Curbing the omnipresence of lead in the European environment since the 1970s – a successful example of efficient environmental policy.

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After decades of regulating the emission of anthropogenic substances into the environment, a retrospective analysis of their effects is informative, as it allows determining the actual costs and benefits related to the regulations. As a first example we have considered the case of gasoline lead in Europe. With the help of a regional climate model, NCEP re-analyses, spatially disaggregated lead emissions from road traffic and point sources, and various local data, an attempt was made to reconstruct the airborne pathway and deposition of gasoline lead in Europe since 1958. It turns out that this approach is successful in describing the time-variable, spatially disaggregated deposition of gasoline lead. Additional data from analyses of concentrations in, for instance, leaves, mussels and human blood, allows an assessment about the impact of the phasing-out of lead on the quality of the environment. Demonstrating the success of the lead policy, the concentrations in leaves and human blood has steadily declined since the early 1980s, whereas the concentration in mussels along the North Sea coast is unaffected.

Introduction

The special property of lead to increase engine performance by preventing self-ignition was discovered in the early 1920s. Lead additives in gasoline, such as tetraethyl lead and tetramethyl lead, solved the combustion problems of Otto engines. Higher-compression engines could be produced and the use of leaded gasoline increased enormously all over the world.

In the 1960s, increased automobile traffic resulted in air pollution problems in high-income countries. While the United States reacted quickly to this challenge and passed the “Clean Air Act Amendments” in 1963, it was not until the 1970s that environmental legislation was enacted in Europe. In those years, environmental damage was perceived in some European countries as a potential risk to human health. Reducing air pollution was one of the main topics in the initial development of environmental policies which concluded with gasoline lead content regulations.

In the “lead study” conducted at the Institute for Coastal Research at GKSS Research Center, the case of the lead emissions in Europe was analysed in some detail. Specifically, questions asked were: How did the lead emissions, atmospheric concentrations and depositions develop in Europe since the 1950s? Was the decline in air concentrations of lead matched by corresponding declines in plants, animals and humans? The strategy of the project included the preparation of a spatially disaggregated atlas of emissions (Pacyna and Pacyna, 2000), together with an analysis of the sequence of political decisions taken at German and European levels and of their economic impacts (Hagner, 2000). The emissions, which rised steadily increase until about 1970 and dropped afterward 1975 in reponse to gasoline-lead regulations, were given to an atmospheric transport model (Costa-Cabral, 2001) which calculated aerial concentrations and depositions in Europe. The transport model was run with 6-hourly regionalized global NCEP re-analyses (Feser et al., 2001). The results were validated against observations from monitoring programs and depositions in a peat bog in Denmark. Since the simulated data are available on a regular grid without gaps in space and time, detailed analyses of the flow and deposition of lead are possible. The changing input of lead into regions such as the Baltic Sea, for example, may be evaluated and time variable emitter-receptor matrices can be computed to establish the influence of each country on other countries and marine regions.. The overall goal of the regulations -- a widespread and significant reduction of the presence of the neurotoxin lead -- was achieved. In a final step, the simulated aerial concentrations and depositions were compared with a variety of local data about the presence of lead in plants, animals and humans.

Emissions, regulations and economic impacts

From 1950 to 1992, gasoline sales increased substantially (Figure 1). In Germany, in 1972 and 1976 the amount of added lead was drastically reduced. In 1985 unleaded gasoline was introduced with the effect that lead emissions dropped only slowly in the following years. This was caused by the low market share of unleaded gasoline in the first years. An interesting detail of Figure 1 are the fingerprints of the oil crises in 1973 and 1979 which initiated two worldwide recessions and intermittent decreases of gas consumption. These repercussions obviously resulted in a decline in the rate of growth of gasoline sales.

Maximum emissions took place in about 1975 with about 160,000 tons after 110,000 tons in 1965 and 62,000 tons in 1955 (Petersen, pers. comm..). After 1975, the emissions declined to 90,00 tons in 1980 and 40,000 tons in 1990. Spatially disaggregated estimates of lead emissions, on a 50 by 50 km^2 grid, were prepared for 1955, 1965, 1975, 1985, 1990 and 1995 (Pacyna and Pacyna, 2000) considering road traffic, metal manufacturing, stationary fuel combustion, waste disposal, cement production and other processes. The result is displayed in Figure 2. The increase until 1975 due to increasing traffic and high lead concentrations in gasoline as well as the decrease afterwards, reflecting the political measures, is clearly seen in Western and Central Europe. In Eastern Europe, however, little change can be detected.

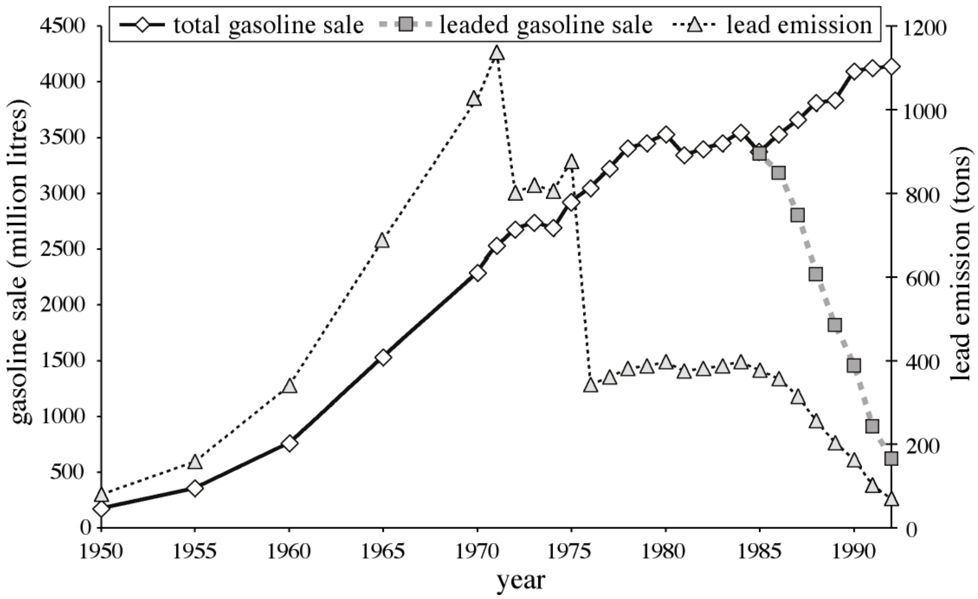
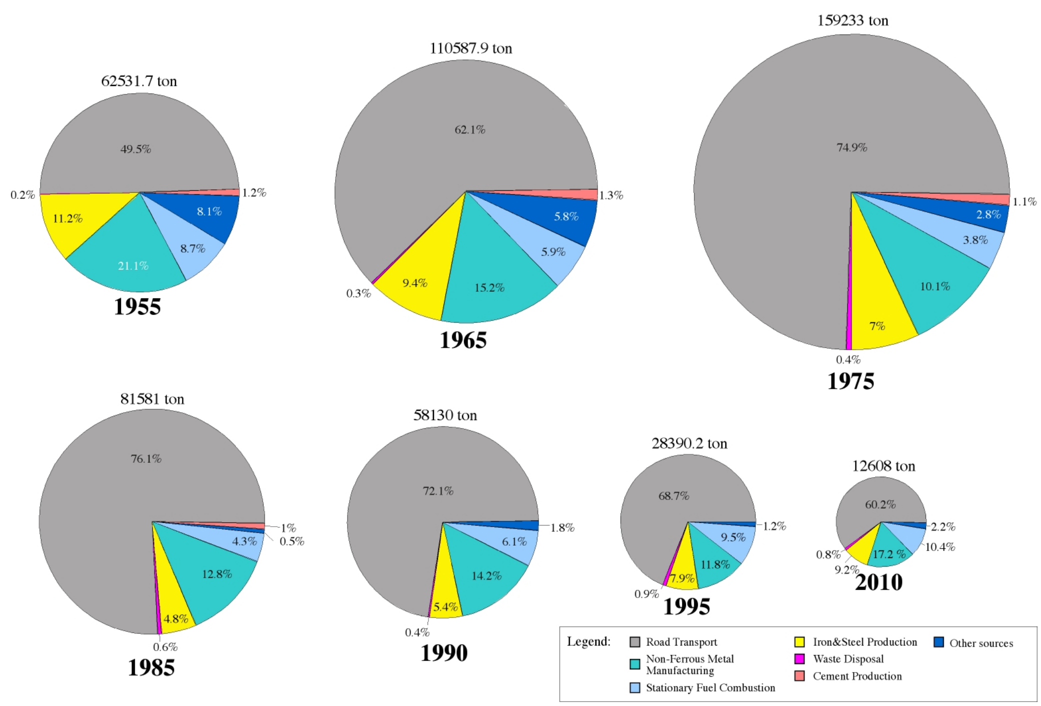
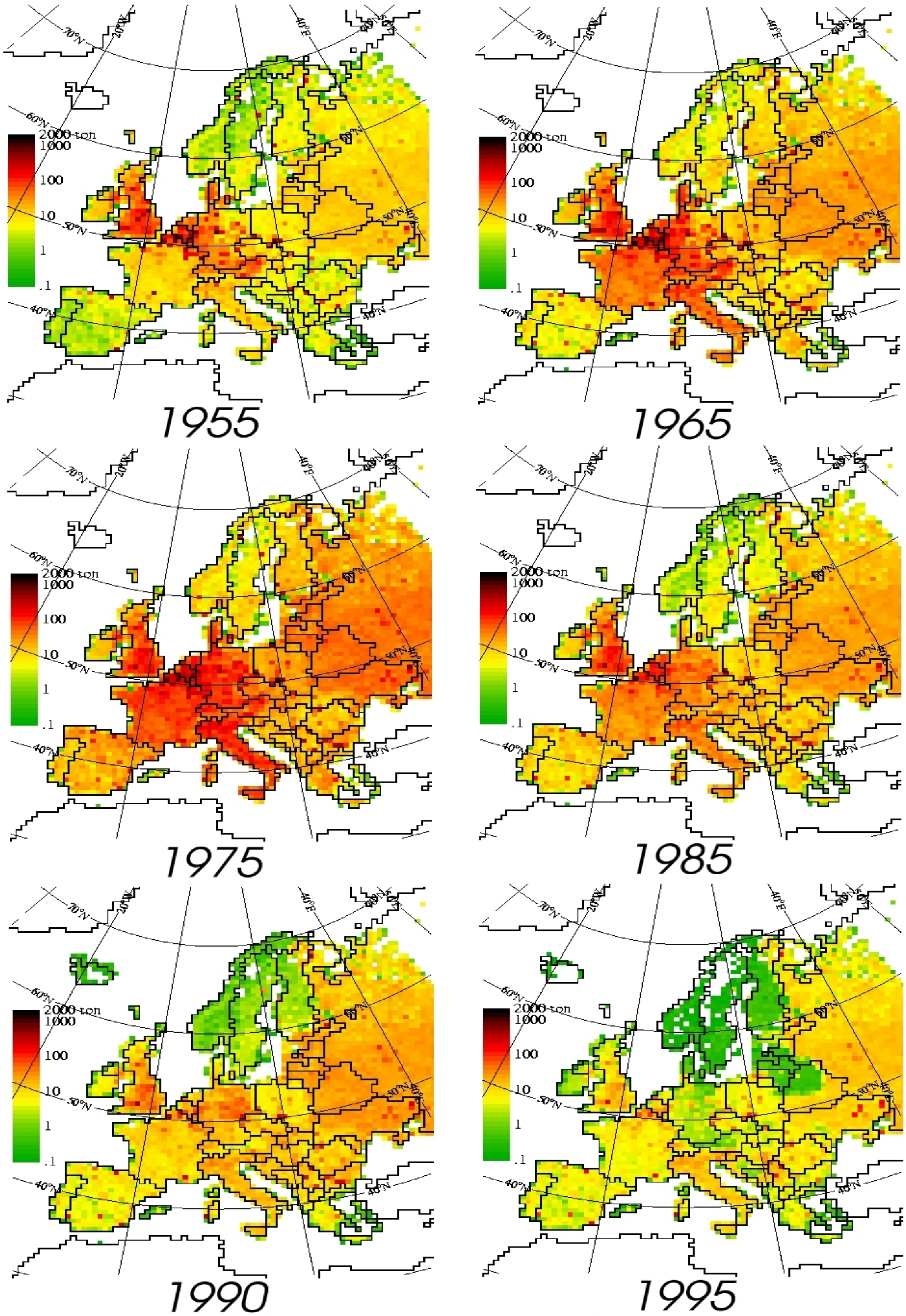


Figure 1: Annual gasoline sales and lead emissions in Germany. Volume of gasoline sold (millions of litres per year; solid) and of leaded gas (after 1985; grey-dashed); amount of lead added to the gasolines (in tons; dotted). From Hagner (2000)

Figure 2 (overleaf): Pacyna and Pacyna's (1999) estimates of European emissions of lead (in tons per pixel of 50x50 km^2) from road traffic and a number of industrial processes (see Figure 3) for the years 1955, 1965, 1975, 1985, 1990 and 1995

Figure 3: Relative contribution to lead emissions in Europe by road traffic and industrial processes. Based on the data of Pacyna and Pacyna (1999).





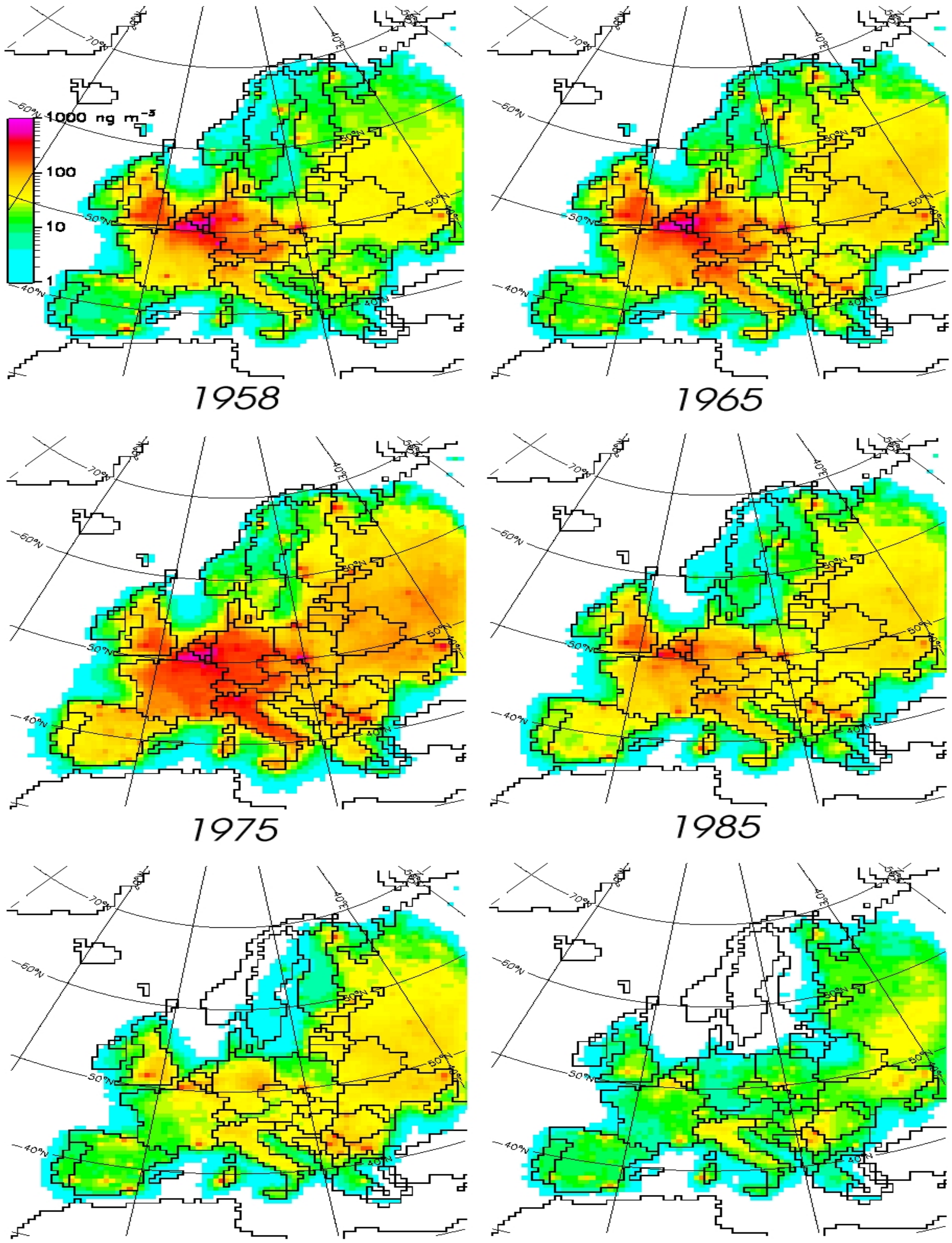
Atmospheric lead emission rates

A breakdown of the different sources is offered in Figure 3. The size of the pies is proportional to the total European emissions, showing a rise until 1975 and a subsequent fall. In the 1950s traffic contributed with about 50%, which increased to 75% in 1985. In 1995 traffic emissions still accounted for about 70% of the now lower total emissions. The second largest contributor was, and still is, non-ferrous metal manufacturing (10-20%). Stationary fuel combustion and iron and steel production contribute both of the order of 10%.

The German government was the first in Europe to regulate lead in gasoline. A maximum gasoline content was imposed in Germany in 1972, equal to 0.4 g Pb/l, which in 1976 was lowered to 0.15 g Pb/l. At the European level, the Council of Europe passed a law that reduced lead additives in gasoline from July 1978 onward. Thereafter it was forbidden for all EU-member states to produce, import or sell gasoline with more than 0.4 g Pb/l (Hagner, 2001). In the 1980s, the discussion about air pollution in Europe was mainly focussed on the reduction of Nitrogen oxides (NOx), Carbonmonooxides (CO) and Hydrocarbons (CxHy), reflecting concerns about widespread damage to forests. It was assumed that the damage to forests was caused not only by acid rain but also by NOx and the photo-oxidation of various chemicals, of which automobiles were the major source. Based on these concerns, Germany, in 1984, was the first European country to draft a law for further reductions of total automobile emissions. This law also included the introduction of unleaded gasoline because the largest reductions NOx, CO, CxHy and other pollutants could be realized with catalysts that were adverse to lead. It was not until 1985 that the EU mandated the member states to offer unleaded gas after October 1989, and recommended a maximum lead content of 0.15 g Pb/l.

In Germany, these gasoline lead content reductions affected particularly the mineral oil and automobile industries. Despite concerns by the mineral oil industry that its production costs might increase following the first regulation in 1972, ist turned out its costs actually dropped thanks to savings in lead additives. After the second regulation in 1976, however, gasoline production costs did indeed rise. New additives with high octane numbers were now required for maintaining gasoline performance. In either case, none of the anticipated bottlenecks in gasoline supply occurred (Hagner 2000).

The impacts of the introduction of unleaded gasoline in 1985 were more complex. The competition among gasoline distributors and car producers was seemingly affected, even though this effect is hard to document because of other changes taking place at the same time. There were technical implications for both industries as well: gasoline stations needed an extra pump for the new unleaded variety, and cars needed a catalytic converter. Installation of the new pump posed a higher financial strain for the independent traders than for the large international companies. The independent traders, usually middle-class firms, seem to have suffered some economic setbacks, as the supply with unleaded gasoline was difficult. Favorable terms of competition were experienced by producers of cars with high technical standards, who had already gained experience with catalyst systems on the U.S.-market. However, the additional costs for the catalytic converters soon declined, so that the effect seems not have had long lasting effects on the market (Hagner 2000).



Mean annual Pb air concentration

Figure 4 (overleaf): Simulated annual mean lead concentrations in the planetary boundary layer

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Reconstructing atmospheric pathways

Atmospheric lead is bound to suspended matter and can be transported by wind over a long distance. Thus, the transport across Europe can be modeled with an atmospheric transport model. Lead is considered a passive tracer, which is removed from the air by dry and wet deposition.

Lead concentrations and depositions over Europe were computed by the two-dimensional Lagrangian model TUBES (Costa-Cabral 2001), using 6 hourly high-resolution weather analyses and the lead emission estimates presented above after suitable temporal interpolation. It is assumed that lead remains within the well-mixed planetary boundary layer, where it is horizontally advected by wind and deposited to the surface through precipitation and turbulent transport.

For running a model of atmospheric lead transport regional weather information are required. Homogeneous global weather analyses available since 1958 from the US National Center for Environmental Prediction (NCEP) were considered too coarse for spatially detailed particle transport modelling. Therefore a regional atmospheric model was used to "downscale" 1958-1998 NCEP re-analysis to a 50 km grid covering all of Europe (Feser et al. 2001).

As a result of the modeling exercise, spatially and temporally complete 6-hourly maps of lead concentrations covering all of Europe became available.

As an example, annual mean concentrations are displayed in Figure 4. Not surprisingly, the annual lead concentrations in Europe increased sharply until about 1975 and diminished substantially by 1985 and 1995. Only local maxima in Southern England and the industrial areas of Belgium, Germany, Northern Italy, Ukraine and Russian Federation remained (Costa-Cabral 2001). The lead deposition in Europe shows the same development of spatial and temporal patterns as the lead concentrations (not shown)

To validate the model results they were compared with local measurements of lead concentration in the air and lead depositions. This approach is of limited values, mainly because of the short length of the observation records as well as the problem of point observations versus areal averages. However, accumulations of lead in peat bogs are a good candidate to compare the model output with (as long as the site of the bog is not too much affected by local topography). In peat bogs little vertical mixing takes place so that it is an almost perfect archive for lead depositions.

We have used a core drilled on Fyn, Denmark (Goodsite et a., 2001), which provides good estimates on time scales of a year and longer (Figure 5). The general pattern of deposition since 1960 is very well reproduced by the model, even if the model is underestimating the depositions by up to 0.5 • g cm^{-2} yr^{-1}. This deviation is well within the level of uncertainty common in such substance transport modeling efforts.

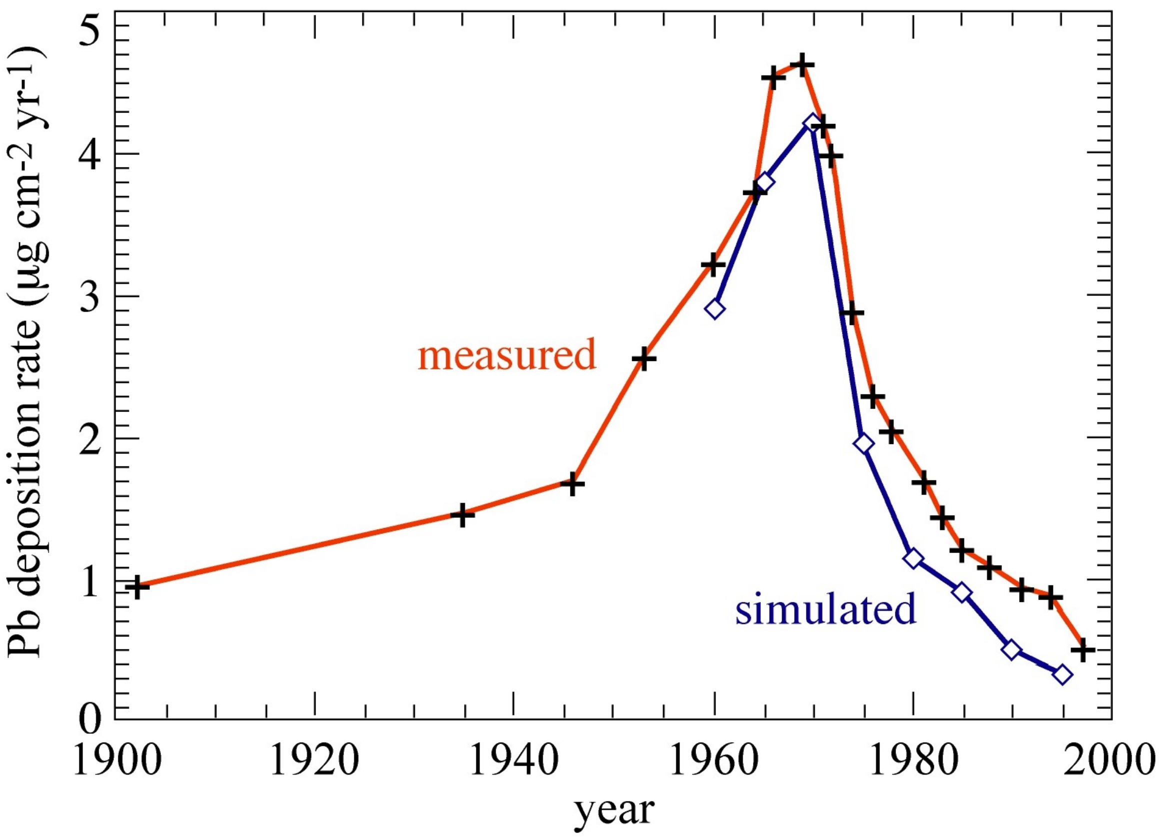


Figure 5: Lead deposition on a peat bog on Fyn, Denmark (crosses; Goodsite et al., 2001) and simulated depositions.

The simulated data may be used to assess how much lead emitted in one country ends up deposited in another country. The results indicate that most depositions in a country originates from its own emissions. Only smaller countries like Switzerland or the Netherlands have suffered substantial depositions from neighboring states (Costa-Cabral 2001): 20% of the Swiss depositions come from France, and 21% of the Dutch emissions from Belgium.

As an example we briefly discuss the depositions into the Baltic Sea. According to the modeled data, 23% of the total depositions over the Baltic Sea originates from Poland, 20% from Germany, 16% from Finland 12% from Sweden, 9% from the Russian Federation, 5% from Denmark and 1% from Norway. All other countries contribute less than 1%. In Figure 6, the temporal evolution of the depositions are shown. The input peaked in the mid 1970s, with 3500 tons annually, and has since then declined to less than 500 tons in 1995. The simulated data compare fine with comprehensive analyses based upon observational evidence in the second half of the 1980s.

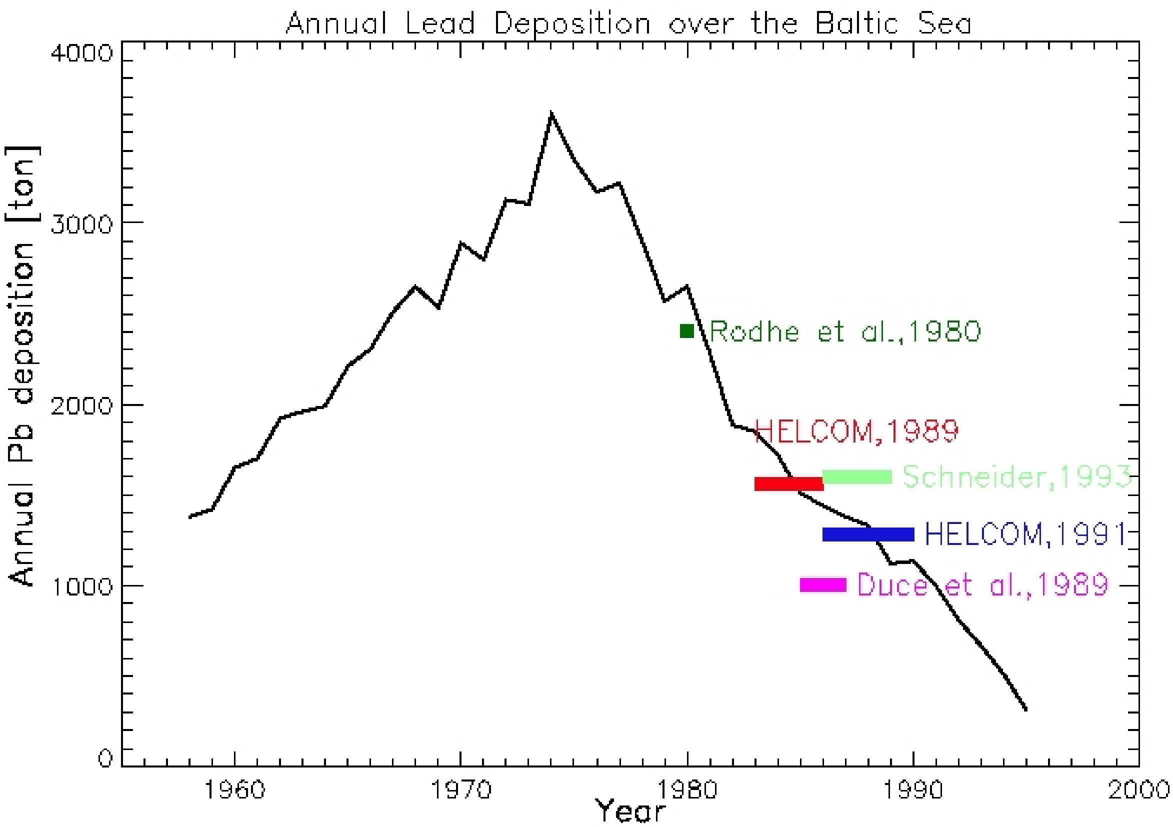


Figure 6: Simulated input of lead into the Baltic Sea (line) and estimates based on comprehensive analyses of observational data.

Environmental impact

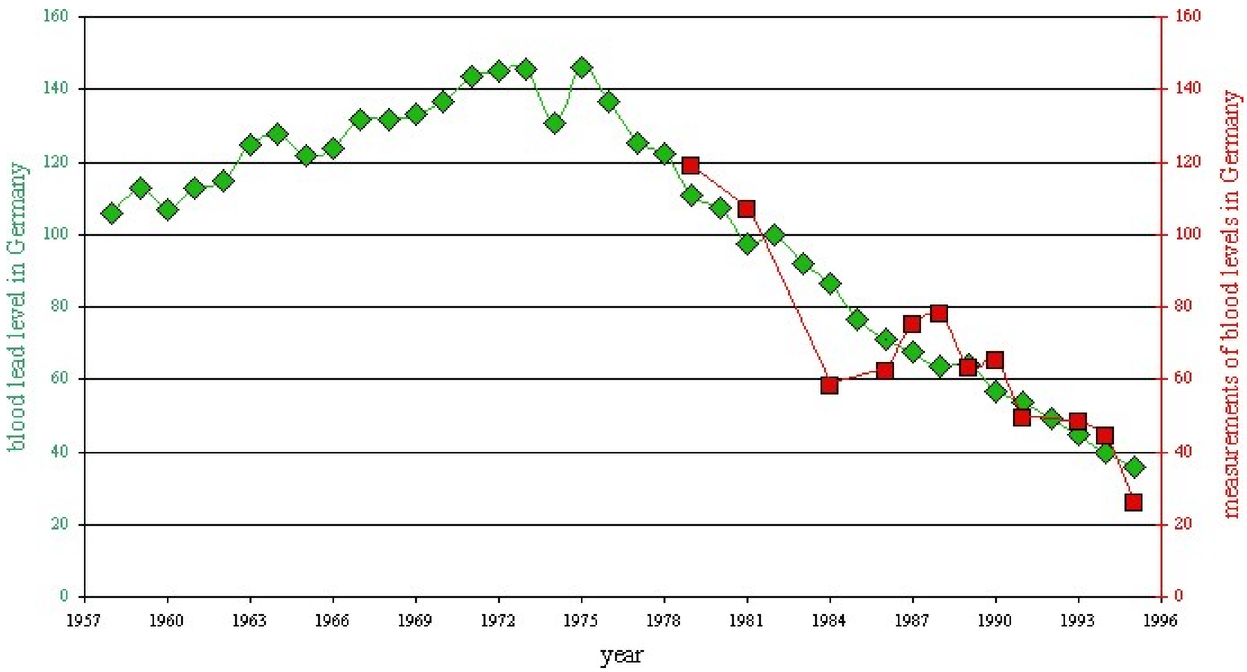
Has the reduction of lead emissions caused a reduction of lead levels in environmental systems? Measurements of lead concentration in the atmosphere in Germany in the 1980s and 1990s showed that the lead levels were significantly higher in urban than in rural areas, caused mainly by automobile traffic. Over this time the aerial lead concentrations were halved in both areas in 4,5 years (Hagner 2000).

The same trend could be observed in plants. In the years 1985 - 1996 the lead levels of annual spruce sprouts and poplar leaves in Germany decreased significantly. But in aquatic organisms the pollution trend was quite different. Measurements of lead concentrations in blue mussels and fish in the North Sea documented that the lead loads did not diminish since the 1980s but had a high variability around a constant level. The different response of terrestrial and aquatic organisms to declining lead emissions is likely caused by their intake mechanism. While plants take in lead mainly from the atmosphere, mussels and fish are mainly influenced by the long-term accumulation of lead in sediments (Hagner 2001).

In the years 1979 - 1997 the blood lead level in humans in Germany was measured by several studies. The results confirmed the opinion of medical experts that in that period the lead concentrations in the German population were too low to cause acute health hazards.

In Figure 7 the blood lead levels were crudely estimated back until 1958 using the recorded lead concentrations in human adults blood (in red) and the simulated aerial lead concentrations in one grid box . The estimated blood levels (green) reached in the early 1970s a peak level of about 150 μg Pb/l.

Figure 7: Recorded (red) and estimated (green) lead concentration in human adult blood (red) .



How realistic this value is remains to be seen. But it is interesting to speculate what such values may have meant. First, the estimated value is an average value, so that half of the adults may have had concentrations above 150 μg Pb/l, and the other half below that level. The mean value of 150 μg Pb/l is below the German threshold of 250μg Pb/l, above which health risks for adults were expected (Hagner 2000). However, a critical value of 150 μg Pb/l was adopted for the mothers of unborn children. That is, it is likely that the concentrations of air in the ambient air in the mid 1970s may have been high enough to raise serious medical concerns. Interestingly, American researchers believe that the intellectual development of children is already disturbed at a blood lead level of 100 μg Pb/l.

Conclusion and Outlook

The atmosphere and the environment in general will remain for the foreseeable future a dump for various anthropogenic substances. Some of these substances will have negative properties so that society will sooner or later begin regulating the emissions of such substances. For doing so, science has to provide society with the tools to assess the situation in the past and to evaluate the possible impacts regulations may have. We have developed such a tool, made up of a detailed emission chronology, a regionalized history of weather events and a transport model. In the future this tool needs to be completed by a model describing the transport, transformations and depositions in catchments and rivers.

This tool has been applied to airborne lead originating mostly from road traffic. We have chosen lead for two reasons. First, lead emissions underwent significant changes, from an almost unabated increase to a series of sometimes drastic reductions. Thus, there is a well defined signal to be detected and described. Second, lead behaves during its aerial transport to first order approximation inert, so that the simulation of the transport and the deposition is relatively simple, as opposed to chemically active substances like mercury or persistent organic pollutants (POPs).

We have demonstrated that for the case of lead our tool is functioning well. It remains to be seen if the success can be repeated with other airborne substances, like radioactive substances, POPs, or pollen.

Our modelled data show that lead concentrations increased heavily until the 1970s. Later the atmospheric concentrations fell strongly, quite consistently with the sparse observational evidence, mainly because of the reduced lead content in gasoline. As a consequence the lead levels in organisms declined for those that take in lead from the atmosphere like terrestrial plants and humans. But in aquatic organisms the lead concentrations remained at a constant level. The economic impacts of the lead reduction in gasoline were insignificant. Except for some short-term effects it hardly burdened the economy. All in all, the lead reduction policies in Europe may be considered a successful example of environmental policy.

However , the success of lead policies in protecting biological systems from lead exposure was limited to atmospheric pathways, underscoring that a low residence time is a necessary condition for substance abatement through emission regulations in a given environmental compartment once considerable substance amounts have already been released. For those anthropogenic substances of long environmental persistence, that are subject to bio-acumulation, and whose main route of human exposure is the food chain, late emission regulations may be ineffective in protecting human health. In such cases, the principle of prevention, by which any significant releases should be precluded from the start, may be the most appropriate.

One should, however, not forget that the large amounts of lead emitted in the past 50 years have not simply vanished but reside now for good ubiquitously in the environment. The use of lead in gasoline was indeed large-scale geophysical pollution exercise, and it remains to be seen if there may show up some long-term effects at a later time. Also this insight may serve as a valuable lesson from the study of the history of lead emissions.

An interesting aspect not covered systematically so far concerns the public debate and reasoning about the reduction of lead in gasoline. As part of the project, a quantitative and qualitative content analysis of European Media has begun. The print coverage of several German, French and British media is studied. First results indicate that the German press goes back to the 1960s, mentioning the health danger caused by leaded gasoline. British articles about the “Menace in the Air” (The Times, July 31st 1970) do not treat lead as danger, but focus on smog problems in big cities. The French government’s group of experts did not see any danger in lead and car emissions in general. The second part of European debates about leaded gasoline took place in the early 1980s, when once again Germany started to care about its ‘German Forest’ dying due to acid rain mainly caused by car emissions. To reduce these emissions, the only solution seemed to be the catalytic converter. Especially the French press mocked the German fear by showing ‘facts’ that the “Waldsterben” was only found due to statistical errors (Le Monde, March 28th 1985). The British strategy can be divided into a first phase of fostering the European efforts for the catalytic converter (until summer 1985) and a second phase when the British government blocked any decision to be taken of the EU. According to the media reports, both, French and British government mistrusted the Germans fearing the negative impact of the introduction of catalytic converters to their automotiv industries producing mostly small and cheap cars. The French car manufacturers even assumed that the Germans were saying “forest and meaning Mercedes” (SZ, February 7th 1986). In general, the press coverage of the 1980s centers the economic problems of the industry and the European troubles finding a compromise. The health risks are published, to a certain degree, in Germany, only.

For further information refer to: http://w3g.gkss.de/staff/blei.

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