Integrated assessment of past European gasoline-lead policies (1958-1995)

Hans von Storch, Charlotte Hagner, Mariza Costa-Cabral, Frauke Feser
Institute for Coastal Research, GKSS Research Center, Geesthacht, Germany

Józef Pacyna and Elisabeth Pacyna
Center for Ecological Economics, Norwegian Institute for Air Research, Norway

Steffen Kolb
Institute for Journalism and Communication Research, University of Hamburg, Germany

Introduction

The atmosphere and the environment in general will remain for the foreseeable future as a dump for various anthropogenic substances. Some substances will have negative properties so that society will sooner or later begin regulating their emissions. To that end, science must provide society with the tools for the retrospective evaluation of the physical and economical impacts of past regulations, and for the predictive evaluation of alternative scenarios of future regulations.

We have developed such a tool for reconstructing past lead air concentrations and depositions across Europe (1958-1995), made up of a detailed emissions, a regionalized history of weather events (with the help of a regional climate model using NCEP re-analyses as input), and an atmospheric transport model.

We used this tool in conjunction with lead measurements in biota and human blood, and with economic analysis to assess past European gasoline-lead regulations. Some of the specific questions asked were: How did lead emissions, atmospheric concentrations and depositions develop since the 1950s? Was the decline in air concentrations matched by corresponding declines in plants, animals and humans? Did the regulations result in considerable economic burdens in Germany (as an example)?

We have chosen lead for several reasons. First, lead emissions underwent significant changes, from an unabated increase to a series of sometimes drastic reductions since the 1970s. Thus, there is a strong and well-defined signal to be detected. Second, once released into the atmosphere, lead will accumulate and persist indefinitely in some environmental compartments, such as aquatic sediments. What might the ecological and human health impacts be of this neurotoxin's environmental distribution? Finally, airborne lead behaves to a first order approximation as inert, so that the simulation of its transport and deposition is relatively simple. In principle, our tool can be used for any other particle-bound substance of limited reactivity.

It turns out that this approach is successful in describing the temporal evolution of the spatial distribution of lead deposition in Europe. Demonstrating the effectiveness of gasoline-lead policies, the reconstructed concentrations in the atmosphere, in plant leaves, and in human blood show a steady decline since the early 1980s, while concentrations in marine organisms along the North Sea coast, however, seem to remain so far unaffected. Contrary to initial expectations, the German mineral oil industry was not negatively affected. While competition conditions changed in the German gasoline and automobile markets, no impacts of the regulations could be identified in the macro-economic indicators.

Gasoline-lead regulations in Europe

Air pollution problems introduced by automobile traffic in the 1960s, of which the most visible was urban smog, were addressed in the US by the 1963 Clean Air Act. In Europe, concern with the resulting risks to human health would only gain momentum in the 1970s. Lead in particular, added to gasoline for its anti-knock properties, was perceived as a health threat at this time, given new evidence of its neurotoxicological effects of especial severity to children. After lead-based paint and lead solder in water pipes and food cans was prohibited, gasoline lead (tetraethyl and tetramethyl lead additives) became the next target.

In the 1970s, the German government was the first in Europe to regulate gasoline lead. A maximum content of 0.4 g Pb/l was imposed in Germany in 1972 (down from the usual 0.6 g Pb/l) and lowered further to 0.15 g Pb/l in 1976. A preliminary analysis of newspaper coverage found that the topic of gasoline lead health dangers entered the German press in the 1960s. British articles did not focus on lead but on urban smog instead. And in 1972, a group of experts of the French government did not acknowledge any automobile emissions to be dangerous (see von Storch et al., 2002). The European Union (EU) fixed its limit modestly at 0.4 g Pb/l starting only in 1981 (Council Directive 78/611/EEC of 1978) (Hagner, 2000).

In the 1980s, the discussion of automobile air pollution in Europe moved to concerns with forest protection from the effects of massive NOx, CO, and CxHy emissions. This discussion too was initiated by Germany, concerned with the death of the 'German Forest' from acid rain and photo-oxidation. In 1985 Germany passed a law to reduce total automobile emissions. This law included the introduction of unleaded gasoline because the largest reductions of NOx, CO, CxHy and other pollutants could be achieved with catalytic converters (already in use in the US) that were incompatible with lead. Opposing reactions from some European countries expressed in the media are briefly reviewed in von Storch et al. (2002). The 1980s press coverage emphasized the expected economic problems of the automobile industry and the European difficulty in finding a compromise solution.

Despite this opposition, in 1985 the EU mandated all member states to offer unleaded gasoline starting October 1989, and recommended a maximum of 0.15 g Pb/l. While some countries promptly adhered, others lagged behind (see Hagner, 2000). The Aarhus Treaty, signed in 1998 by nearly all European countries, stipulates the exclusive usage of unleaded gasoline by the year 2005.

Reconstructing atmospheric pathways

For running a model of atmospheric lead transport, regional weather information – wind speed and direction, precipitation rate and boundary layer depth – are required. Global weather analyses available from NCEP since 1958 at 2 ^{o} spatial resolution were considered too coarse, hence the regional atmospheric model REMO was used to "downscale" them to a 0.5 ^{o} grid (roughly, 50 km scale) covering all of Western Europe and parts of the North Atlantic (Feser et al. 2001).

The regional climate model is a grid-point model and uses a terrain-following hybrid coordinates system in the vertical direction. The physics scheme of the global model ECHAM4 was adapted to the higher resolution of 0.5 ^{o} and was then incorporated into the regional model. The prognostic variables are surface air pressure, horizontal wind components, temperature, specific humidity, and cloud water.

Emission estimates disaggregated to the 0.5^{o} grid were provided by Pacyna and Pacyna (2000) for 1955, 1965, 1975, 1985, 1990 and 1995. Figure 1 shows the yearly totals, peaking at nearly 160,000 tons in 1975, and shows the predominance of automobile emissions. The sharp decrease since the 1970s resulted from the gasoline-lead regulations as well as from abatement of fixed-source lead emissions (industrial and others).

Using these emission estimates and the regionalized atmospheric forcing, lead concentrations and depositions over Europe were computed by the two-dimensional Lagrangian model TUBES (Costa-Cabral 2001), using a 6-hourly time step and 0.5^{o} spatial resolution. A feature of this model is that flow tubes of variable width are used instead of the commonly used linear trajectories. It was assumed that lead remains within the well-mixed planetary boundary layer, where it is horizontally advected by wind and deposited to the surface by turbulent transport and precipitation scavenging. The dry settling velocity used was 0.2 cm s^{-1} and the precipitation scavenging constant used was 5x10^{5}.

To validate the model results they were compared with local measurements of lead concentrations and depositions by EMEP (von Storch et al., 2002). Also accumulations of lead in peat bogs are a good candidate to compare the model output with (Figure 2). The general pattern of deposition since 1960 is very well reproduced by the model.

Simulation results indicate that most of the deposition in a country originates from its own emissions. Only smaller countries like Switzerland or the Netherlands have suffered substantial depositions from neighboring states (von Storch et al., 2002). For the Baltic Sea, 23% of total depositions originate from Poland, 20% from Germany, and 16% from Finland. The total input peaked in the mid-1970s, surpassing 3,500 tons annually, and declined to under 500 tons in 1995 (Figure 3). Simulations compare favorably with comprehensive analyses based on observational evidence in the second half of the 1980s (Figure 3).

Some environmental and economical impacts

Measurements in Germany in the 1980s and 1990s showed that atmospheric lead concentrations were halved about every 4.5 years (Hagner 2000). The same trend could be observed in plants, such as in the decline in 1985-1996 in lead levels in annual spruce needles and poplar leaves in Germany. But in marine organisms, such as mussels and fish in the German Wadden Sea, for example, lead levels have not diminished since the 1980s (Hagner 2001).

In 1979 – 1997, the human blood lead levels in Germany was measured by several studies. Levels always remained below those indicated by medical experts as hazardous for adults. In Figure 4 the blood lead levels are 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 (in green) reached in the early 1970s a peak level of about 150 µg Pb/l. This estimate is an average value, so that some adults may have had concentrations well above 150 µg Pb/l. The mean value of 150 µg Pb/l is below the German Human Biomonitoring Commission threshold of 250 µg Pb/l, above which health risks for adults are expected (Hagner 2000). However, a critical value of 150 µg Pb/l was adopted for pregnant women and for children. That is, it appears likely that the lead concentrations 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.

What about the most immediate economical impacts of the regulations? Despite concerns by the German mineral oil industry that gasoline production costs might increase following the first regulation in 1972, it turned out its costs actually dropped thanks to savings in lead additives. Only after the second regulation in 1976 did production costs indeed rise because new additives with high octane numbers were now required for maintaining gasoline performance (Hagner, 2000).

The impacts of introducing unleaded gasoline in 1985 were more complex. Tax incentives for unleaded gasoline and for low-emission cars increased sales of both. Most independent gasoline traders went bankrupt, as gas-station reconstruction represented a higher financial strain for them than for the large international companies. Automobile manufacturers Daimler-Benz — whose motors were easily compatible with catalysts, and whose customer demand was inelastic —, and VW — who offered a long array of catalyst-equipped cars — were greatly benefited. Favorable terms of competition were experienced by car manufacturers with the highest technical standards, who had already gathered experience with catalyst systems on the U.S. market (Hagner, 2000).

Aside from these shifts in market competition conditions, no significant impact could be seen in German macro-economic indicators including gross national product, economic growth, price stability, unemployment level, or foreign trade balance.

Conclusion and outlook

We have developed a tool for a reconstruction of past lead air concentrations and depositions across Europe. With the help of regionalized atmospheric data, spatially disaggregated lead emissions from road traffic and point sources, and various local data, an attempt was made to reconstruct the airborne pathways and deposition of gasoline lead in Europe since 1958. We have also analyzed trends in concentrations in biota and human blood, and evaluated the most direct economic impacts of gasoline-lead regulations.

We have demonstrated that for the case of lead our tool is functioning well. Our modeled data show that European gasoline-lead reduction regulations may be considered a successful example of environmental policy. However, the success of lead policies was limited to atmospheric pathways, having had little effect on some marine biota, underscoring the fact 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-accumulation, 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 are precluded from the start, may be 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 global environment. The use of lead in gasoline was indeed a large-scale geophysical pollution exercise, and it remains to be seen if long-term effects may emerge at a later time.

In the future, the modeling system needs to be extended by modules, describing the transport in river catchments and channels, substance transformations, depositions and resuspension, and the interactions with the ecosystems. Furthermore, we want to apply our methodology to other substances. Candidates are Persistent Organic Pollutants, radioactive substances and pollens, among others. Because of the increased complexity with respect to such substances, in particular concerning chemical transformations, cooperation partners are sought.

For further information refer to: http://w3g.gkss.de/staff/blei. The annual emissions, and modeled concentrations and depositions data are available for download from a link on this page.

References

Costa-Cabral, M. C., (2001): Reconstruction of Atmospheric Lead Fluxes in Europe Over Four Decades (1958-1995). Part I: The TUBES model of long-range tracer transport and deposition. Part II: Results, submitted 2001.

Feser, F.; R. Weisse; H. von Storch (2001): Multi-Decadal Atmospheric Modeling for Europe Yields Multi-purpose Data. Eos, American Geophysical Union, 82 (28): 305-310.

Goodsite, M. E., W. Rom, J. Heinemeier, T. Lange, S . Ooi, P.G. Appleby, W. Shotyk, W. O. van der Knaap, C. Lohse, and T. S. Hansen (2001): High Resolution AMS 14C Dating of Post -Bomb Peat Archives of Atmospheric Pollutants, in Proceedings of the 17th International 14C Conference, Edited by I. Carmi and E. Boaretto, Radiocarbo n 43(3): 453-473.

Hagner, C. (2000): European Regulations to Reduce Lead Emissions from Automobiles - Did they have an Economic Impact on the German Gasoline and Automobile Markets ?. Regional Environmental Change, 3-4 : 135-151.

Hagner, C. (2001): Regional and Long-Term Patterns of Lead Concentrations in Riverine, Marine and Terrestrial Systems and Humans in Northwest Europe. Water, Air and Soil Pollution, 134: 1 - 39.

Pacyna, J. M., and E. G. Pacyna (2000): Atmospheric Emissions of Anthropogenic Lead in Europe: Improvements, Updates, Historical Data and Projections. GKSS Report 200 0/31, GKSS Research Center.

Von Storch, H., M. Costa-Cabral, C. Hagner, F. Feser, J. Pacyna and E. Pacyna (submitted, 2002): Four Decades of Gasoline Le ad Emissions and Control Policies in Europe: A Retrospective Assessment.

Figures

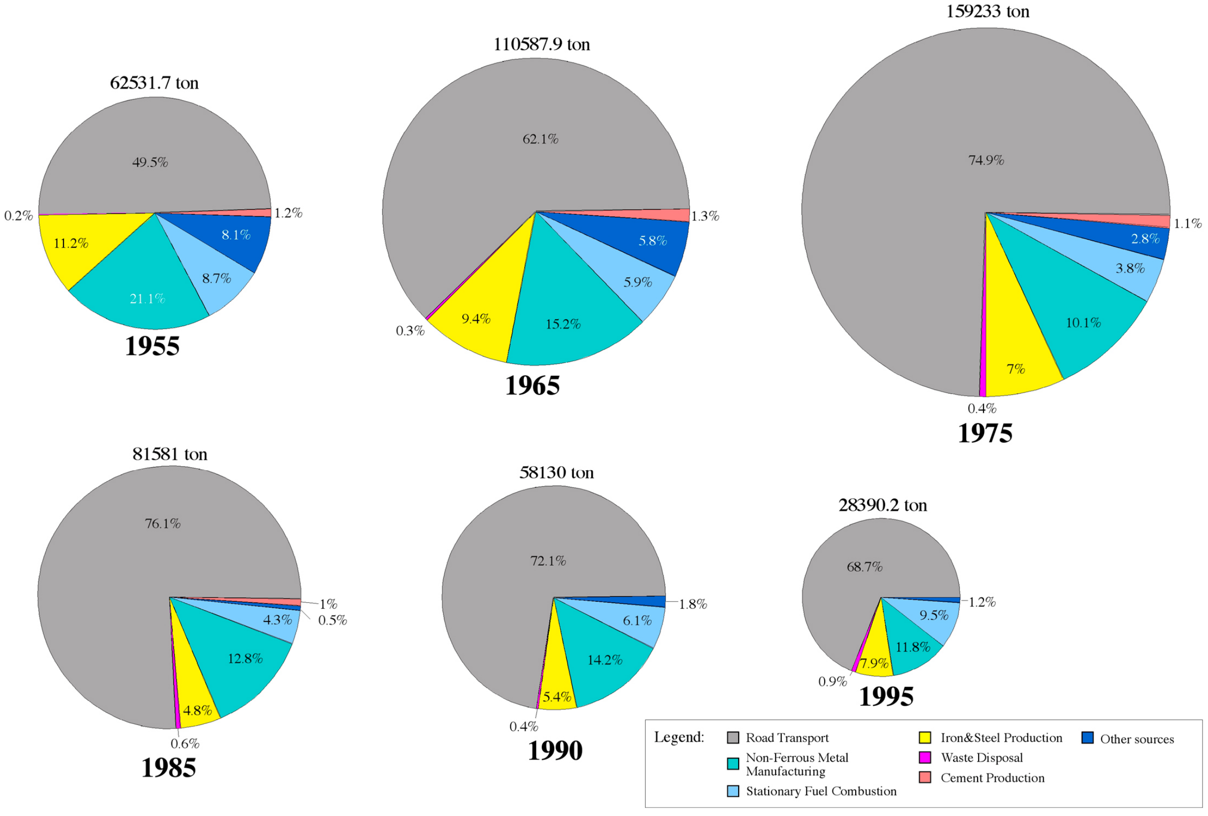

Figure 1: European lead emissions estimates by source category (from Pacyna and Pacyna, 2000).

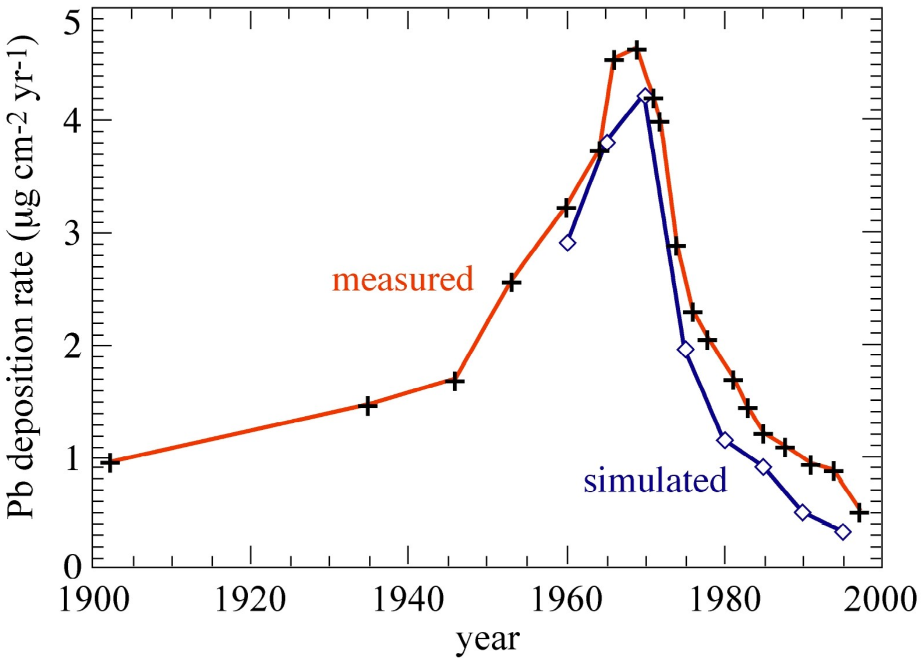

Figure 2: Lead deposition on a peat bog in Denmark (crosses; Goodsite et al., 2001), and simulated depositions.

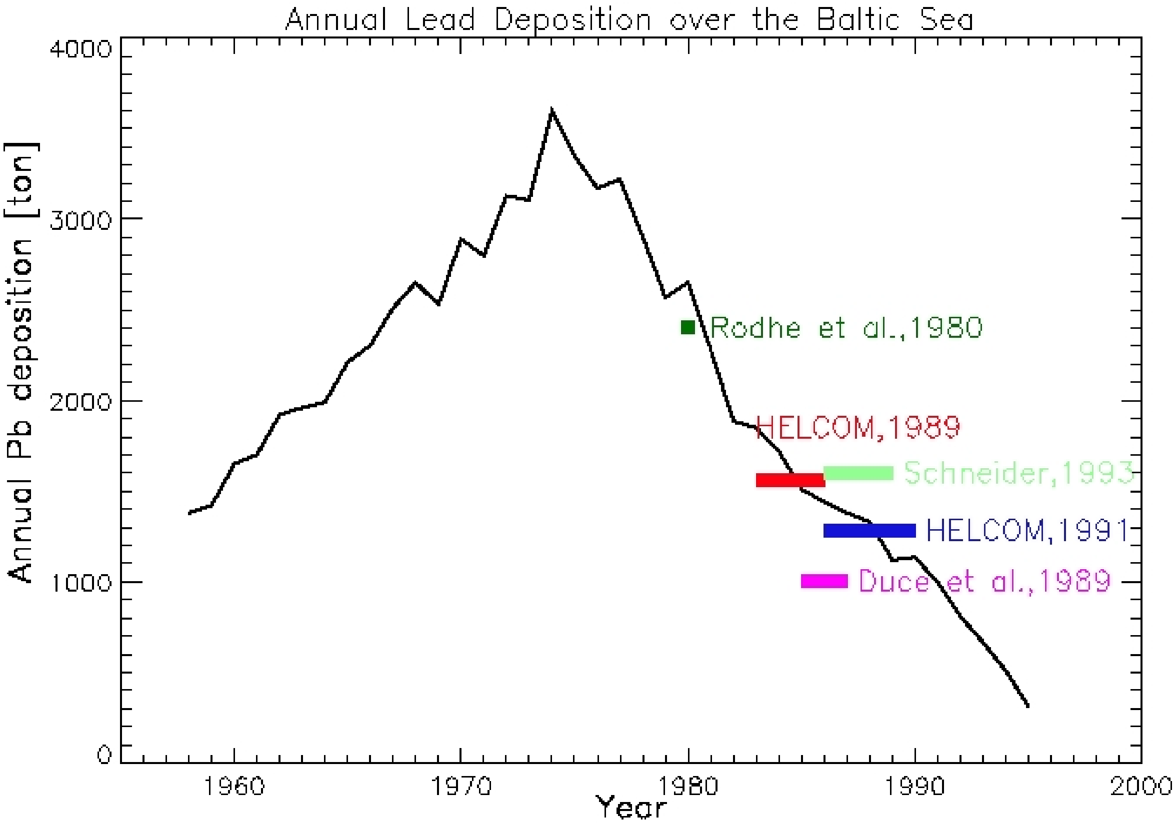

Figure 3: Simulated input of lead into the Baltic Sea (line) and estimates based on comprehensive analyses of observational data (colored bars).

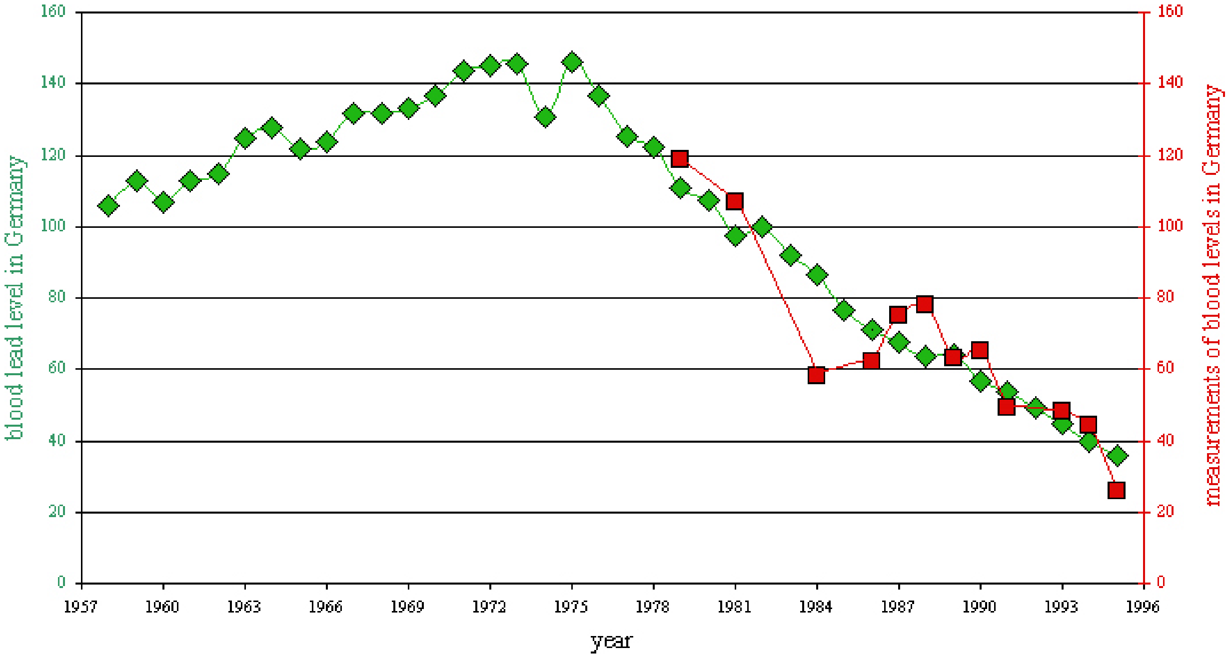

Figure 4: Recorded (red) and estimated (green) lead concentration in adult human blood in Germany.