 2010) for SO₂ are achieved by both country groups in both scenarios (Figure 3.9). For 2020, ceilings of the revised Gothenburg protocol (GOTH REV 2020 in the figures below) would be collectively achieved in the old Member States by the CAFE baseline scenario with the legislation of 2005. The Gothenburg ceilings, however, are substantially higher than the indicative targets for SO₂ emissions of the 2005 Thematic Strategy on Air Pollution. They are also above the recent TSAP-2012 baseline case, which assumes full implementation of current legislation.

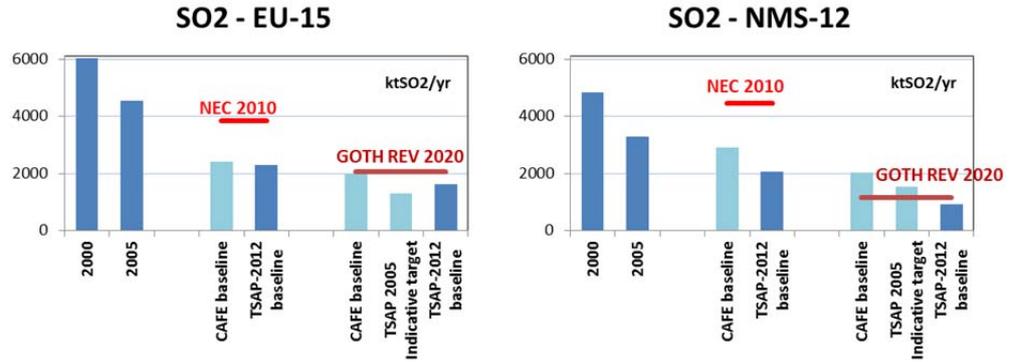


Figure 3.9: SO₂ emissions in the EU-15 and NMS-12, compared to the international commitments for 2010 and 2020.

Aggregated SO₂ emissions of the new Member States (NMS-12) were significantly below the NEC directive ceilings in 2010. The Gothenburg ceilings for 2020, however, are 43% lower than the CAFE baseline projection, and 25% lower than the indicative targets stated in the 2005 Thematic Strategy. For the TSAP-2012 baseline scenario, these ceilings would be safely met without further measures.

3.2.2 NO_x emissions

In the old Member States, total NO_x emissions developed up to 2010 closely to the trend of the CAFE baseline, and the TAP-2012 projection to 2020 follows the earlier scenario (Figure 3.10, left panel, red lines). Also earlier assumptions on primary energy use agree rather well with statistics and further trends (blue lines), as well as the expectations on the NO_x intensities of the energy mix (green lines). GDP projections were too high, as discussed above. For the new Member States, the CAFE assumptions on these drivers turned out as too optimistic, both for energy use, NO_x intensities and total NO_x emissions (Figure 3.10, right panel).

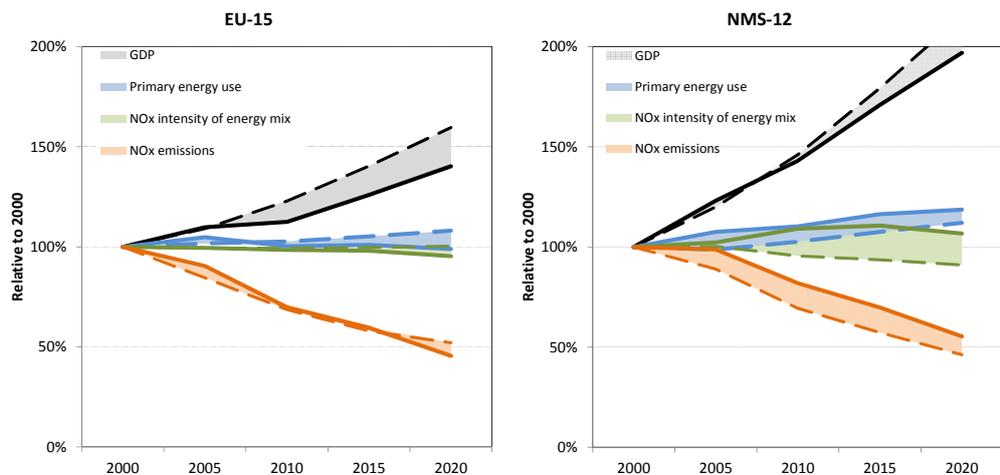


Figure 3.10: Old Member States: Differences in the projections of GDP, total energy consumption, the NO_x intensity of the fuel mix, and resulting NO_x emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

The close match, especially for the old Member States, is somewhat surprising, as there is clear evidence that the assumptions on the effectiveness of vehicle emission standards of light duty diesel vehicles did not materialize in real-life driving patterns (Borken-Kleefeld & Ntziachristos, 2012). Thus, it is instructive to examine trends separately for stationary and mobile sources.

Stationary sources

For stationary sources, in 2010 actual emissions of NO_x were close to the CAFE baseline, although they were significantly higher in 2005. Energy intensity improvements turned out to be lower and to have less effect on emissions than earlier anticipated, and also the switch to cleaner fuels (i.e., phase-out of coal) occurred to a lesser extent than expected in the CAFE baseline (Figure 3.11). Higher end-of-pipe controls compensated the lower NO_x declines from these factors.

For the future, the TSAP scenario maintains the optimism of CAFE about lower coal consumption, and reflects additional emission reductions from recent legislation (e.g., the IED directive). Thereby, the latest projections for 2020 end up in slightly lower emissions than those of CAFE.

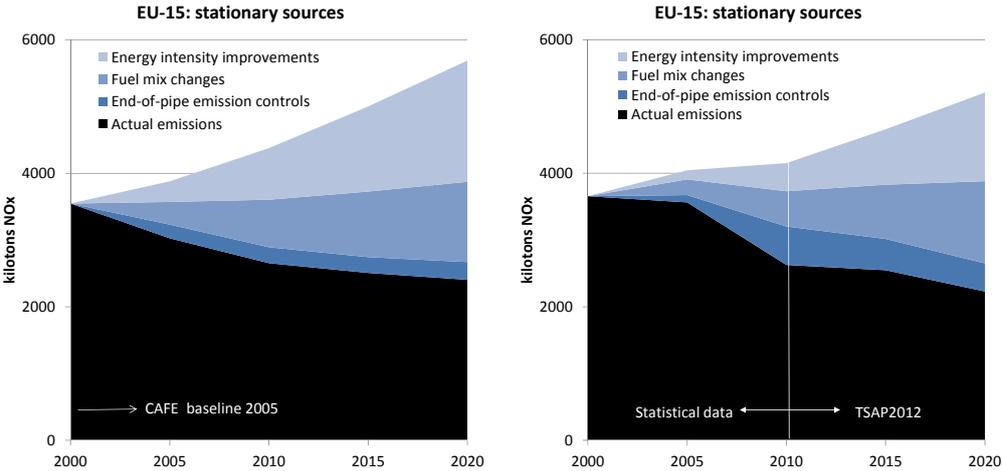


Figure 3.11: Impacts of the driving forces (GDP, energy efficiency improvements, fuel mix changes and end-of-pipe controls) on total NO_x emissions from stationary sources in the old Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

In the new Member States, the persistence of coal in the energy mix had an even larger impact on NO_x emissions, which however was not fully compensated by end-of-pipe measures (Figure 3.12). For the future, the TSAP-2012 foresees now a much larger role for end-of-pipe measures, which would compensate higher coal use and thereby maintain the emission levels of the CAFE baseline.

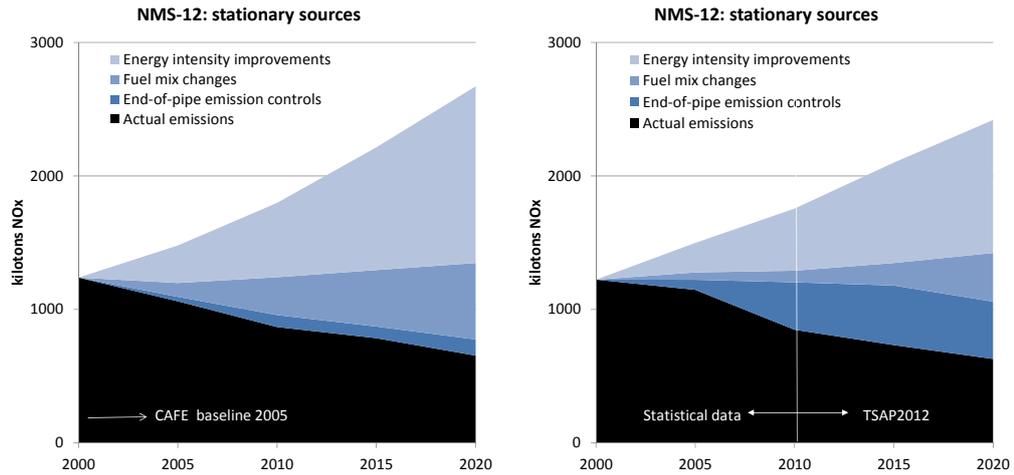


Figure 3.12: Impacts of the driving forces (GDP, energy efficiency improvements, fuel mix changes and end-of-pipe controls) on total NO_x emissions from stationary sources in the new Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

Mobile sources

For mobile sources, the decomposition clearly highlights the non-delivery of emission control legislation. In the old Member States, emission cuts from end-of-pipe measures fell short by 20% from the expected level. As different trends in the other factors did not greatly influence emissions, total NO_x emissions were 12% or 500 kt higher than anticipated (Figure 3.13).

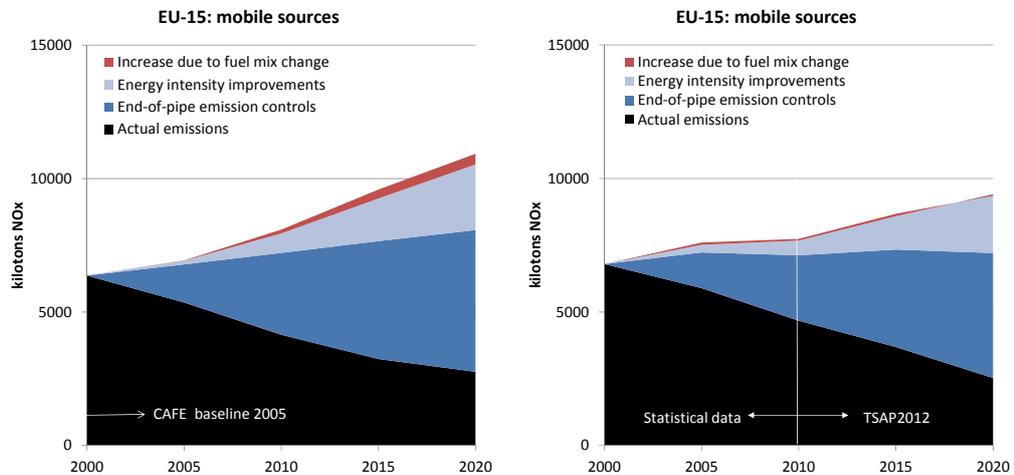


Figure 3.13: Impacts of the driving forces (GDP, energy efficiency improvements, fuel mix changes and end-of-pipe controls) on total NO_x emissions from mobile sources in the old Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

NO_x emissions from mobile sources in the new Member States developed rather differently following the divergent evolution of the main driving forces. First, GDP trends differ significantly, especially for the future (Figure 3.14). Furthermore, transport intensity of the economies increased more than foreseen, with tends to increase NO_x emissions. As vehicle emission standards did not deliver the envisaged

results, emissions in 2010 were 30% or 200 kt higher than expected by CAFE. For the future, the TSAP-2012 baseline assumes timely and effective implementation of EURO 6 standards (see Borken-Kleefeld & Ntziachristos, 2012), so that emissions would decline rapidly, although they would not achieve the levels anticipated in the CAFE 2005 baseline.

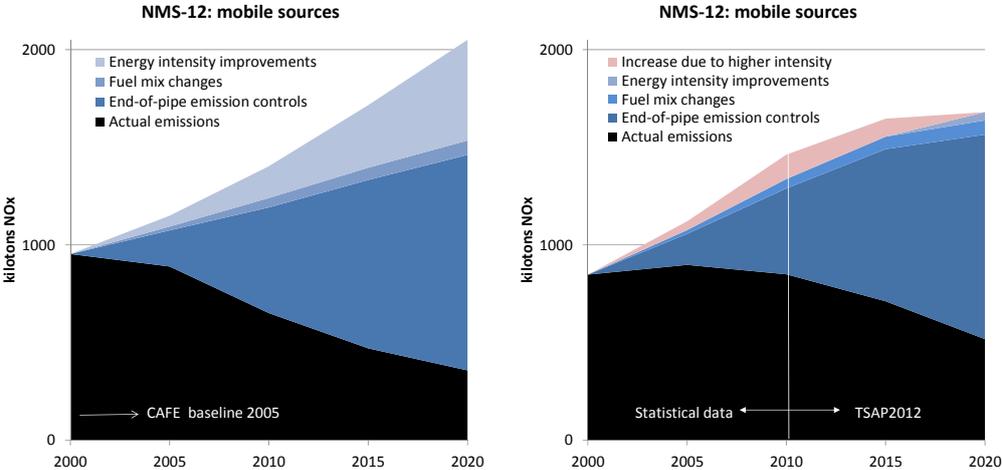


Figure 3.14: Impacts of the driving forces (GDP, energy efficiency improvements, fuel mix changes and end-of-pipe controls) on total NO_x emissions from mobile sources in the new Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

Comparison to international commitments for NO_x

At the aggregated level for the EU-15, NO_x emission ceilings of the NEC directive have been exceeded by 12% in 2010, while the CAFE-2005 baseline assumed compliance. For 2020, the aggregated ceilings of the revised Gothenburg protocol are close to the CAFE-2005 baseline, while the TSAP proposed 25% lower targets. NO_x emissions of the TSAP-2012 baseline would be 9% below the Gothenburg ceilings (Figure 3.15).

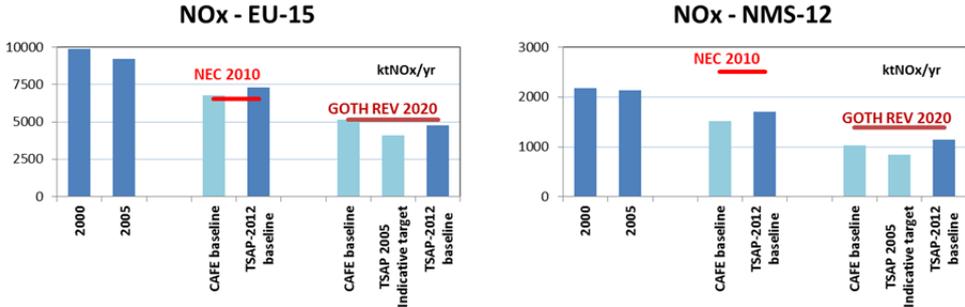


Figure 3.15: NO_x emissions in EU-15 and NMS-12 regions compared to the international commitments for the years 2010 and 2020.

For the new Member States, both the CAFE-2005 and actual emissions in 2010 are clearly below the NEC ceilings. The recently agreed Gothenburg ceilings for 2020 are 35% higher than the CAFE-2005 baseline, and even 65% above the target indicated

by the Thematic Strategy. Although emissions of the TSAP-2012 baseline are 37% above the targets of the 2005 Thematic Strategy, they still remain 21% below the Gothenburg ceilings.

3.2.3 PM2.5 emissions

Most relevant for the evolution of PM emissions is the higher than anticipated growth of biomass combustion to meet the renewable and climate targets, a larger share in diesel in transport fuels, and the introduction of the diesel particle filter.

Old Member States

Differences in the projections of total primary energy use had only little impact on PM emissions, while the recent changes in the fuel mix, in particular a larger share of diesel vehicles and more biomass combustion, tends towards higher PM emissions compared to what was assumed in the CAFE 2005 baseline (Figure 3.16). The overriding factor is the effectiveness of dedicated PM emission control measures. While for 2010 the CAFE scenario was rather accurate (resulting in only minor differences in total PM2.5 emissions), the TSAP-2012 baseline including Euro-6 with particle filters results for 2020 in larger emission reductions than what was earlier foreseen. Thereby, more efficient technology balances the impact of the switch to less favourable fuel mixes (Figure 3.17).

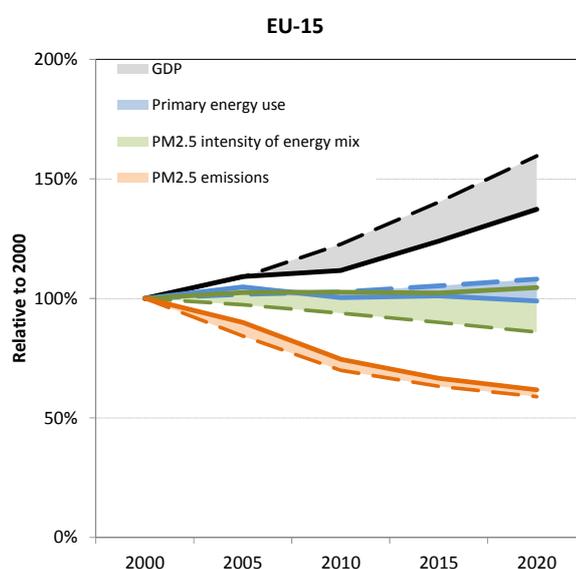


Figure 3.16: Old Member States: Differences in the projections of GDP, total energy consumption, the PM2.5 intensity of the fuel mix, and resulting PM2.5 emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

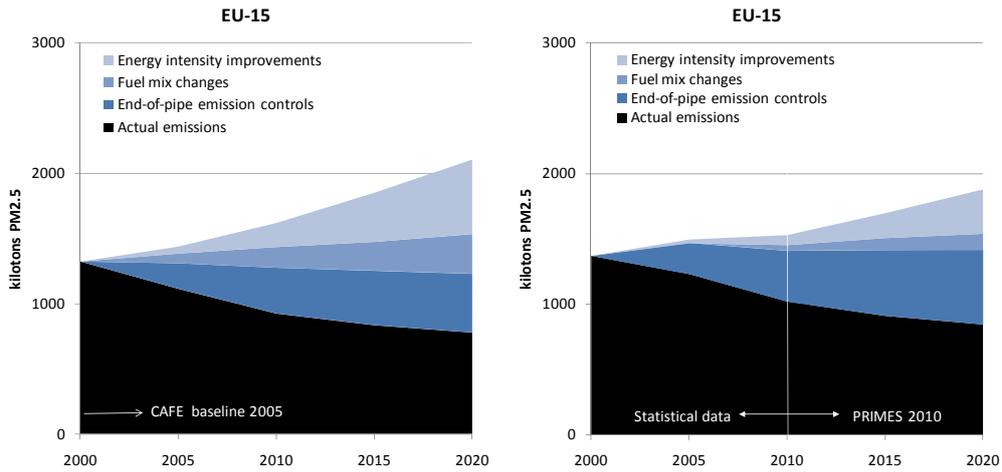


Figure 3.17: Impacts of the driving forces (GDP, energy use, fuel mix and end-of-pipe controls) on total PM_{2.5} emission in the old Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

New Member States

For the new Member States, the actual development to 2010 and recent expectations for the next decade are rather different from what was assumed in the CAFE 2005 baseline. Actual fuel mix changes did not induce such large emission reductions in 2010 as it was projected in 2005. Add-on measures contributed to PM_{2.5} abatement to a much larger extent compared to CAFE (Figure 3.18), but total emissions are significantly above the earlier expectations (Figure 3.19).

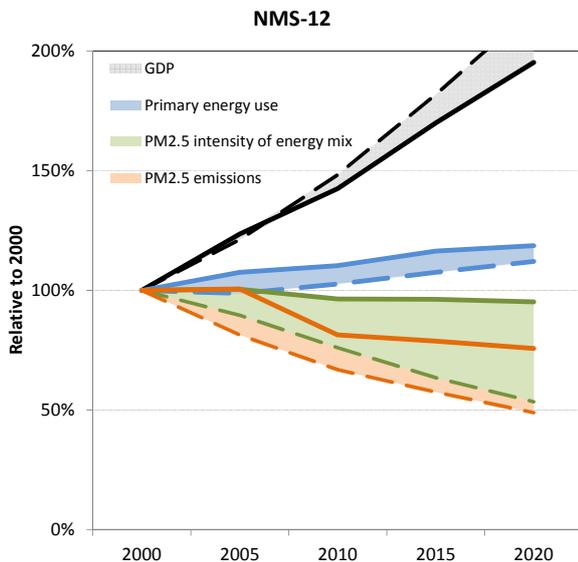


Figure 3.18: New Member States: Differences in the projections of GDP, total energy consumption, the PM_{2.5} intensity of the fuel mix, and resulting PM_{2.5} emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

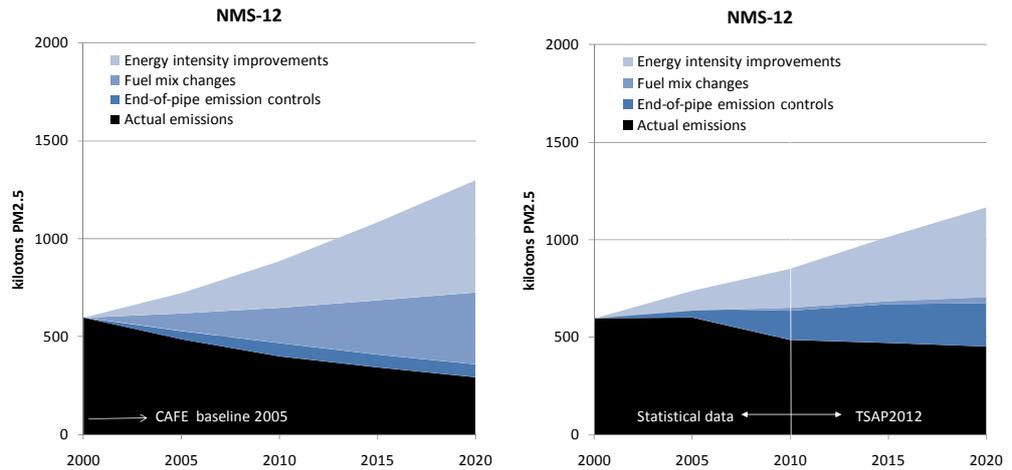


Figure 3.19: Impacts of the driving forces (GDP, energy use, fuel mix and end-of-pipe controls) on total PM_{2.5} emission in the new Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

Comparison to international commitments for fine particles

While there are no obligations for PM_{2.5} for 2010, the recent baseline projections suggest for 2020 higher emissions compared to the CAFE scenario. For 2020, the ceilings agreed in the revised Gothenburg protocol are 5% above the CAFE baseline (with the 2005 legislation), and 36% above the target level indicated in the 2005 Thematic Strategy, while the most recent TSAP-2012 baseline results in 4% higher emissions than the Gothenburg ceiling (Figure 3.20). For the new Member States, the Gothenburg ceilings for 2020 are 16% above the CAFE baseline, and 53% above the target level of the 2005 Thematic Strategy, while the higher projection of the TSAP-2012 baseline exceeds the Gothenburg ceilings by 22%.

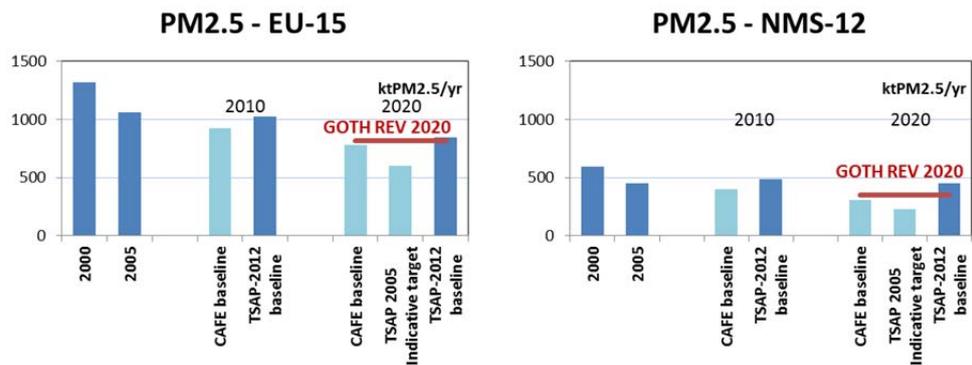


Figure 3.20: PM_{2.5} emissions in EU-15 and NMS-12 regions compared to the international commitments for the years 2010 and 2020.

3.2.4 NH₃ emissions

As ammonia (NH₃) emissions originate mainly from agricultural activities, they respond to different driving forces than the more energy-related pollutants. Thus, they are strongly influenced by population development, the levels of agricultural activities (e.g., livestock numbers), the structural composition of livestock, and applied emission control measures. Differences in population projections are rather small compared to the other drivers (black lines in Figure 3.21). In contrast to what has been expected in the CAFE baseline, animal numbers (in terms of livestock units) fell in the old Member States, and did not follow the growth assumptions in the new Member States (blue lines). The NH₃ intensity of agricultural activities (related mainly to the share of cattle in total livestock) declined in the old Member States after 2010, while it was expected to grow (green lines). As a consequence, NH₃ emissions in the old Member States declined until 2010 by 6%, and the TSAP-2012 baseline assumes for 2020 a rebound to the 2005 levels (red lines). For the new Member States, the anticipated increase in emissions did not materialize, and emissions remained close to the 2000 level.

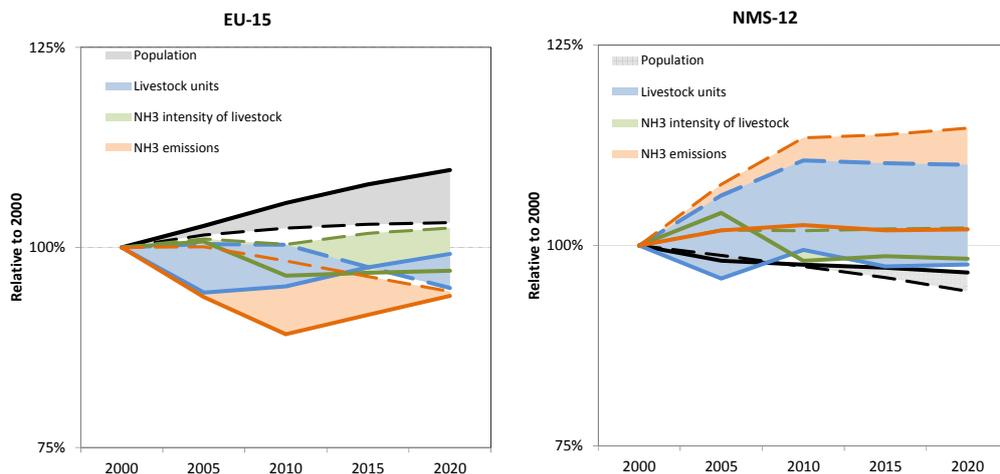


Figure 3.21: Differences in the projections of GDP, total energy consumption, the NH₃ intensity of the agricultural production, and resulting NH₃ emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010). Left panel: old Member States, right panel: new Member States

With these trends, ammonia emissions have decreased in the old Member States mainly due to the unexpected drop in animal numbers (Figure 3.22). In the new Member States, many of the differences in the assumptions cancelled out for total emissions to some extent.

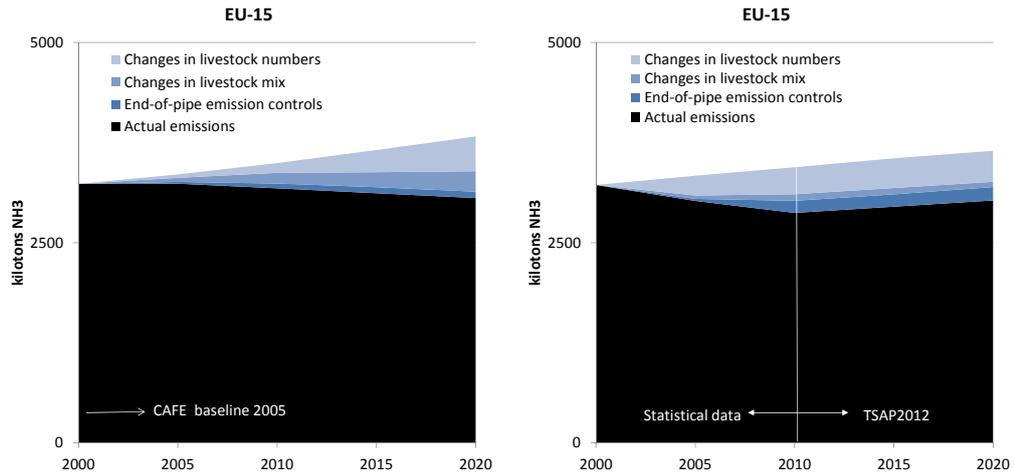


Figure 3.22: Impacts of the driving forces (Population, changes in livestock number, changes in livestock mix and emission controls) on NH₃ emission in the old Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards

Comparison to international commitments for ammonia

The 2010 emission ceilings of the NEC directive have been achieved in both country groups (Figure 3.23), although the CAFE baseline projection expected non-compliance for the old Member States. The Gothenburg ceilings for 2020 are 8% below the CAFE baseline projection for the old Member States, and 27% for the new Member States, so that compliance would require further measures. Further measures would also be required for the achievement of the target emission level indicated in the 2005 Thematic Strategy, which is 21% lower than the Gothenburg protocol. For the new Member States, there are only small differences between the Gothenburg ceilings, the indicative target levels of the Thematic Strategy and the TSAP-2012 baseline.

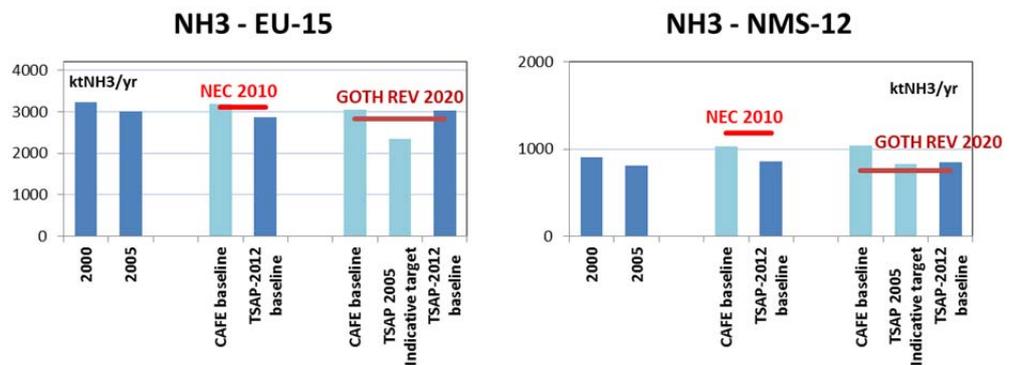


Figure 3.23: NH₃ emissions in EU-15 and NMS-12 regions compared to the international commitments for the years 2010 and 2020.

3.2.5 VOC emissions

VOC emissions in the old Member States decline in both projections over time and result in comparable VOC levels by 2020 (Figure 3.24). However, intensity/efficiency improvements relative to 2000 played a larger role in the EU-15 than assumed earlier. In 2020, structural changes in the TSAP-2012 baseline, for example shift from gasoline to diesel, will contribute to VOC reductions nearly as much as end-of pipe measures (Figure 3.25).

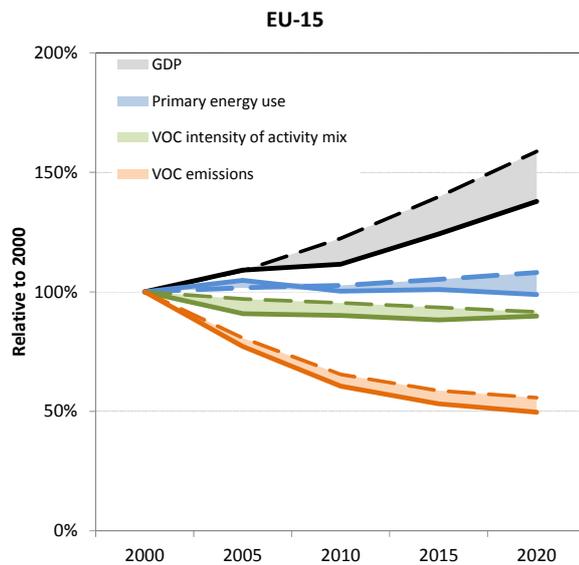


Figure 3.24: Old Member States: Differences in the projections of GDP, total energy consumption, the VOC intensity of the agricultural production, and resulting VOC emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

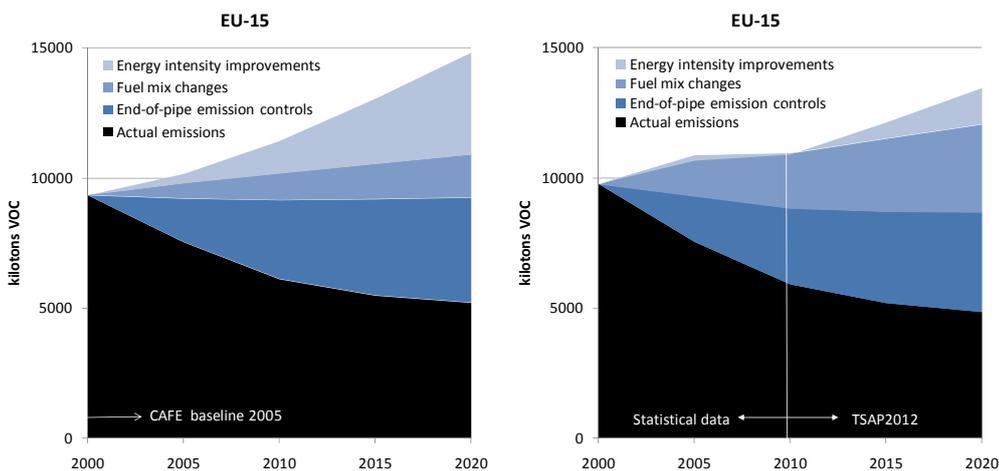


Figure 3.25: Impacts of the driving forces (GDP, energy use, fuel mix and end-of-pipe controls) on VOC emissions in the old Member States. Left panel: CAFE 2005 perspective; right panel: Actual development up to 2010, TSAP-2012 perspective from 2010 onwards.

In the new Member States, the largest impact to VOC-reduction comes from end-of-pipe measures (see Figure 3.27). Dedicated abatement options for VOC are also a dominant factor driving down emissions in the TSAP-2012 baseline in 2020. This is

different to the CAFE projections, where the GDP-related intensity improvement was the main contributor to the lower VOC emissions in 2020.

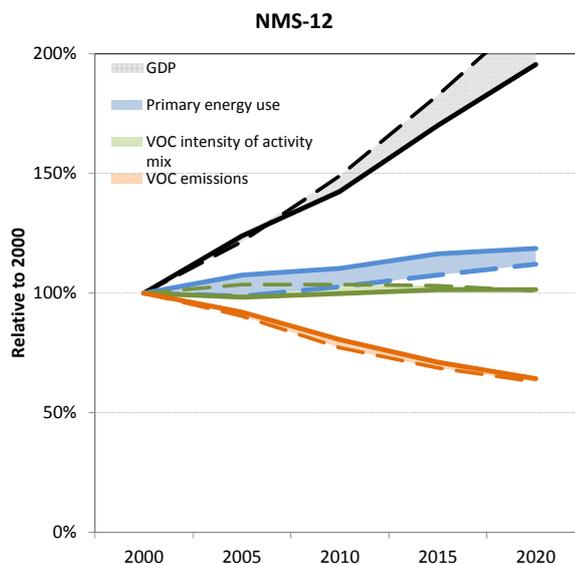


Figure 3.26: New Member States: Differences in the projections of GDP, total energy consumption, the VOC intensity of the agricultural production, and resulting VOC emissions between the CAFE scenario (dashed lines), the actual development (solid lines until 2010) and the TSAP-2012 projections (solid lines after 2010)

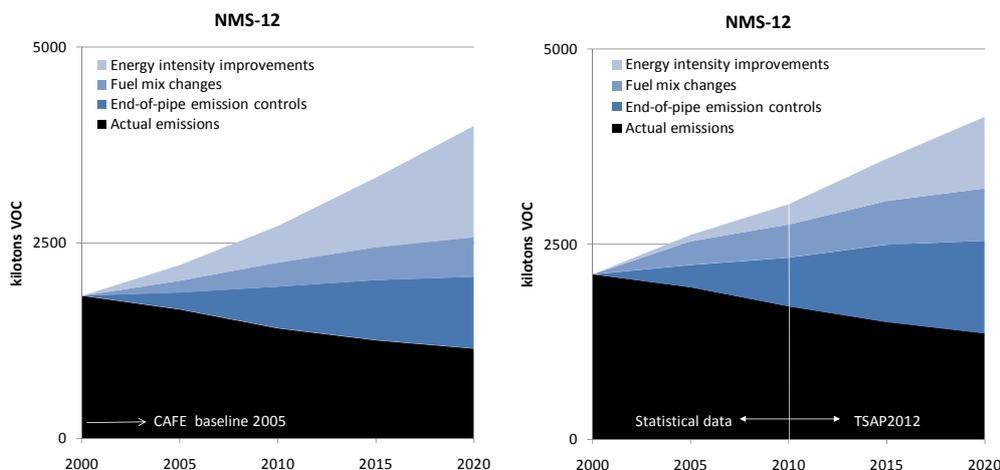


Figure 3.27: Left panel - Evolution of factors affecting the VOC emissions in NMS-12 relative to the year 2000; CAFE2005 dotted lines, TSAP2012 solid lines. Middle panel – determinants of VOC emission reductions in CAFE2005 compared to 2000; Right panel - determinants of VOC emission reductions in TSAP2012 compared to 2000.

Comparison to international commitments for VOC

For the EU as a whole, today’s levels of VOC emissions are below the NEC ceilings for the year 2010. For 2020, the Gothenburg ceilings exceed the target levels indicated in the 2005 Thematic Strategy on Air Pollution by 7% for the old Member States and

by 48% for the new Member States. They are, however, close to the baseline levels of the TSAP-2012 scenario (Figure 3.28).

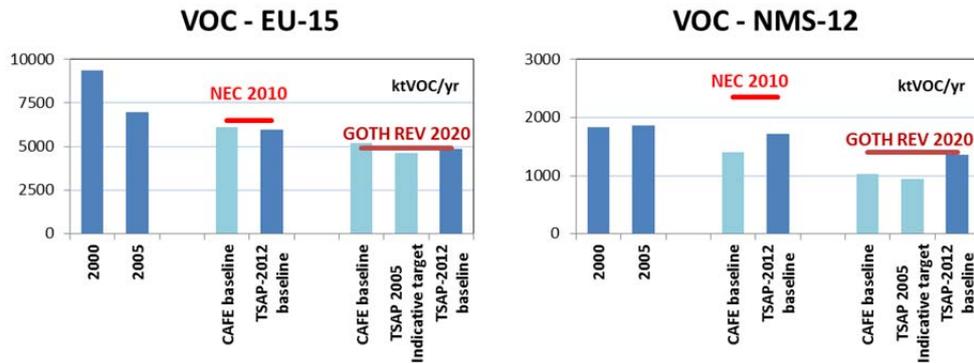


Figure 3.28: VOC emissions in EU-15 and NMS-12 regions compared to the international commitments for the years 2010 and 2020.

3.3 Costs of air pollution abatement

From the decomposition analysis presented above for five air pollutants, several common patterns occur that influence emission control costs.

The CAFE 2005 baseline that considered climate measures assumed significant changes in the fuel mix, mostly associated with shifts from coal towards natural gas and other energy forms. In reality, this shift did not materialize at the rate that was expected in 2005. At the same time, energy consumption did not grow at the anticipated extent, not at least because of lower economic activities during the economic recession.

As a consequence, the GAINS cost estimates for the TSAP-2012 baseline in 2010 are now 2% lower for the old Member States and 34% higher for the new Member States, compared to the CAFE estimates that have been conducted with the RAINS model.

In addition, new emission control legislation has been decided within the EU, and air quality legislation became more stringent (e.g., Euro-6, Euro-VI, the IED directive, etc.). This will affect baseline emission control costs in the future. In combination, additional legislation, lower energy consumption, fewer changes in fuel mix, and higher unit costs of abatement lead for the TSAP-2012 in 2020 to higher air pollution abatement costs per unit of energy use compared to the CAFE 2005 baseline (Figure 3.29). In 2020, estimated costs for implementing (different sets of) current legislation for the TSAP-2012 baseline are 7% higher in the EU-15, and 55% in the new Member States than in the CAFE projections. Note that in 2005 Bulgaria and Romania had not yet joined the EU, and that the CAFE cost estimates did not include full costs for introducing EU legislation in these countries.

If emission control costs are related to GDP, differences between CAFE and TSAP-2012 decline as cost figures are adjusted for GDP development. In this case, estimates for 2010 have increased from 0.48% to 0.51%, mainly due to higher consumption of coal that requires more emission control efforts. For 2020, differences increase by 0.11 percentage points, inter alia as a consequence of the additional legislation included in the TSAP baseline (Figure 3.2).

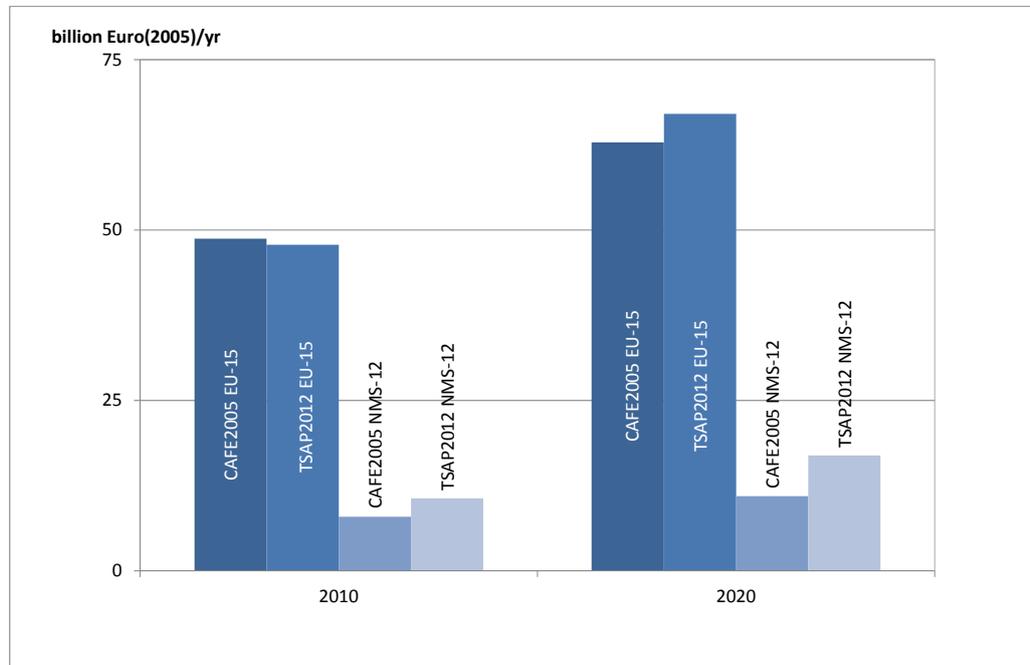


Figure 3.29: Comparison of air pollution abatement costs in EU-15 and NMS-12 regions for the CAFE2005 and TSAP2012 Baseline scenarios in the years 2010 and 2020.

Table 3.2: Emission control costs as estimated by the RAINS model for the CAFE baseline in 2005, and the GAINS estimates for the TSAP-2012 baseline. CAFE figures have been converted into Euros of 2005.

		Emission control cost (billion Euro ₂₀₀₅)		GDP (billion Euro ₂₀₀₅)		Share of GDP in	
		2010	2020	2010	2020	2010	2020
Old MS	CAFE	48.7	62.9	11209	14433	0.43%	0.44%
	TSAP	47.8	67.0	10619	13110	0.45%	0.51%
New MS	CAFE	7.9	10.9	696	1030	1.14%	1.06%
	TSAP	10.6	16.9	767	1055	1.39%	1.61%
EU-27	CAFE	56.7	73.8	11905	15463	0.48%	0.48%
	TSAP	58.5	84.0	11385	14164	0.51%	0.59%

4 Distance to the 2005 TSAP targets for air quality

As a ‘distance to target’ analyses, the environmental impacts that would result from the TSAP-2012 baseline have been compared against the environmental targets established by the 2005 Thematic Strategy on Air Pollution. To maintain comparability with the figures given in the Thematic Strategy, this calculation is carried out on the same methodological basis that has been employed for the analyses for the revision of the National Emission Ceilings directive and the revision of the Gothenburg protocol. In particular, this analysis uses the earlier version of the GAINS model, the atmospheric dispersion characteristics that have been derived from the 2005 version of the EMEP Eulerian model, the 2008 version of the critical loads data and the earlier estimates of urban background concentrations of PM from the City-Delta approach. Note that the forthcoming calculations for the revision of the Thematic Strategy will rely on the 2012 computations of the EMEP Eulerian model with a finer spatial resolution, the new hybrid approach to estimate urban background concentrations of PM, and the 2011 data on critical loads.

Calculated on a comparable basis, the TSAP-2012 baseline, without further measures, would fail to achieve the targets for the protection of human health, eutrophication and forest acidification. It would attain the TSAP targets for water acidification and ground-level ozone.

Table 4.1: Impact indicators for the year 2020, EU-27

	2000	Revised Gothenburg protocol in 2020	TSAP-2012 baseline in 2020	TSAP target for 2020 (relative to 2000)	TSAP target based on GAINS estimates for 2000
PM2.5 (million years of life lost)	204.7	132.1	123.9	-47%	108.5
Acidification for forests (km ²)	280300	110743	91828	-74%	72878
Acidification water (km ²)	53246	22693	19632	-39%	32480
Eutrophication (km ²)	1188000	1005107	994728	-31%	819720
Ozone (cases of premature deaths)	22707	18927	17572	-10%	20436

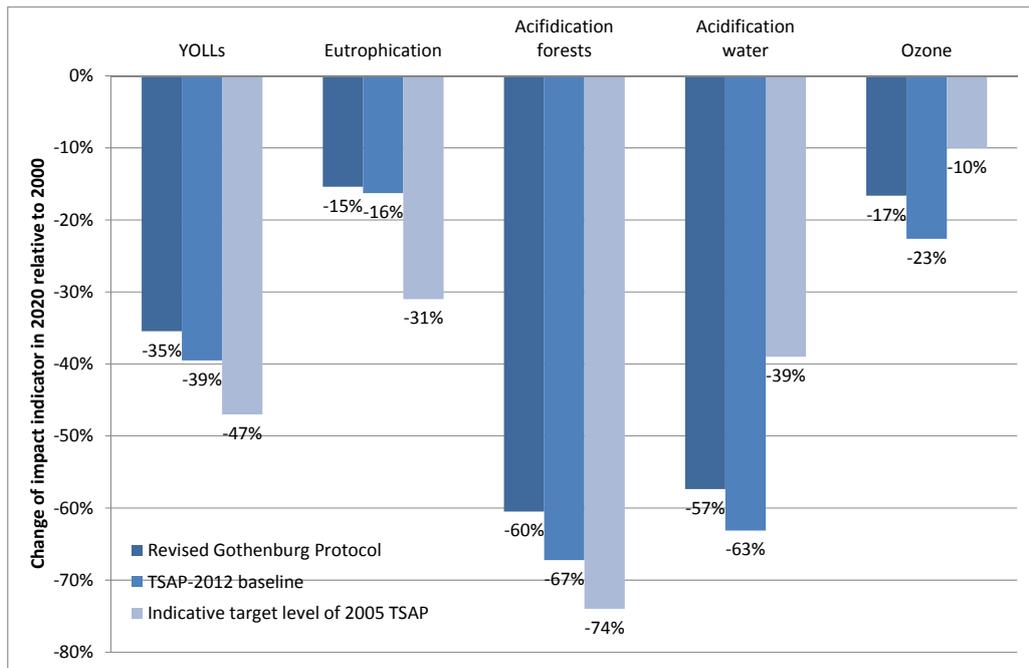


Figure 4.1: Changes in impact indicators for 2020, for the emission ceilings of the revised Gothenburg protocol, the TSAP-2012 baseline and the targets of the 2005 Thematic Strategy on Air Pollution

To support the European Commission in the review of the 2005 Thematic Strategy on Air Pollution, this report revisits the baseline scenario that was presented in 2005 in view of today's knowledge, in particular taking into account the impacts of the economic crisis on economic and energy development, and real-life experience with newly implemented emission regulations.

This report compares the final baseline emission projection developed in 2005 within the Clean Air For Europe (CAFE) programme for the Thematic Strategy on Air Pollution (Amann et al., 2005a) against the recent baseline projection prepared for the revision of the Thematic Strategy in 2012 (the TSAP-2012 baseline), which is presented in TSAP Report #1 (Amann et al., 2012).

The report reviews the main drivers of emission changes, i.e., demographic trends, economic growth, changes in the energy intensity of GDP, switches to other fuels, and application of dedicated emission control measures.

Compared to the assumptions in 2005, population has grown faster up to 2010, and the recent TSAP-2012 baseline anticipates a 6% higher population in 2020 than the CAFE scenario. Economic growth has developed less favourable, as the economic downturn was not foreseen in 2005. By 2010, GDP was 6% lower than expected, and for 2020 the TSAP-2012 scenario assumes GDP to be 10% below the CAFE projection. In contrast to the CAFE assumptions on more or less stable world energy prices, oil and gas prices have increased by a factor of 2.5 up to 2010, and are expected to grow further in the TSAP-2012 scenario.

Since 2000, the energy intensity of GDP declined less than anticipated. The slower transition to less energy-intensive economic structures as well as the lower rates of energy efficiency improvements compensated the effects of lower GDP growth, so that total primary energy consumption did not change much in the last decade, especially in the old Member States. There was, however, an increase in energy consumption of the new Member States due to fast economic growth.

The anticipated phase-out of coal and replacement by natural gas has occurred at a significantly lower rate, while the penetration of diesel vehicles was significantly stronger than expected in 2005.

By 2010, the decline in SO₂ emissions anticipated by CAFE was slightly less optimistic than the actual development, mainly because the baseline did not consider the recently emission control legislation. For 2020, the TSAP-2012 baseline suggests 20% less SO₂ emissions than the earlier CAFE projection. The application of dedicated emission controls emerges as the dominating factor for lower emissions. It compensated the lower decline in total energy consumption as well as the delay in the phase-out of coal.

For NO_x, many factors developed differently than anticipated, e.g., economic growth was lower, energy intensity improvements happened slower, coal was phased out less, emission controls for stationary sources were more important, and some vehicle

emission standards did not fully deliver the expected improvements. However, in total these factors almost cancel out at the EU-27 level, so that there are relatively small differences between the CAFE baseline and the actual development until 2010, and the TSAP-2012 projections to 2020.

For PM emissions, the recent changes in the fuel mix, in particular the increasing share of diesel vehicles and more biomass combustion, tend towards higher PM emissions compared to what was assumed in the CAFE 2005 baseline. However, also for PM the effectiveness of dedicated PM emission control measures turns out as the overriding factor. While for 2010 the CAFE projection was rather accurate, the TSAP-2012 baseline including EURO 6 with particle filters results for 2020 in larger emission reductions than what was earlier foreseen. Thereby, more efficient technology balances the impact of the switch to less favourable fuel mixes.

In the old Member States, 2010 emissions of NH₃ were 6% below the CAFE 2005 baseline due to an unforeseen drop in animal numbers. While key drivers for the new Member States developed rather differently from what assumed, different factors cancel out so that impacts on total emissions are small.

VOC emissions decline in both projections over time and result in comparable VOC levels by 2020, especially in the old Member States. However, intensity/efficiency improvements relative to 2000 played a larger role than assumed earlier. In 2020, structural changes in the TSAP-2012 baseline, for example shift from gasoline to diesel, will contribute to VOC reductions nearly as much as end-of pipe measures.

A re-analysis of air pollution control costs based on the actual statistics for 2010 suggests costs growing from the earlier CAFE estimate of 0.48% of GDP to 0.51%, mainly due to higher consumption of coal that required more emission control efforts. For 2020, the cost difference increase by 0.11 percentage points, inter alia as a consequence of the additional legislation that is now included in the TSAP-2012 baseline (e.g., the EURO 6/VI standards).

For 2020, emissions of the new TSAP-2012 baseline (without additional measures) exceed the indicative targets for emission reductions established by the Thematic Strategy in 2005. For SO₂, the baseline is 6% above the indicative targets, for PM_{2.5} 53%, for NH₃ 16% and for VOC 13%. For NO_x, the TSAP-2012 baseline would meet the indicative target under the assumption that EURO 6 standards would bring down real-life emissions from light duty trucks to 150% of the test cycle value (120 mg/km). If real-life emissions declined only proportional to the changes in test cycle values, total NO_x emissions in the EU-27 would exceed the indicative TSAP target by 27%.

As a consequence, the environmental targets established by the TSAP for the protection of human health, eutrophication and forest acidification would not be met by the TSAP-2012 baseline without additional measures.

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