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# Factorization of air pollutant emissions: Projections versus observed trends in Europe

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## HIGHLIGHTS

- EU's air pollution scenarios from 2005 are revisited in light of today's knowledge.
- Decomposition analysis is performed to identify factors driving emission trends.
- Controls in stationary sources were effective, fuel mix change missed expectations.
- Emission cuts from vehicle standards used after 2005 fell short of expectations.
- New emission projections will not meet policy targets without additional measures.

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## ABSTRACT

This paper revisits the emission scenarios of the European Commission's 2005 Thematic Strategy on Air Pollution (TSAP) in light of today's knowledge. We review assumptions made in the past on the main drivers of emission changes, i.e., demographic trends, economic growth, changes in the energy intensity of GDP, fuel-switching, and application of dedicated emission control measures. Our analysis shows that for most of these drivers, actual trends have not matched initial expectations. Observed ammonia and sulfur emissions in European Union in 2010 were 10% to 20% lower than projected, while emissions of nitrogen oxides and particulate matter exceeded estimates by 8% to 15%. In general, a higher efficiency of dedicated emission controls compensated for a lower-than-expected decline in total energy consumption as well as a delay in the phase-out of coal. For 2020, updated projections anticipate lower sulfur and nitrogen oxide emissions than those under the 2005 baseline, whereby the degree to which these emissions are lower depends on what assumptions are made for emission controls and new vehicle standards. Projected levels of particulates are about 10% higher, while smaller differences emerge for other pollutants. New emission projections suggest that environmental targets established by the TSAP for the protection of human health, eutrophication and forest acidification will not be met without additional measures.



## 1. Introduction

In its 2005 Thematic Strategy on Air Pollution (TSAP), the European Commission (EC) 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 interim health and environmental objectives and outlined emission reduction pathways that would achieve these targets by 2020 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 EC launched a comprehensive review and revision of its air pollution policy, in particular of the TSAP and related legal instruments (CEC, 2011a).

To provide an analytical perspective on the current policy-making process, this paper presents for the first time a comprehensive reassessment of the scenarios that were envisioned in 2005, taking particular account of the impacts of the economic crisis on economic and energy development and real-life experience with recently implemented emission regulations. We compare the emission projections developed within the Clean Air For Europe (CAFE) program in 2005 for TSAP (Amann et al., 2005a) against the recent projections prepared for the revision of TSAP, as presented by Amann (2012). Both sets of projections represent baseline scenarios (i.e., without any additional abatement measures) and run through 2020. They address five air pollutants, i.e., sulfur dioxide ($SO_2$), nitrogen oxides ($NO_x$), fine particulate matter ($PM_{2.5}$), ammonia ($NH_3$) and volatile organic compounds (VOC). In addition, the environmental and health impacts that would result from the new TSAP baseline are compared against the indicative targets established by the 2005 CAFE projections. In the literature, there are examples of ex-post analyses of other European air pollution policies,

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particularly the evaluation of Gothenburg Protocol by Kelly et al. (2010) and an assessment of interim objectives the EU National Emission Ceilings Directive by Hettelingh et al. (2013), however, these studies are based on different methodological basis and have different temporal and spatial coverage.

In our analysis, we make use of the statistical information on European emissions and underlying drivers that is now available through 2010. Using this data we illustrate how, over the last decade, the European Union (EU) has moved towards achievement of the interim targets defined in the National Emission Ceilings (NEC) directive (CEC, 2001). We also address projections through 2020, for which fundamental expectations have changed since 2005. In particular, we evaluate the assumptions made in 2005 in the context of recent developments and in comparison with assumptions adopted for current emission projections. In order to interpret changes in actual and future emission trends, a quantitative decomposition of the major factors that determine the development of air pollutant emissions is presented. By comparing actual trends and recent projections of driving factors against the trajectories anticipated in 2005, the analysis reveals the degree to which development has materialized as foreseen, and quantifies the effects of various factors that evolved in unexpected directions. The methodology applied herein has been used by the authors for decomposing the European air emission trends observed in the period 1960–2010 (Rafaj et al., 2014); in this study we extend the computation framework to the comparative assessment of the air pollution scenarios through 2020.

The analysis was undertaken 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, or for the two groups combined (EU-27). The following section provides a brief overview of the methods and data used to lay the foundations for subsequent quantitative analyses. In the first part of Section 3, an analysis of the development of key drivers responsible for changing emissions is provided. Thereafter, observed emissions from 2000 to 2010, as well as recent projections of emissions through 2020, are decomposed and compared against earlier expectations, highlighting the most important changes that led to unexpected developments in emission profiles. The same section also provides a comparison of performance of selected scenarios for a set of environmental and health indicators. The final section presents conclusions and discusses some policy implications of the main findings.

## 2. Methodology and data sources

Patterns of emissions over time are influenced by a variety of factors. Emissions are directly related to levels of emission-generating activities (e.g., energy consumption or transport volumes), which are influenced, in turn, by the development of different economic sectors and the energy intensity of economic activities. The composition of fuel consumption also has significant impacts on emissions, as different fuels emit different quantities of air pollutants. In addition, targeted control measures (e.g., end-of-pipe emission control technologies) are a critical determinant of final emission levels (Amann et al., 2013). Some of these factors are subject to dedicated environmental policies (e.g., fuel quality standards), 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 energy structure, overall economic growth and technological advances, we perform a simplified additive form of the index decomposition analysis described by Hoekstra and van den Bergh (2003). Specifically, the relationships between these factors are clarified analytically following the decomposition procedure by Rafaj et al. (2014), and the resulting equations applied to data for EU countries, with reference to both the 2005 scenarios and the recent revisions which update projections through 2020.

### 2.1. Determinants of emission changes

In consideration of the Kaya identity (Kaya and Yokobori, 1997), total emissions in a region can be described in general terms as the product of three factors, i.e., population, per-capita income, and emissions per unit of GDP:

$$\text{Emissions} = \text{Population} \cdot \left(\frac{\text{GDP}}{\text{Population}}\right) \cdot \left(\frac{\text{Emissions}}{\text{GDP}}\right). \tag{1}$$

Each factor evolves over time, influencing patterns of total emissions. The first two terms are usually beyond the direct impact of environmental policies. Rather, these mainly affect the third term (i.e., emissions/GDP), which subsumes autonomous technological progress, structural changes in national economies, behavioral changes and dedicated environmental policies. To reveal the relative importance of these individual components, we extend identity (1), decomposing changes in emissions into three factors: (i) energy intensity (i.e., changes in energy use per GDP and conversion efficiency); (ii) fuel mix (i.e., the share of different fuel types in total energy use); and (iii) air pollution abatement measures (i.e., as they affect emission rates per unit of fuel type). As such, emission changes relative to a selected base year can be described with identity (2):

$$\Delta\text{Emissions} = \text{GDP} \cdot \underbrace{\left[\Delta\left(\frac{\text{Energy}}{\text{GDP}}\right) \cdot \Delta\eta\right]}_{\text{(i)}} \cdot \underbrace{\left[\Delta\left(\frac{\text{Emissions}}{\text{Energy}}\right)\right]}_{\text{(ii)}} \cdot \underbrace{\left[(1-eff) \cdot \Delta X\right]}_{\text{(iii)}}. \tag{2}$$

The actions of these factors can be briefly described as follows:

(i) Changes in energy intensity, i.e., the energy required to produce a single unit of GDP, determine overall energy consumption, and influence resulting emission levels. The evolution over time of differences in energy intensities across countries reflects variations in socio-economic structures as well as in behavioral patterns. In our approach, the energy is a combination of secondary (e.g., power and conversion sectors) and final energy forms.
Energy intensity is complemented by the efficiency of the energy system ($\Delta\eta$), i.e., the efficiency at which primary energy (e.g., coal, crude oil) is converted into different forms of final energy (e.g., electricity). Long-term systemic changes result from improved efficiencies of power generation technologies, of the combustion of final energy carriers in the industry, transport or household sectors, and 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.

(ii) The fuel mix of different energy forms affects emission intensities. Inter-fossil fuel switching and changes in the fraction of non-fossil fuels in the energy supply largely determine long-term trends. Substitution of traditional fuels with electricity and heat also contribute to this mitigation component. Fuel switches can be triggered by environmental regulations, but more commonly result from considerations of cost and convenience (Pock, 2010; Andersen et al., 2011).

(iii) Emission controls reduce the amount of pollutants emitted per unit of energy through, for example, end-of-pipe measures or improved fuel quality due to lowered sulfur content of coal or heating oil. Changes in emission factors over time can also be influenced by modified import patterns and by exploitation of resources with different characteristics. The resulting emission coefficient consists of the removal efficiency (*eff*) of a given abatement measure adopted at a specific rate ($\Delta X$).

Our formulation, described in further detail by Rafaj et al. (2014), is useful for isolating the impacts of dedicated environmental policy interventions from other driving forces. To this end, we compute four