Curbing the omnipresence of lead in the European environment since the 1970s – a successful example of efficient environmental policy[1]

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Abstract

The emission and deposition of gasoline lead since the 1950s resulted in global scale anthropogenic pollution. In Europe and North America, emissions have successfully been curbed by gasoline lead content regulations, while in Asia, Africa and South America emissions are ongoing. We have done a retrospective analysis of the environmental and economic implications of lead regulations in Europe. With the help of a regional climate model, global weather 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, spatial distribution of gasoline lead deposition. Demonstrating the success of lead policies, the concentrations in leaves and human blood have steadily declined since the early 1980s, while concentrations in marine organisms along the North Sea coast seem unaffected.

1. Introduction

The atmosphere and the environment in general will remain for the foreseeable future to serve 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 global weather re-analyses as input), and an atmospheric transport model (for a summary, refer to von Storch et al., 2002, 2003).

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? How was the media coverage of the issue of lead in gasoline?

We have chosen lead for several reasons. Lead, specifically tetraethyllead has been usef or a long time as an anti-knock in gasoline (cf., Berwick, 1987; Seyferth,

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[1]This article is an updated and extended version of: von Storch, H., C. Hagner, M. Costa-Cabral, F. Feser, J. Pacyna, E. Pacyna and S. Kolb, 2002: Reassessing past European gasoline lead policies, EOS 83, 393 + 399

2003) The usage of lead in gasoline underwent significant changes, from an unabated increase of emissions to a series of sometimes drastic reductions of emissions 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 almost 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 unaffected – at least until recently. 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.

While the lead pollution has successfully been curbed in Europe and North America, in many parts of the world, among others Africa, the problem persists.

2. Gasoline-lead regulations in Europe

Air pollution problems related by automobile traffic in the 1960s were addressed in the US by the 1963 Clean Air Act.[2] 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 (Kolb, 2005). 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

[2] Actually, the debate about the health implications of using lead in gasoline began already in the 1920s in the United States. An account of this exciting and sometimes harrowing history is provided by Kitmann (2000). See also Seyferth (2003).

of the ‘German Forest’ from acid rain and photo-oxidation (Kolb, 2005).[3] 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 reviewed by Kolb (2005; for a short English account refer to von Storch et al. (2003). The 1980s press coverage emphasized the expected economic problems of the automobile industry and the European difficulty in finding a compromise solution.

For Switzerland a detailed account of the socio-political process which led to the regulation of the usage of lead in gasoline is given by Breu et al. (2002) and Mosiman et al. (2002). A pan-European account fo the introduction of unleaded gasoline is offered by Berwick (1987).

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, stipulated the exclusive usage of unleaded gasoline by the year 2005.

3. Reconstructing regional pathways of lead

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 (Kalnay et al., 1996) 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).

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 a two-dimensional Lagrangian model (Costa-Cabral, 1999), using a 6-hourly time step and 0.5^o spatial resolution. 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 5×10^5.

To validate the model results, they were compared with local measurements of lead concentrations and depositions by EMEP (for details refer to von Storch et al., 2003). The general pattern of deposition since the beginning of the monitoring (mostly in the early 1980s) 1960 is very well reproduced by the model. The added

[3] The media coverage of the legal efforts to reduce the usage of lead as an antiknock in gasoline is covered by Steffen Kolb in another contribution to this volume.

value provided by the model is the complete space-time coverage, and the extension for two decades (1960-1980) with hardly any observations.

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., 2003). For the Baltic Sea, for instance, 23% of total depositions originate from Poland, 20% from Germany, and 16% from Finland. According to our estimation, total input peaked in the mid-1970s, surpassing 3,500 tons annually, and declined to under 500 tons in 1995 (Figure 2). Simulations compare favorably with comprehensive analyses for the overall deposition of lead into the Baltic Sea based on observational evidence in the second half of the 1980s (Figure 2).

Schulte-Rentrop et al. (2005) extended the analysis – by simulating the overland transport of the lead after it has been deposited at the surface. They considered the catchment of the river Elbe, and described the transport into the river in terms of atmospheric deposition on the surface of the river, erosion and runoff. A major finding was that the flux of lead into the river diminished since the 1970s, but that the ongoing deposition, with decreasing rates since the 1970s, was associated with a steady accumulation of lead in the soil (see also Johansson et al., 2001). Accordingly, the soil released (via erosion and runoff) increasing amounts of lead into the river. Only the atmospheric depositions into the river decreased parallel to the decreasing atmospheric loads. The overall effect was, however, a reduction of the flux into the river (Figure 3).

4. 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 (Figure 4; Hagner 2001).

In 1979 – 1997, the human blood lead levels in Germany were measured by several studies (Hagner, 2002). During this period, levels always remained below those indicated by medical experts as hazardous for adults. In Figure 5 blood lead levels are crudely estimated back until 1958. To do so a regression-type model was constricted using the recorded lead concentrations in human adults blood and the simulated aerial lead concentrations in one grid box (von Storch and Hagner, 2004). Available were not only sample mean concentrations (i.e., mean values across a sample of many people) but also 90 and 95%iles, so that 10% (or 5%) of all people have lead concentrations in their blood above the 90%ile (95%ile), whereas 90% (95%) have levels below that number. In Figure 5, colored backgrounds indicate critical levels as stipulated by the German Human Biomonitoring Commission. For levels above 250 μg Pb/l health risks for adults are expected, and for levels above 150 μg Pb/l monitoring is advised (Hagner 2000). For pregnant women and for children, a critical value indicating health risks of 150 μg Pb/l was adopted.[4]

[4] Interestingly, some American researchers believe that the intellectual development of children is already disturbed at a blood lead level of 100 μg Pb/l.

The estimated mean blood levels reached in the early 1970s a peak level of about 150 μg Pb/l (von Storch and Hagner, 2004). 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 for half of the population. The 90%ile reached a level of 250 μg Pb/l, and the 95%ile a level of 300 μg Pb/l. Thus, 10% of the whole population was exposed to a serious health risk in the early 1970s.[5] After that the levels diminished and have now reached much lower levels, well below the critical levels suggested by the Human Biomonitoring Commission. For an international comparison, refer to Thomas et al. (1999).

An assessment of the most immediate economical impacts of the regulations is a difficult task. Hagner's (2000) analysis indicates that despite concerns voiced by the German mineral oil industry that gasoline production would become costlier following the first regulation in 1972, its costs actually dropped thanks to savings in lead additives. Only after the second regulation in 1976 production costs rose somewhat 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. Many independent gasoline traders went bankrupt, as gas-station reconstruction represented a higher financial strain for them than for the large international companies. 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 detected in German macro-economic indicators including gross national product, economic growth, price stability, unemployment level, or foreign trade balance.

5. Conclusion and outlook

We have developed a tool for reconstructing 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 not the effect of lowering concentrations in some marine biota and on soil concentrations.

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

[5] At last for the site, where the blood monitoring was done – the city of Münster on North Rhine Westphalia.

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.

The major conclusion to be drawn from our analysis is that the regulation of the usage of lead as anti-knock in gasoline after two decades of unabated increase was mostly successful. The regulation solved the problem for the atmospheric pathway, and that part of the ecosystem, which essentially “passes through” the toxin in relatie short time. Thus, the relatively short 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 other parts of the ecosystem, which accumulate and store the toxin for an extended time, such a regulation is better than nothing but certainly insufficient. For such systems only the prevention from the pollution to develop will help.

The success of the environmental protection policy was mostly limited to the developed world (Figure 6, Thomas, 1995, Thomas et al., 1999; Thomas and Kwong, 2001). Almost everywhere in Africa as well as in the Near East, at least in the early 1990s, lead was still used in the early 2000s on a large scale as an anti-knock in gasoline – lead concentrations were mostly 0.3 g Pb/l and higher. For instance, Thomas et al. (1999) report about 0.39 g Pb/l in gasoline and 156 μg Pb/l in human blood for Caracas in 1991; in Mexico City numbers went down from 0.2 g Pb/l in gasoline and 122 μg Pb/l in human blood in 1988 to 0,06 g Pb/l in gasoline and 70 μg Pb/l in human blood in 1993. For Cape Town the latest numbers available to me aree form 1990 with 0.4 g Pb/l in gasoline and 72 μg Pb/l in human blood. In Egypt all gasoline had in 1994 lead in it, with 0.35 g Pb/l (Thomas, 1995); the same account reports of 0.66 g Pb/l in Nigeria (no year given) and 0.84 g Pb/l in Equador (in 1993). One would hope that the situation has improved in these countries.

Our methodology is presently extended to more “interesting” chemicals, in particular benzo(a)pyrene (Matthias et al., 2007; Aulinger et al., 2007).

6. Acknowledgements

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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.

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8. Figures

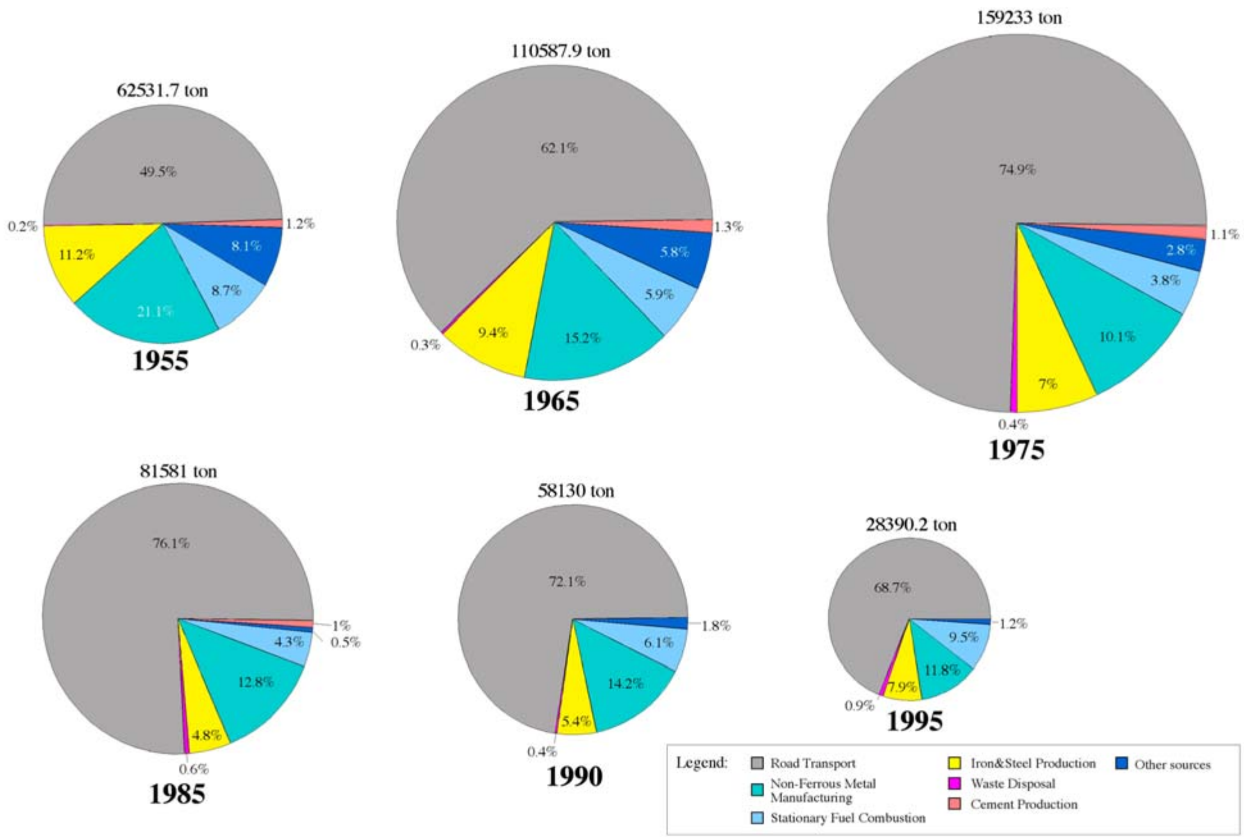


Figure 1: European lead emissions estimates by source category (from Pacyna and Pacyna, 2000).

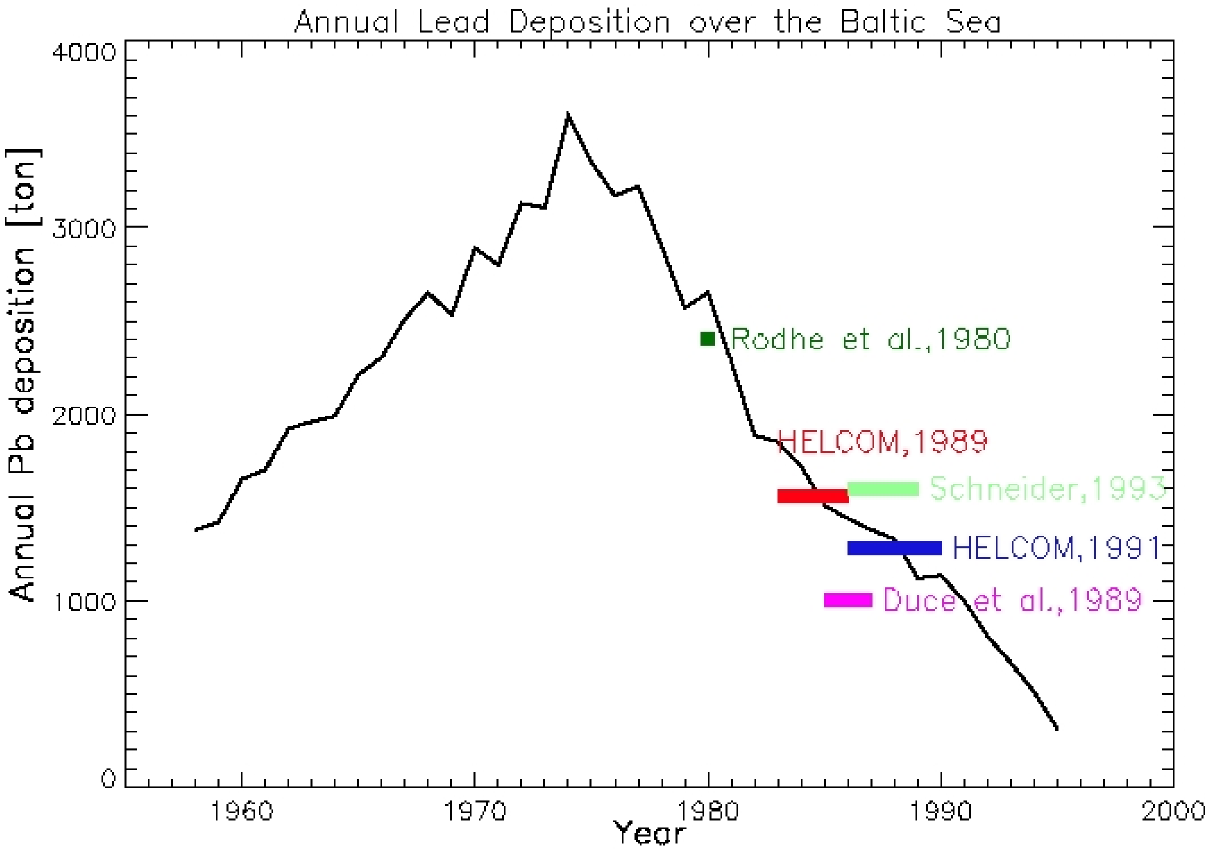
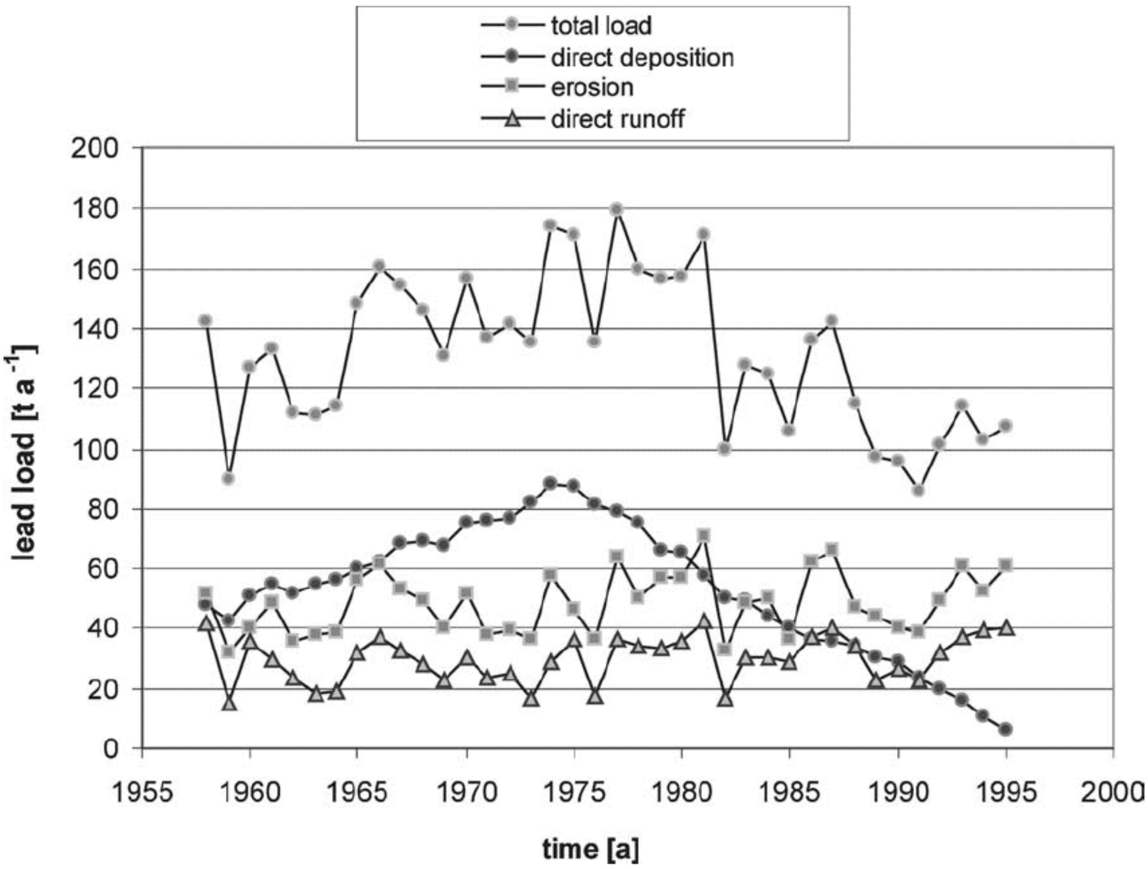


Figure 2: Simulated input of lead into the Baltic Sea (line) and estimates based on comprehensive analyses of observational data (colored bars) (von Storch et al., 2003)



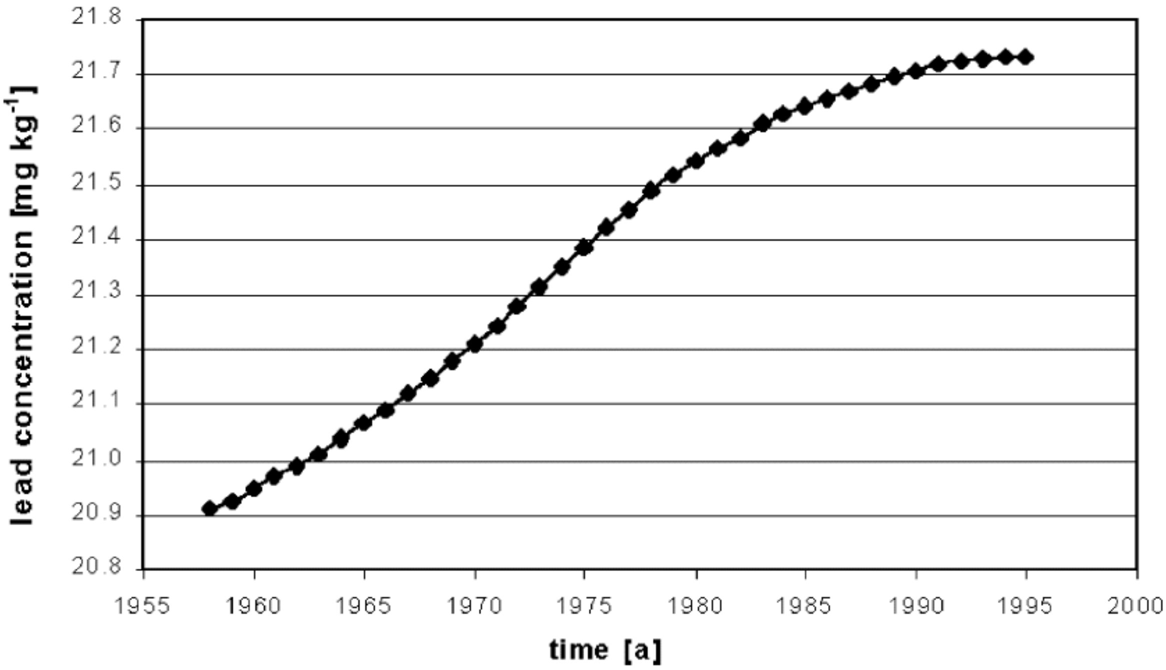


Figure 3: Transport of lead in the Elbe catchment (Schulte-Rentrop et al., 2005).
Top: Simulated lead loads *via* the three pathways into the river – direct deposition, erosion and run-off.
Bottom: Mean simulated lead concentration of the soils in the Elbe catchment.

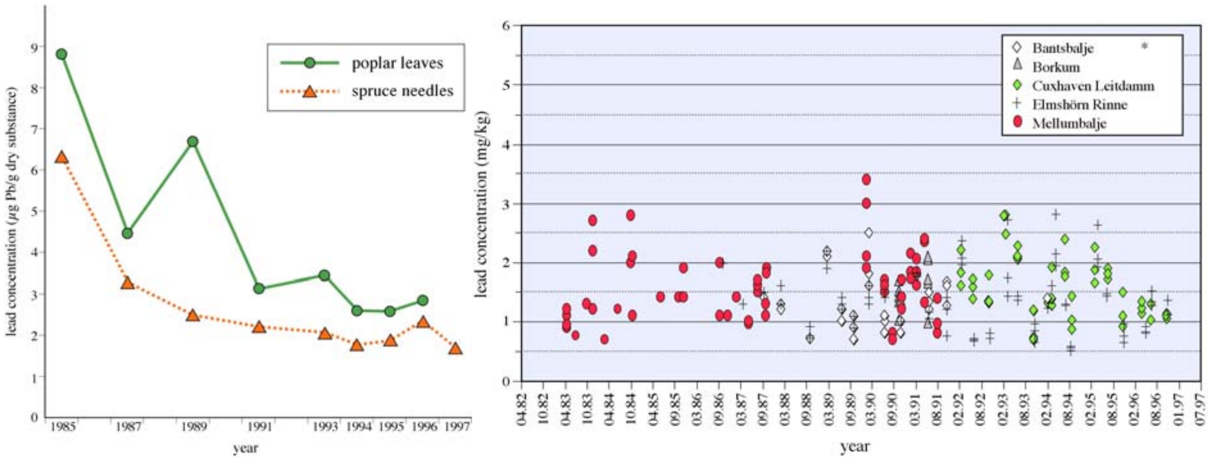


Fig 4: Left: Lead concentrations (mg/g) in spruce (Picea abies) sprouts and poplar (Populus nigra) leaves in urban areas in Saarland (Germany), 1985-1996. Right: Lead concentration (mg/kg) in Blue Mussels (Mytilus Edulis) along the southern in North Sea coast, 1982-1997. After Hagner (2002)

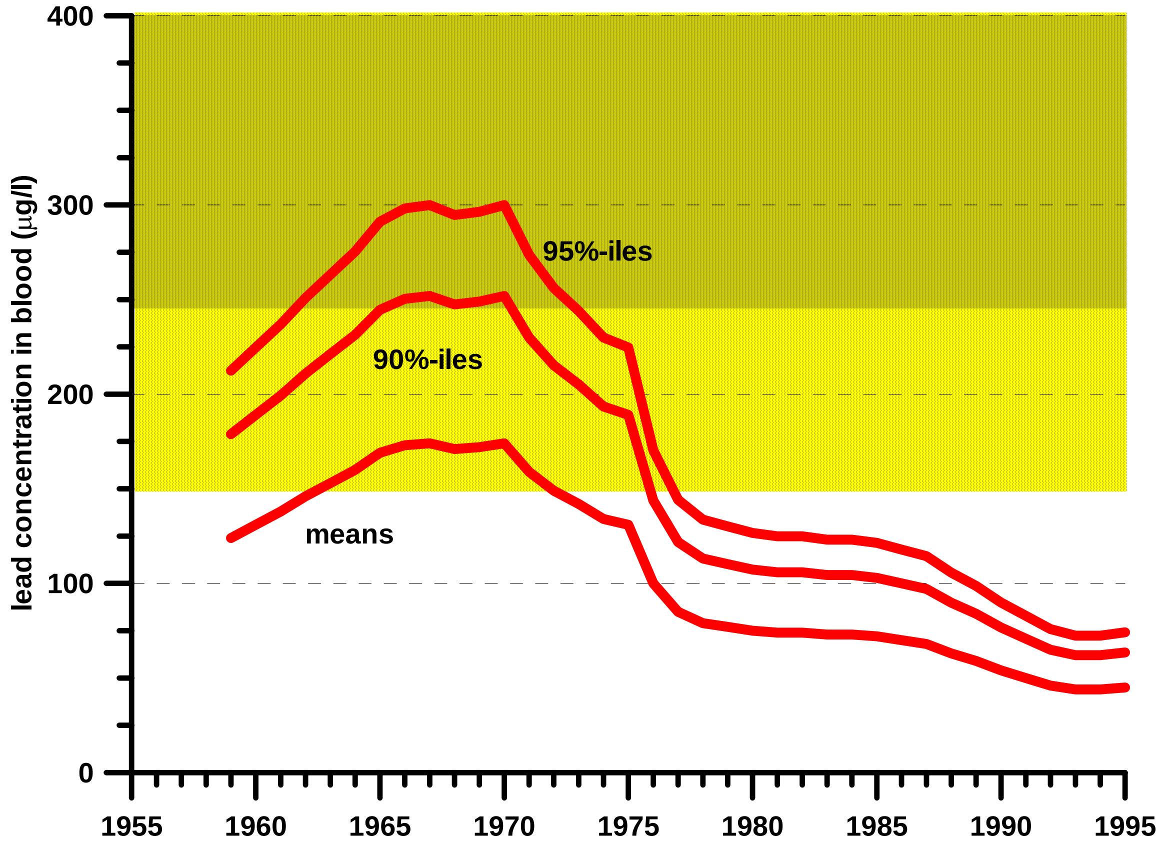


Figure 5: Estimated lead concentration in adult human blood in Germany. The lowest curve relates to the population mean, so that half of the adults have blood concentrations below the cure, and half above. The uppermost curve refers to the 95%ile, so that 5% of all adults have concentratiosn aboe the curve. The middle curve describes the 90%ile. The three coloured backgrounds refer to domain used by the German Human Biomonitoring Commission to classify health risks – in the white domain no dangers are expected, and in the upper class (densely stippled) a health risk prevails. (von Storch and Hagner, 2004)

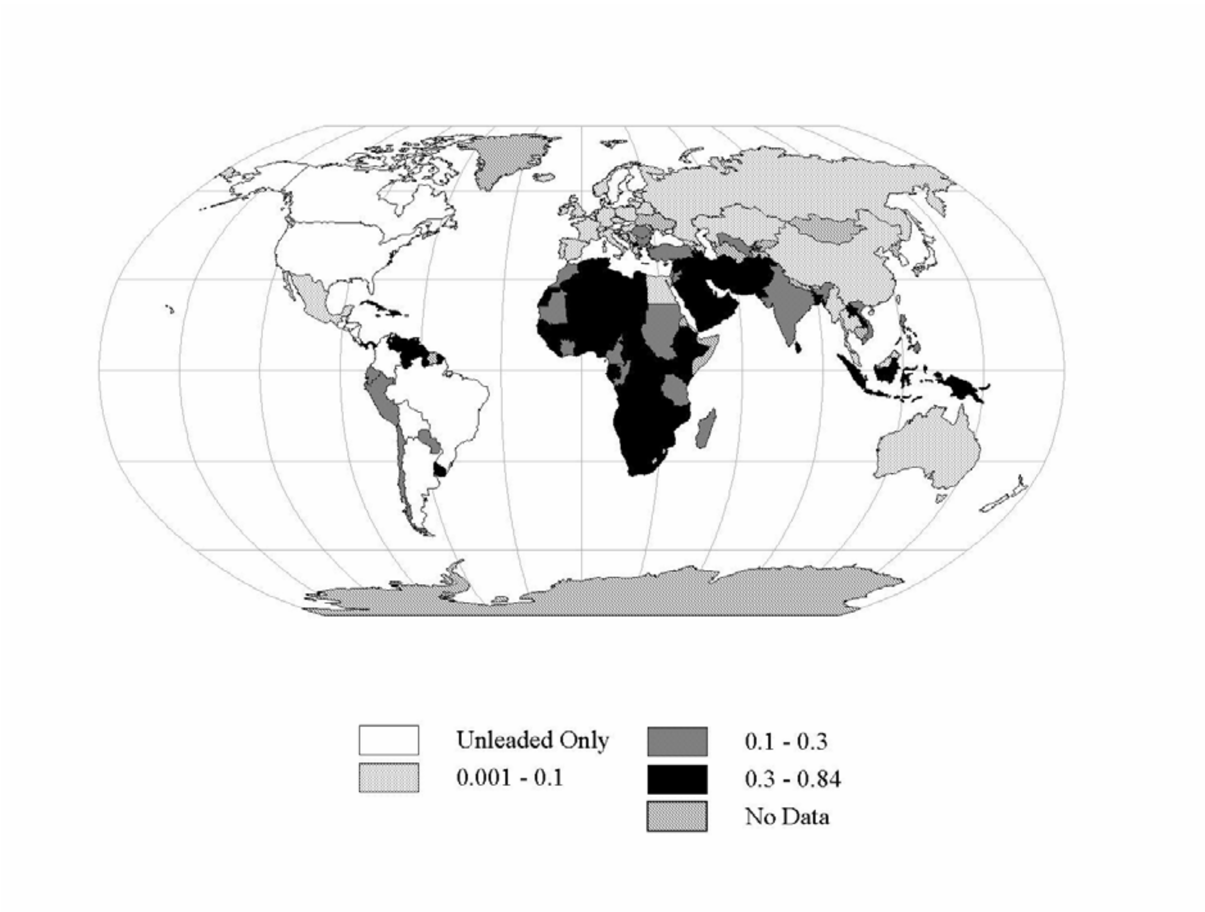


Figure 6: Usage of leaded gasoline in different countries of the world. After Thomas and Kwong (2001). The unit is g Pb/l. Values in most of Europe are 0.0015 g Pb/l – which is sold as "lead-free".