Metals in the Netherlands: a Problem Solved?

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1 Introduction

Environmental problems related to heavy metals have a long history. Heavy metals have toxic properties, leading to adverse effects on human and ecosystem health even in small doses. Another problem-causing property is their non-degradability: once they enter the environment, there is no getting rid of them. Metals tend to accumulate in soils and sediments, immobilization only occurs through geological, and therefore extremely slow, processes. Accumulation in the food chain may lead to an increased stock in biota, thereby magnifying the human dose.

Well known examples of metals poisoning in past centuries include the lead poisoning from water pipes in ancient Rome and the mercury poisoning of the “mad hatters” in Europe. In this century we have encountered among others the disaster of mercury poisoning in the Minamata Bay in Japan through the coastal fish, and of cadmium poisoning through the rice. Lead in petrol has lead to health problems in cities, especially related to children. These and comparable incidents have stirred up governments to formulate environmental policies and industries to reduce emissions considerably. If we compare the current emissions from industrial and point sources to those of several decades ago, at least in the industrialized countries, we can see that they are very much reduced indeed (Ayres & Rod, 19??; Stigliani & Anderberg, 1992). Present policies regarding heavy metals include not only end-of-the-pipe emission reduction, but also recycling and even more source-oriented measures limiting or banning certain applications altogether (VROM, 1991; Council of the EC, 1991). In the Netherlands, a comprehensive heavy metals policy is being formulated currently. In general there is the feeling that the main problems really have been solved, and that it is now a question of tying up some loose ends and then maintaining legislation. One of these ends is the existence of polluted sites, a leftover from the past, described by Stigliani & Salomons (1993) as chemical time bombs. Such sites are not suitable for agriculture and not feasible for residential building, and if they remain unattended metals may become available and leach to the groundwater through increasing acidity. Other loose ends refer to still existing applications considered risky, such as metal-based pesticides and paints.

Although the emissions in the Netherlands have undoubtedly been reduced - at present, the major source for surface water pollution is what enters our country with the Rhine - there are some aspects still causing concern. One is the fact that the environmental concentrations in the Netherlands are not decreasing. This might be due to a time lag - once the emissions are lowered, the metals already in the environment disappear only at geological speed - but it may also have more serious causes. We observe that the inflow into the economic system, on a global level equivalent to the amount of metals being mined, has not decreased but has remained at a high level. This leads to the question that if emissions indeed are reduced, then where does this inflow end up? Possibilities are, in theory:

- Although point source emissions have decreased, we have no insight in the more diffusive emissions. An example of such diffusive emissions is phosphate fertilizer, which is polluted with small amounts of metals, and which is emitted directly into agricultural soils. Of such emissions there is no record, they may even have increased.
- Emissions may have been replaced by landfill, there has been a shift from emissions to the atmosphere and surface waters to dumping on landfill sites.
- The metals entering the economy may accumulate in materials in products, thus increasing the societal stock and in due course, upon entering the waste stage, causing emissions to rise once again.
- The Netherlands might have exported the more polluting stages of the metals’ life cycle to other countries, thus enjoying the benefits of consumption while putting the burden of mining, production and waste management elsewhere.
- A safe storage may have been established for waste metals, reducing the emission from waste materials to zero.

Beforehand, one possibility seems more credible than another. We do know, for example, that no storage at present qualifies as "safe" in the sense of reducing emissions to zero. Pollution export may indeed take place on the level of a small country but does not allow for a global emissions decrease. The other three possible explanations all appear reasonable. All of them, in varying grades and shapes, place question marks with the image of the metals problem as a problem of the past.

The problem of heavy metals in the Netherlands is investigated within the framework of the NWO research program Sustainability and Environmental Quality. Five environmental research groups from four universities - Leiden University, University of Amsterdam, Free University Amsterdam, and Wageningen Agricultural University - have tackled this problem in a combined effort in the research project "Accumulation of metals in economic/environmental cycles: mechanisms, risks and possible management strategies", or shortly the Metals Program. Methods and models have been developed to analyze this problem and generate solutions. In this paper, an application is presented of the outcomes of two of the developed models: FLUX, an SFA program used to describe and model flows of heavy metals in the Dutch economy (Boelens & Olsthoorn, 1998), and Dynabox, a multimedia environmental model which calculates environmental flows and concentrations (Heijungs, 1998). The outcome of the combination of these two models is evaluated with the help of a number of indicators, also developed in the Metals Program (Van der Voet et al., 1998). This modeling-and-evaluation combination is applied to the metabolism of cadmium, copper, lead and zinc for the total Dutch economy (Guinée et al., 1998). An inventory was made for the flows in 1990; FLUX was used to balance the data. Input data for 1990 such as data on flows in the economy, accumulations, emissions and transboundary pollution have been taken mainly from Annema *et al.* (1995). The 1990 emissions have been introduced in Dynabox to calculate the concentrations in the environmental compartments and the human intake through the various routes.

The 1990 situation is compared with the steady-state situation: the situation that ultimately emerges when the present metals' management is continued indefinitely. The reason for this was to get an insight in the long-term consequences of the current metals management regime. It is at present unclear whether the emission reduction realized over the past decades does not have unforeseen adverse consequences in the future. The procedure for calculating the steady state situation boils down to establishing the equilibrium belonging to the present structure of supply and demand of the metals. Note that the steady state must not be interpreted as a prediction of any future situation: it contains no trends, no socio-economic developments and no policies. It is a tool to evaluate the present management on its potential future consequences from a sustainability point of view. The steady state emissions, the result of FLUX, were introduced in Dynabox once again to obtain the steady state environmental concentrations.

The results of these calculations with FLUX and Dynabox are evaluated with the help of the indicators concerning environmental risks and societal metabolism Most of the indicator values have been calculated by simple spreadsheet manipulations of FLUX results. The indicators referring to human and ecosystem health risk came out of Dynabox. Below, the results of the calculations are discussed. The indicators are divided in three groups, related to the research questions of the Metals program:

- indicators for the fate of the mined metals
- indicators for the evaluation of the present management in terms of sustainability
- indicators for the design of a sustainable management.

2 The fate of the mined metals

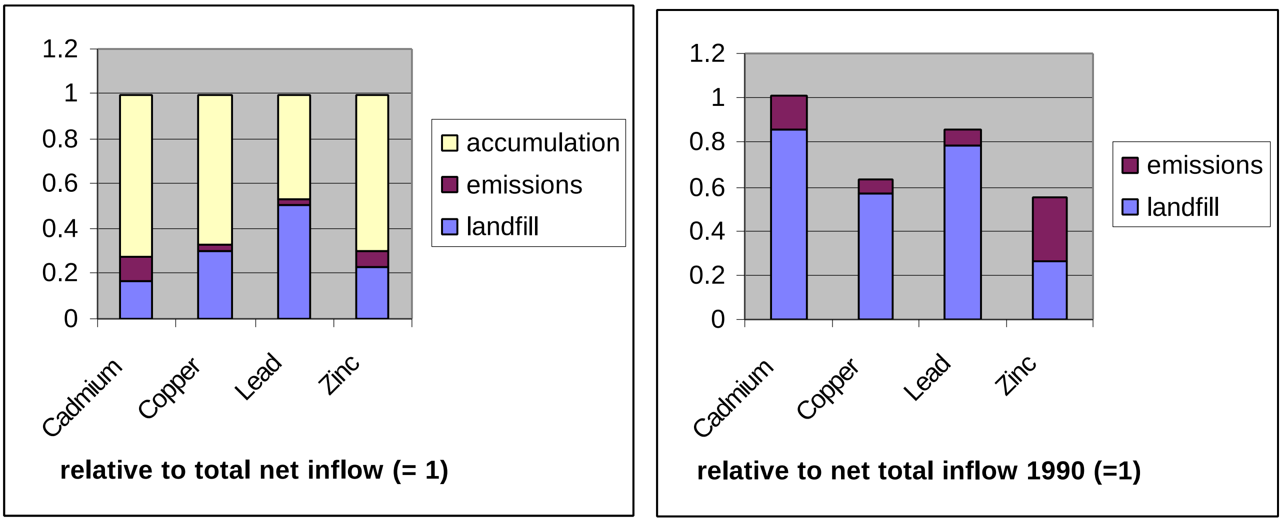
The indicators developed for the fate of the metals are:

- total emissions
- total landfill
- accumulation in the economy
- pollution export

Figure 1 shows the fate of the total net inflow of the four metals in 1990 and the steady state, divided into three categories: emissions, landfill, and accumulation in the economy. We can see that the net inflow is significantly lowered in the steady state for three of the four metals. Only for cadmium the inflow has remained more or less constant. However, both landfill and emissions have risen, since in the steady state the accumulation of course no longer exists. For zinc we see that in the steady state the emissions roughly equal landfill. An evaluation is presented below.

Figure 1 The fate of the 1990 and steady state inflow of cadmium, copper, lead and zinc in the Netherlands.

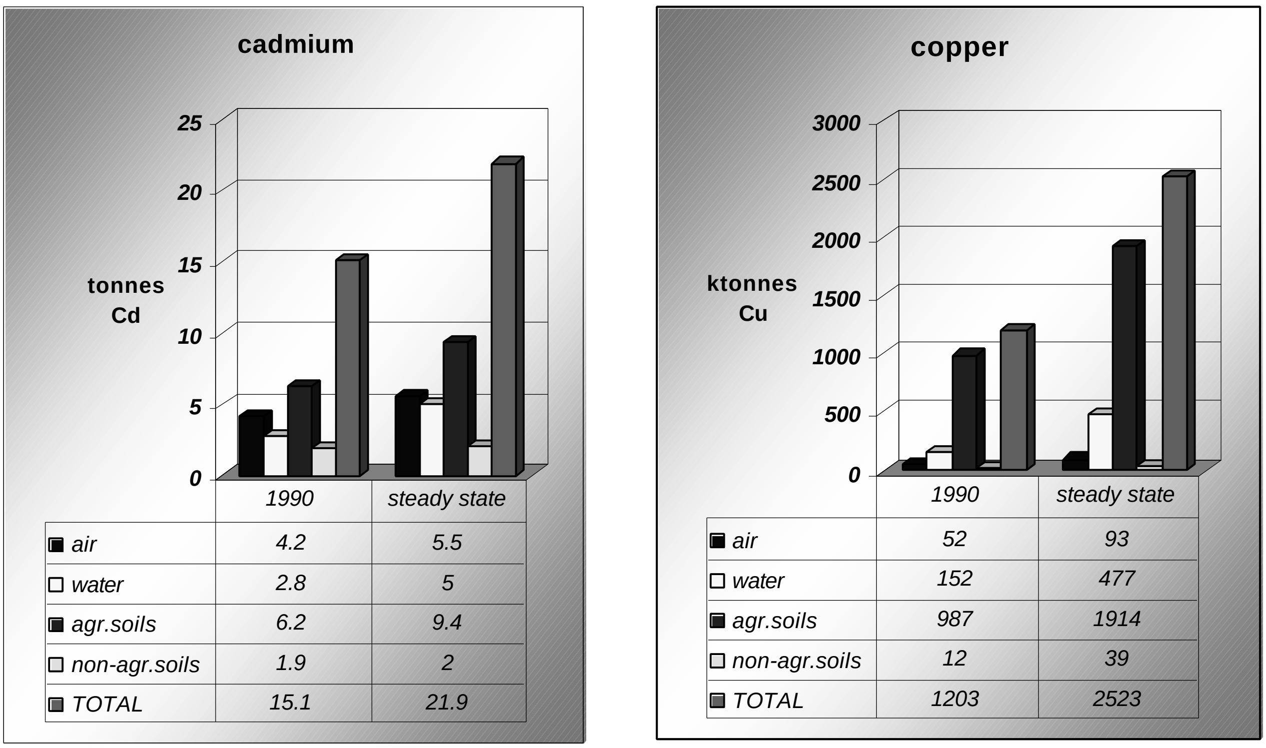
1990 steady state

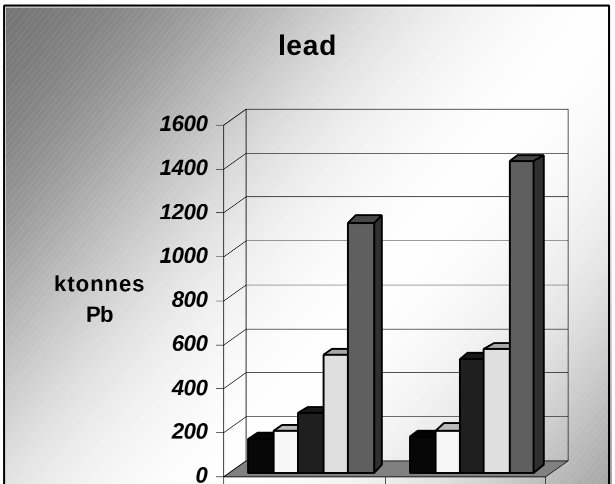


Total emissions

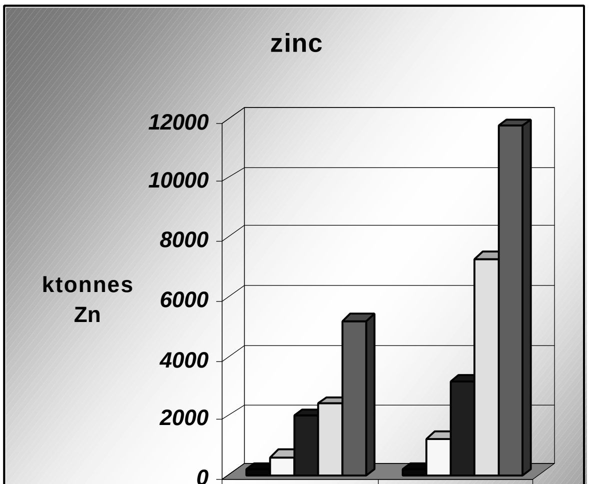
From Figure 1 it can be concluded that in most cases the emissions constitute a small part of the total fate of the metals. This does not imply that these emissions cause no problems: metals are toxic in small doses. An evaluation of the harmful potential of these emissions is given in section 3.
As is shown in Figure 2, the emission indicators show an increase of emissions in the steady-state situation compared to the 1990 situation, which is marked especially for zinc. A further breaking down of the indicator regarding the different environmental media has been performed.

Figure 2 Emissions of heavy metals in the Netherlands, 1990 and steady state





	1990	steady state
air	152	156
water	185	191
agr.soils	266	510
non-agr.soils	533	559
TOTAL	1136	1416



	1990	steady state
air	183	160
water	617	1221
agr.soils	1992	3124
non-agr.soils	2400	7278
TOTAL	5192	11783

It appears that the increase of air emissions in the steady-state situation compared to the 1990 situation is generally moderate. The increase for cadmium is mainly caused by the incineration of spent NiCad batteries, for copper it is due to overhead railway wires. For zinc, air emissions for the steady-state compared to 1990 decrease, since the amount of zinc in galvanized iron is decreasing.
For all four metals, the increase of water emissions in the steady-state situation compared to the 1990 situation is due mainly to the corrosion of metals in building materials (e.g. zinc gutters, galvanized steel, tap water heating equipment and bulk materials such as concrete). However, with respect to the total input to water, it is not the emissions within the Netherlands but the inflow of metals from outside the Netherlands via rivers like the Rhine and Meuse that constitute the dominant source for all four metals (up to over 70%).

The increase of steady-state emissions to agricultural soils compared to 1990 emissions is significant for all metals and is due to increasing flows of organic manure and of source-separated vegetable, fruit and garden waste (the latter being less relevant for lead). The ultimate source behind these increasing flows of copper and zinc is animal fodder. It appears that in the steady-state situation the agricultural soil emissions of copper and zinc are due overwhelmingly (about 80-90%) to the addition to fodder of copper and zinc, respectively. This is an example of closed-loop accumulation (CLA): copper and zinc are added to fodder, which is imported from abroad and fed to Dutch cattle. The manure produced by the cattle, including its copper and zinc content, is spread on agricultural land as an organic fertilizer. Soil concentrations of copper and zinc consequently rise and, with them, the copper and zinc concentrations in maize, pit grass, fresh grass and hay. The livestock are additionally fed with maize, pit grass, fresh grass and hay, and the metals are thus returned to the economy. The eventual steady-state soil concentration due to this cycling of copper and zinc leads to several risk ratios above 1. For non-agricultural soils, a large increase is shown only for zinc. This is due mainly to corrosion of building materials which is expected to increase. Apart from that, losses from landfill sites are expected to rise (see below), as well as the emissions from applications of waste materials in building and road construction.

It should be noted that all steady-state indicators presented in this section are based on 1990 data and do not take into account any effects of policy measures taken since. For example, the decrease of lead in fuel and the decrease of cadmium in zinc gutters have not been taken into account in the current steady-state results. The use of copper and zinc in fodder has also been reduced since 1990, but this has been neutralized by an increase of the Dutch pig stock, resulting in a higher flow of copper and an equal flow of zinc in fodder in 1994 (Westhoek *et al.*, 1997) compared with 1990. The closed-loop-accumulation example of copper and zinc in fodder is thus still valid.

Total landfill

From Figure 1 it appears that the amount of landfilled metals is significantly higher in the steady state. At present, the landfill equals roughly a third of the net inflow. In future, it equals almost the total inflow. Whether this landfill in itself is considered problematical is another issue. Increased landfill may lead to increased leaching to the environment. In the steady state, because of the balance requirement, the amount of leaching necessarily equals the total amount of landfilled metals. This however is not included in the indicators, since the time-scale on which something like that might happen is not relevant for environmental decisions. When introduced in Dynabox, it appears that such leaching contributes only in a minor amount to the health risk indicators out of the second group (see Section 3), even in the steady state. The squandering of scarce resources may also be regarded as a problem. By some, landfill sites are considered mines for the future (Brunner et al., 1998). Others see this in a less favorable light. Last but not least, when we assume a steady demand, we also have to assume that every landfilled kilogram must be replaced by newly produced metals, which implies the generation of emissions associated with production processes.

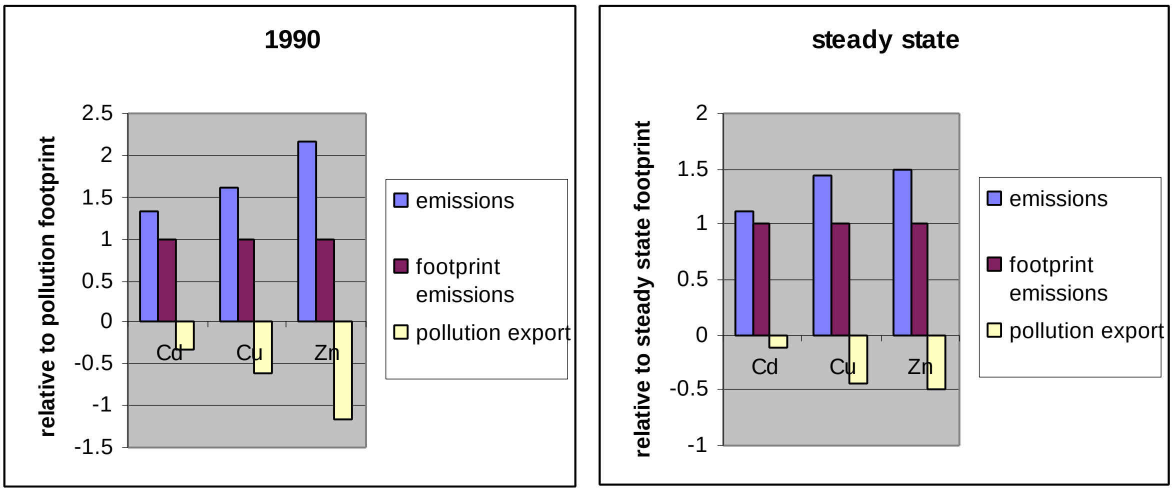
Accumulation in the economy

For all four metals, the accumulation in the economy is at present the most important sink. Relative to the gross inflow the accumulation in the economy ranges between 7 and 14%, being highest for copper and lowest for lead. Relative to the net inflow, as can be concluded from Figure 1, the accumulation ranges from roughly half to three quarters. In the steady state this accumulation will have disappeared and will have resulted in increased landfill and emissions. An indication of the time it will take to reach the steady-state situation in the economy can be obtained from the life spans of the products and applications involved. For example, the average life span of functional applications as building materials lies somewhere between 30 and 50 years, while for non-functional flows of metals in bulk building materials such as concrete this may be a century.

Pollution export

The results for the pollution export indicator are presented in Figure 3. To be able to compare the results for the different metals, the footprint pollution was used as a reference. The actual pollution, i.e. emissions plus landfill, is larger than the footprint in every case. Pollution export is therefore negative. This indicates that the Netherlands is, and will remain, a net importer of pollution for cadmium, copper and zinc. This means there is no net shifting of problems to other countries. For lead this indicator has not been calculated, since it only gives useful information if the economic processes in the region are more or less representative of the average economic processes in the world, which is not the case for lead extraction and refining processes in the Netherlands.

Figure 3 Pollution export indicator for cadmium, copper and zinc in the Netherlands, 1990 and steady state



3 The evaluation of the present management in terms of sustainability

The indicators for the evaluation in terms of sustainability are the following:

- environmental concentrations *(PEC/PNEC, predicted environmental concentrations divided by predicted no-effect concentration)*
- human intake *(PDI/ADI, predicted daily intake divided by acceptable daily intake)*
- environmental accumulation.

Environmental concentrations(PEC/PNEC)
Figure 4 shows the risk ratios for aquatic ecotoxicity, Figure 5 for terrestrial ecotoxicity.

Figure 4 Aquatic ecotoxicity risk ratios for cadmium, copper, lead and zinc in the Netherlands, 1990 and steady state

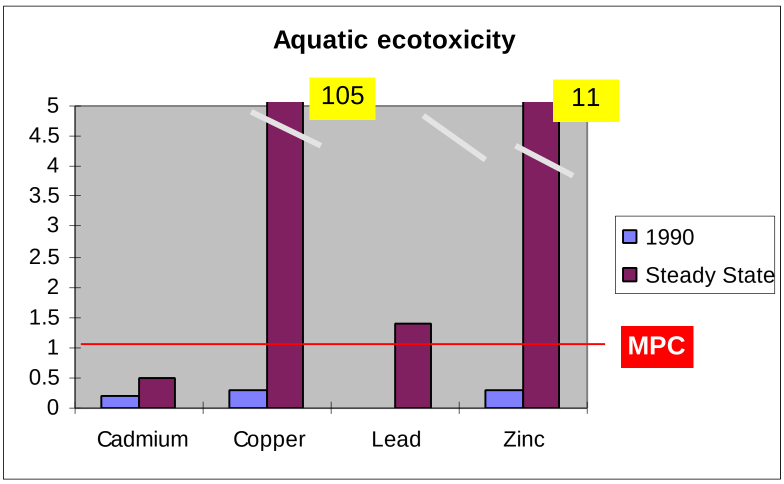
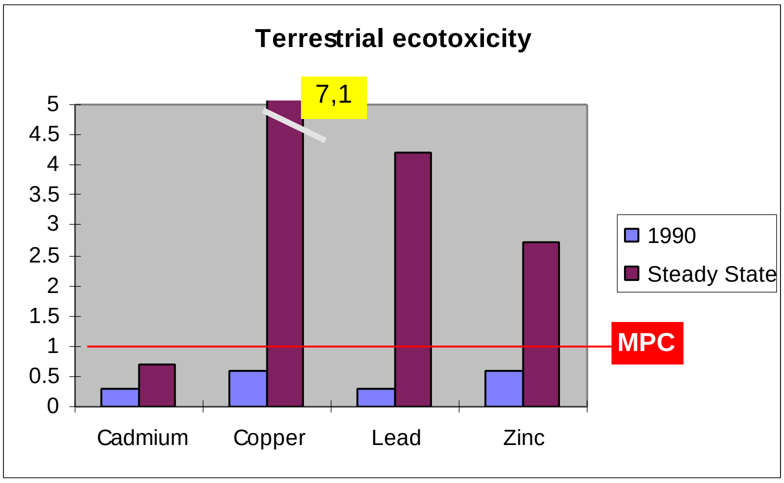


Figure 5 Terrestrial ecotoxicity risk ratios for cadmium, copper, lead and zinc in the Netherlands, 1990 and steady state

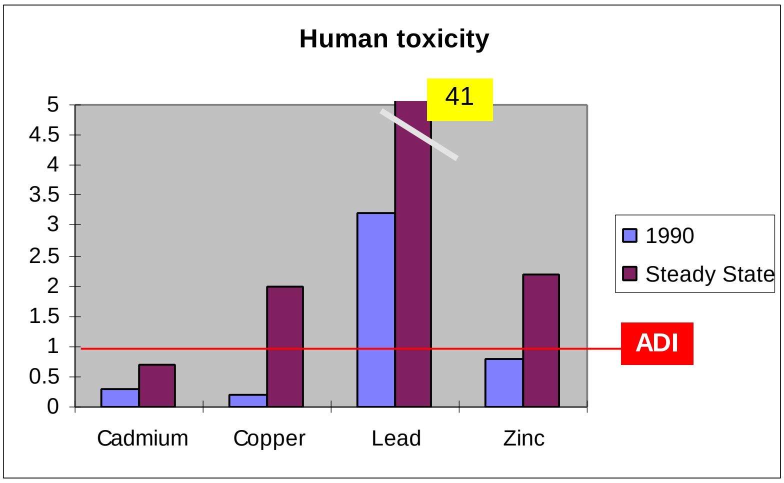


The Dutch Maximum Permissible Concentration (MPC) values have been applied as PNEC values in calculating the risk ratio for aquatic and terrestrial ecotoxicity. The MPC is an ecotoxicological value. MPC values and background concentrations are taken from Crommentuijn *et al.* (1997 and Van Drecht *et al.* (1996). All standards are used as risk indicators; it has not been analyzed which exposure levels and effects are actually found at the concentrations calculated.

At present, MPC values are not transgressed for any of the metals. However, in the steady state ecotoxicological risk ratios are expected to be above 1 for all metals except cadmium.

Human intake: PDI/ADI or PDI/TDI

Figure 6 Human toxicity risk ratios for cadmium, copper, lead and zinc in the Netherlands, 1990 and steady state.



In 1990, only the ADI for lead is transgressed. This risk may be expected to go down or disappear altogether since it is caused for an important part by lead in petrol, which is being phased out altogether. However, in the steady state the ADI is transgressed for three out of the four metals, which indicates that the present metals' management regime will lead to health risks in the long run.

Environmental accumulation

About 50% of the environmental inflow of copper and zinc and about 25 % of the inflow of cadmium and lead accumulated in the environment in 1990. This means that the environmental stock is growing rapidly, which explains the high risk ratios in the steady state. The speed of accumulation can be used to comment on the transition period, i.e. the time it takes to reach a risk ratio of 1. The transition periods for the various metals are also shown in the table below. In calculating the transition periods, current background levels in the various environmental media have been taken into due account. The transition periods vary from 0 years for lead to reach the ADI, to 1000 years also for lead to reach the aquatic MPC level. The transition times for copper and zinc in aquatic ecosystems seem rather short. The results for soil have been compared with the results of the more sophisticated Dynamic Soil Concentration and Balance model (Moolenaar, 1998) and appear to be fairly similar.

Transition period for risk ratios for cadmium, copper, lead and zinc in the Netherlands (years).

	cadmium	copper	lead	zinc
MPC aquatic	∞	3	1000	16
MPC terrestrial	∞	30	550	120
ADI	∞	460	0	130

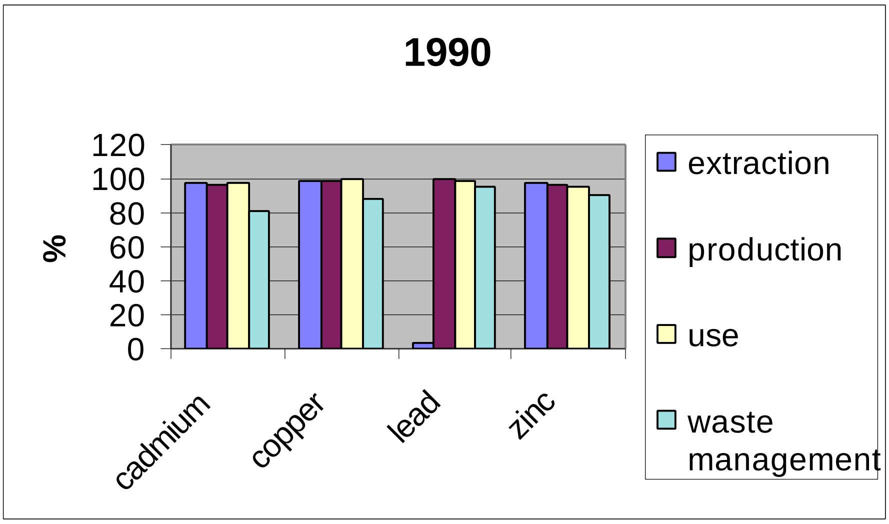
4 The design of a sustainable management

Two indicators have been defined for this purpose:

- technical efficiency
- recycling rate

For the technical efficiency, the results are shown in Figure 7 below, for the basic year 1990 and the steady state. The efficiency of the extraction and production stages is generally high. This indicates that, in order to prevent emissions, not much can be gained by a further boost of industrial efficiency. Comparing the steady-state efficiencies to the 1990 efficiencies, we see a decrease in the use and waste-management efficiencies - due, for example, to corrosion of asphalt, cement and concrete in (utility) buildings, overhead rail wires, cement and landfill emissions - for all metals.

Figure 7 Technical efficiency of the life-cycle stages of cadmium, copper, lead and zinc in the Netherlands, 1990 and steady state



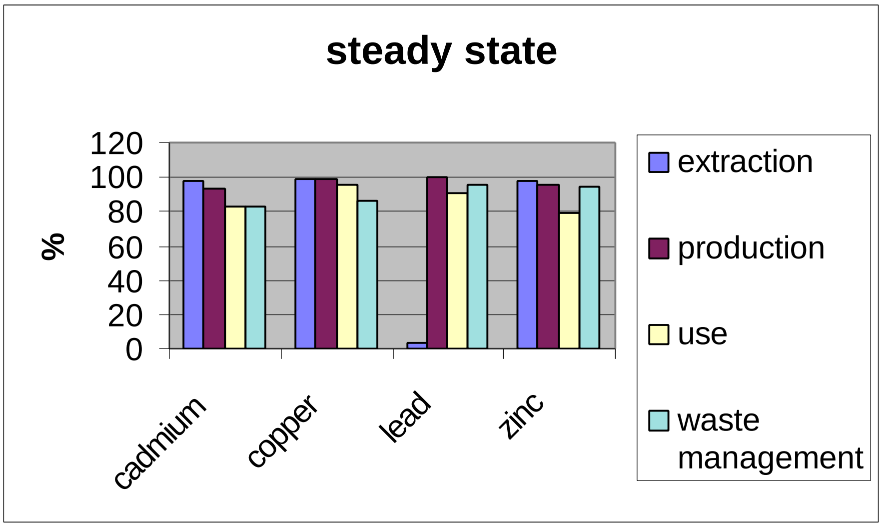
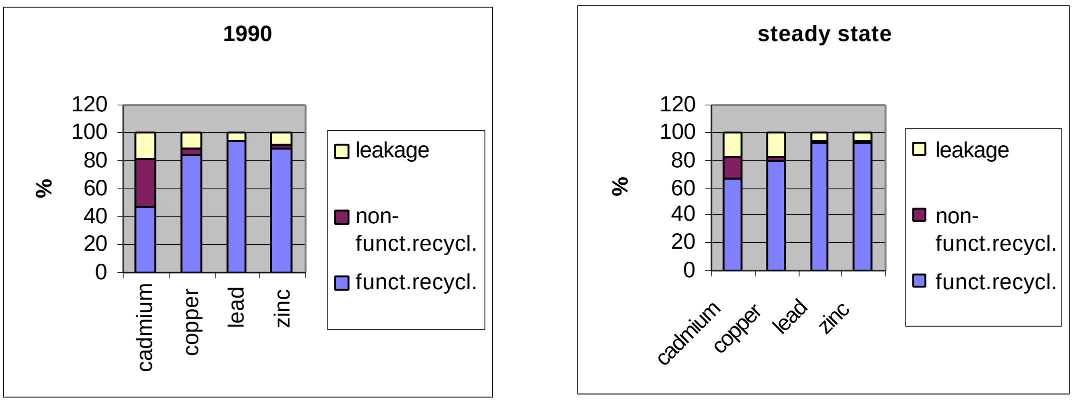


Figure 8 shows the results for the recycling rate. For copper, lead and zinc, functional recycling is at present quite high. There is no significant change in the steady state. The recycling rate is determined largely by the recycling of building materials. A boost of recycling seems difficult, since only the dissipative applications are not recycled at present. For cadmium the recycling refers mainly to various types of NiCad batteries. Due to the present rapid growth of the stock this recycling is expected to increase. Non-functional recycling, i.e. in reused waste materials such as fly-ash, slag and compost, is quite high for cadmium. This might lead to problems in future.

Figure 8 Recycling rate for cadmium, copper, lead and zinc in the Netherlands, 1990 and steady state



5 Conclusions

Regarding the fate of the mined metals, the following conclusions can be drawn:

- the Netherlands do not engage in problem shifting to other countries
- the fate of the net inflow of metals into the Dutch economy is, in decreasing order of magnitude: accumulation in the economic system in stocks of products, landfill, and emissions. In the future, landfill and emissions are expected to rise significantly as the stocks increase.

Regarding the sustainability of the present metals' management in terms of risks, we conclude the following:

- the 1990 flows and accumulations of the metals pose significant long-term risks to human health and ecosystem health

- for all metals, the built environment, agriculture and landfills are the most important sources of the increase in emissions for the steady-state situation based on the 1990 regime.

In contrast to the apparent general view that these metal flows are well under control, the conclusions of this case study points in a different direction. The problem is all the more pressing since the recycling rates of the metals are already quite high.

From the indicators for the design of a sustainable management we conclude:

- the increase in emissions takes place despite quite high efficiencies and substantial functional recycling rates; apart from Cd, these were at least 80% in 1990.
- the non-functional recycling flows are a major cause of diffuse emissions to the important media (air, water, agricultural soil) for human and ecotoxicity.

A further increase of efficiency and functional recycling therefore is difficult to attain, and moreover might not be effective. In fact, relatively small concentrations in specific flows in the economy cause a marked increase of risks through a closed-loop accumulation process, as in the example of Cu and Zn in fodder. A management strategy therefore must look in other directions.

Although the models used include the full spectrum of flows and accumulations in the economy and environment, it must be stressed that the results are merely indicative. Besides the uncertainties in the modeling, a further limitation is that resource availability has not yet been taken into account. In fact this is assumed to be infinite. So perhaps the high risk ratios will not be reached because of enforced declines in resource extraction. However, this is by no means certain, given the continually rising estimates of resource availability. Consequently, the results at least imply a warning signal as to the sustainability of current metal metabolism.

6 References

- Annema, J.A., H. Booij, L. Paardekoper, L. van Oers, E. van der Voet & P. Mulder (1995). Stofstroomanalyse van zes zware metalen - gevolgen van autonome ontwikkelingen en maatregelen. RIVM rapport no. 601014010
- Ayres, R.U. and S.R. Rod (1986). Patterns and Pollution in the Hudson-Raritan Basin. Environment 28, pp 14-20 and 39-43.
- Boelens, J. & A.A.Olsthoorn (1998). Software for material flow analysis. In: Vellinga, P., F. Berkhout & J. Gupta: Sustainable Sustainability. Kluwer Publishers, Dordrecht.
- Brunner, P.H., T. Lahner, R. Obernosterer, U. Lohm, B. Bergbäck, J. Hedbrandt, R. Kleijn, E. van der Voet, M. Deistler, G. Bauer, A. Gleiss, T. Matyus, P. Baccini, S. Kytzia, M. Redle (1998). Materials Accounting as a Tool for Decision Making in Environmental Policy (MAcTEmPo), Final Report april 1998, IWAS TU Vienna.
- Council of the European Communities (1991). Directive 91/338/EEC, concerning the 10th Amendment of Directive 76/769/EEC on the approximation of the laws, regulations and administrative provisions of the Member States relating to restrictions on the marketing and use of certain dangerous substances and preparations. Brussels, COM (91) L 186/59, enacted 18-6-1991.
- Crommentuijn, T., M.D. Polder & E.J. van de Plassche (1997). Maximum Permissible Concentrations and Negligible Concentrations for metals, taking background concentrations into account. Report no. 601501001, RIVM, Bilthoven.
- Drecht, G. van, L.J.M. Boumands, D. Fraters, H.F.R. Reijnders & W. van Duijvenbooden (1996). Landelijke beelden van de diffuse metaalbelasting van de bodem en de metaalgehalten in de bovengrond, alsmede de relatie tussen gehalten en belasting. Report no. 714801006, RIVM, Bilthoven.
- Guinée, J.B., J.C.J.M. van den Bergh, J. Boelens, P.J. Fraanje, G. Huppes, P.P.A.A.H. Kandelaars, Th.M. Lexmond, S.W. Moolenaar, A.A. Olsthoorn, H.A. Udo de Haes, E. Verkuijlen & E. van der Voet (1998). Evaluation of risks of metal flows and accumulation in economy and environment. Ecological Economics, in press
- Heijungs, R., J.B. Guinée & A. Wegener Sleeswijk (1998). Dynabox. A generic dynamic multimedia fate model. In preparation.

- Moolenaar, S.W. (1998). Sustainable management of heavy metals in agro-ecosystems. Ph.D.-thesis Landbouwuniversiteit Wageningen, Wageningen.
- Stigliani, W. & W. Salomons (1993). Our fathers' toxic sins. New Scientist 11 december 1993, pp 38-42.
- Stigliani, W.M. & S. Anderberg (1992). Industrial Metabolism at the Regional Level: the Rhine Basin. IIASA working paper WP-92-10, Laxenburg Austria, 40 pp.
- Voet, E. van der, J.B. Guinée and H.A. Udo de Haes (1997). Indicators for integrated substance chain management as a measure for environmental quality and sustainable development. CML report no. 139 - Section Substances and Products. CML, Leiden.
- VROM (1991). Policy on cadmium. Distributiecentrum VROM, Zoetermeer.
- Westhoek, H.J., L. Beijer, W.J. Bruins, P.H. Hotsma, J.W.M. Janssen & E.J.R. Maathuis (1997). Aan- en afvoerbalansen van zware metalen van Nederlandse landbouwgronden. IKC Landbouw, Ede.