Systems analysis of stock buffering: development of a dynamic substance flow-stock model for the identification and estimation of future resource, waste streams and emissions

Elshkaki, A.

Chapter 6 Long Term Consequences of Non-intentional Flows of Substances: Modelling Non-intentional Flows of Lead in the Dutch Economic System and Evaluating Their Environmental Consequences [*]

Abstract

Substances may enter the economy and the environment through both intentional and non-intention flows. These non-intentional flows, including the occurrence of substances as pollutants in mixed primary resources (metal ores, phosphate ores and fossil fuels) and their presence in re-used waste streams from intentional use may have environmental and economic consequences in terms of pollution and resource availability.

On the one hand, these non-intentional flows may cause pollution problems, for instance by being emitted to air, water and soil or leaching out from road beds and landfill sites when secondary materials are utilized or landfilled. On the other hand, these flows have the potential to be a secondary source of substances and, thus, a possible solution for an expected shortage in the availability of some substances.

This chapter aims to quantify and model the non-intentional flows of lead related to the mixed primary resources and waste streams from intentional use, to evaluate their long-term environmental consequences and compare these consequences to those of the intentional flows of lead.

To meet this aim the model combines all the sources of non-intentional flows of lead within one model, which also includes the intentional flows. The demand for both intentional and non-intentional applications of lead is modelled on the basis of socio-economic variables.

Application of the model shows that the non-intentional flows of lead related to waste streams associated with intentional use are decreasing over time, due to the increased attention given to waste management. However, as contaminants in mixed primary resources applications lead flows are increasing, as demand for these applications is increasing.

The main source of lead emissions is the production of other heavy metals. Although non-intentional inflows of lead constitute less than 10% of the total lead inflow into the economy, the emissions of lead to the air from non-intentional applications are equal those from the intentional applications. Non-intentional flows of lead presently contribute 75% of the total amount of lead going to landfill and this is expected to rise to almost 90% by 2025.

The model presented in this chapter is illustrated by lead, can also be applied to other non-intentional flows of heavy metals.

Key words: substance flow analysis, dynamic modelling, lead, non-intentional flows

[*] Originally, “Elshkaki, A., Van der Voet, E., Van Holderbeke, M., Timmermans, V. (Submitted)”.

6.1 Introduction

The chemical and physical properties of heavy metals, such as lead, zinc, cadmium, copper, germanium, gallium and others means that they have many useful and intentional applications within the economy. Non-intentional applications of these metals arise from their natural occurrence in fossil fuels, other metal ores and phosphate ores and, in addition, secondary flows of these metals result from the processing of waste flows of their intentional applications.

These non-intentional flows have consequences in terms of pollution problems and resource availability. The consequences of the intentional flows of these substances have been studied extensively and several policies have been implemented to minimize their negative impacts. Less attention has been given to the consequences of the non-intentional flows, especially to the long-term consequences. This chapter seeks to provide an in-depth analysis of the potential problems caused by the non-intentional flows of lead in the Dutch economy.

Lead is a highly toxic metal. The American EPA cites lead as one of the 17 most dangerous chemicals in terms of the threat it poses to human beings and the environment (Wu et al., 2004). Lead can cause behavioural problems, learning disabilities, and can be fatal to children who inhale or ingest it. Moreover, lead can be toxic to plants, diminishing their productivity or biomass, and eliminating some species (Singh et al., 1997, Xiong, 1997 and Patra et al., 2004). Due to extensive use in the past, large stocks of lead have been built up in the economy and environmental concentrations may still be rising due to continuing emissions.

Several measures have been taken to reduce the negative impacts of lead. These include end of pipe technologies, stimulating recycling and phasing out some applications of lead, such as in water pipes, paint and gasoline. A recent EU directive prevents member states from allowing new electrical and electronic equipments containing lead, mercury, cadmium, chromium VI, and PBB or PBDE to be put on the market (Wu et al., 2004). Such measures have been effective in reducing emissions of lead to the environment, reducing human exposure and the subsequent health effects of the intentional applications of lead. However, despite effective management of these intentional applications, lead may still threat human health through indirect routes of non-intentional flows. For example, lead enters the agricultural chain via phosphate fertilizer and accumulates there, leading to significant concentrations in manure. The processing of metal ores and the use of fossil fuels leads to emissions of lead to the environment, which may end up in waste streams. Part of this waste is landfilled and part is used as fly ash, bottom ash and slag in construction materials. In addition to direct emissions of lead to the air, water and soil, the accumulated lead in roads, buildings, agricultural soil and landfill sites may leach to the soil or ground water.

Thus, the environmental consequences of non-intentional flows of lead stem from different sources, which might develop differently in the future. For example, the flows of lead in the re-used waste stream from intentional use might decrease in the future due to policies aimed at reducing lead applications, or through increased recycling. On the other hand, flows of lead in fossil fuels, fertilizer or other metals may continue to rise as long as the demand for these applications is increasing.

The aim of this chapter is to evaluate the long-term direct environmental consequences of the non-intentional flows of lead, compare these with the consequences of the intentional flows of lead. In meeting this aim a dynamic model for non-intentional flows and stocks of lead is developed.

The accumulated secondary flows in roads and buildings can also be seen as secondary sources of lead. The availability of lead in the utilized and landfilled secondary materials (fly ash, bottom ash and slag) generated from the production of other heavy metals, electricity production from coal and the incineration of intentional applications of lead and of the accumulation of lead in buildings, roads and landfill sites will be discussed in the subsequent chapter.

To evaluate the long-term consequences of non-intentional flows of lead and other substances, the sources of these flows need to be combined and the factors determining their long-term development should be identified. Both economic factors related to supply and demand and technological factors describing process efficiency need to be included in the model.

The developed model combines functions that describe the long-term development of the main sources of non-intentional flows of lead (electricity production, production of other heavy metal, oil production and fertilizer use), based on statistical approaches and scenarios that describe the demand as a function of socio-economic variables such as GDP, population, price and other specific variables for each application (Burney, 1995, Ranjan and Jain, 1999, Mohamed and Bodger, 2004, Roberts, 1996, Moore and Tilton, 1996, Crompton, 2000, Mergos and Stoforos, 1997 and Bouwman and Hoek, 1997) and technological

factors describe process efficiency, with specific detailed models for the intentional applications of lead (Elshkaki et al., 2004).
This chapter is structured as follows. Section 2 outlines the methodology used in modelling non-intentional flows of lead in the economy and the environment. Section 3 quantifies the model's relations. Section 4 contains the results of the model's calculations and section 5 is dedicated to discussions and conclusions.

6.2 Methodology

6.2.1 General set up of the model

The core of the model used is based upon Substance Flow Analysis (SFA). SFA is widely used in the study of both pollution and resources. It is based on the materials balance principle, which enables different types of analysis. Substance flow accounts can be used to identify major flows and accumulations and to spot trends. Static models can be used to identify causes of pollution problems and assess the effectiveness of contra-measures (Van der Voet, 1996, Bringezu et al., 1997 and Bauer et al., 1997). Dynamic models allow for the analysis of the long-term development of stocks and flows, of forecasts of future emissions and waste streams from the stocks built-up within society and the inclusion of loops and cycles within the system (Kleijn et al., 2000 and Elshkaki et al., 2004). As such they can provide a relevant input for strategic environmental policy planning. In addition, SFA has proved to be a particularly suitable tool to spot the non-intentional flows: the occurrence of a substance as a trace contaminant in materials derived from fossil fuels, phosphate rock etc. (Guinée et al., 1999). This section presents the general set up of the dynamic SFA model for non-intentional flows of lead.
The non-intentional flows of lead in the economic and environmental systems are partly related to the waste streams of the intentional applications of lead and partly to the applications of mixed primary resources. The sources of non-intentional flows of lead are shown in Fig. 1.

Input of lead from mixed primary resources containing lead as a contaminant

The inflows of lead into the production of electricity, oil, and other heavy metals and its inflow into agricultural soil through its natural occurrence in ores and fossil fuels are determined by the demand these applications and the content of lead in the ores and fossil fuels.
The model uses a general function (Eq. 1) to describe the past development in the demand for electricity, oil, heavy metals, and phosphate fertilizers. The same function is used for the future with an assumption about the future development in the explanatory variables.

$$Y(t) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i(t) + \varepsilon(t) \qquad (1)$$

Y (t) is the production of electricity, other heavy metals, oil and fertilizer use at time t, *Xi's* are the socio-economic variables at time (t), *β's* are the model parameters and *ε(t)* is the model error.

An alternative, especially relevant when insufficient data are available or a discontinuity is expected is the use of scenarios. Here, the input of lead is modelled based on the amount of lead per ton of produced metal, per kwh electricity produced, and per ton of phosphate fertilizers used, as given by Eq. 2.

$$F_{L,Y}^{in}(t) = Y(t) \cdot L_x \qquad (2)$$

where $F^{in}_{L,Y}(t)$ is the inflow of lead at time t, and L_x is the amount of lead

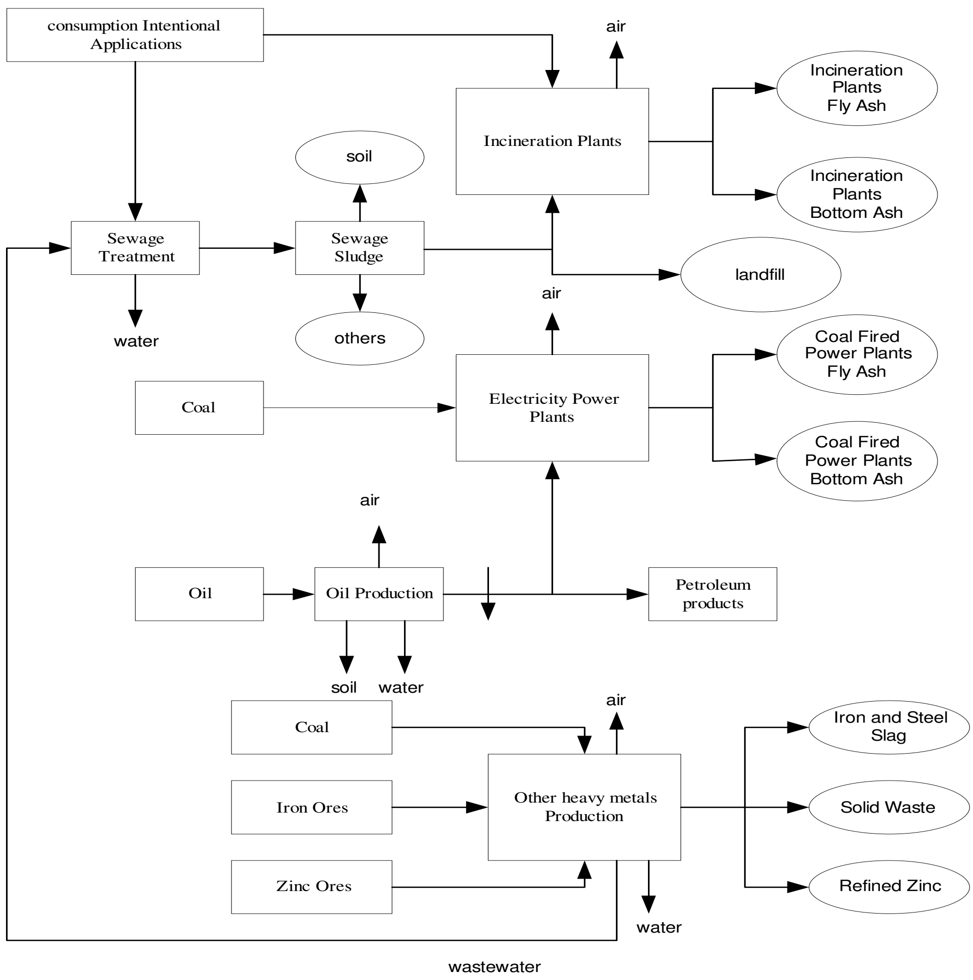

Fig. 1: Non-intentional flows of lead in the economy and the environment

Input of lead arising from the waste streams from lead intentional use

The inflows of lead into the economy through emissions from intentional applications during their use phase and the processing of their waste streams are determined by the demand for lead in intentional applications, their life span, the emissions factors and the waste management of discarded products.
The input of lead into sewage treatment plants originates from emissions of lead during the use phase of lead sheets, the production of other heavy metals and the consumption of food and animal products, as given by Eq. 3.

$$F_{ST}^{in}(t) = F_{CE,ST}^{out}(t) + F_{OHM,ST}^{out}(t) + F_{CFAP,ST}^{out}(t) \tag{3}$$

where $F^{in}_{ST}(t)$ is the inflow of lead into sewage treatment plants at time t, $F^{out}_{CE,ST}(t)$ is the flow of lead originating from emissions during the use phase at time t, $F^{out}_{OHM,ST}(t)$ is the flow of lead originating from the production of other heavy metals, and $F^{out}_{CFAP,ST}(t)$ is the flow of lead originating from consumption of food and animal products at time t.

The inputs of lead to sewage treatment plants from the use phase of lead sheets is estimated as a fraction of the emissions of lead during the use phase, as given by Eq. 4. Emissions of lead during the use of lead sheet are estimated as a fraction of the stock-in-use of lead sheet, as given by Eq. 5 (see Elshkaki et al., 2004).

$$F^{out}{}_{CE,ST}(t) = C_1 \cdot F^{out}{}_{C,E}(t) \tag{4}$$

$$F^{out}{}_{C,E}(t) = C \cdot S(t) \tag{5}$$

where $F^{out}{}_{C,E}(t)$ is the outflow due to emissions at time t, C_1 is the fraction that determines the amount of lead ending up in sewage treatment, C is the emission factor and $S(t)$ is the stock at time t.

The inflow of lead from the consumption of food and animal products is estimated from the amount of lead taken up from the agricultural soil by food and fodder. The uptake of lead by food and fodder is estimated as a fraction of the lead stock in the agricultural soil.

The inflow of lead from the production of other heavy metals is estimated as a fraction of the inflow of lead through iron ores and coal used in steel production, as given by Eq. 12.

The input of lead into incineration plants originating from the waste stream of lead containing products discarded from the stock-in-use and that part of the produced sewage sludge that is incinerated as given by Eq. 6. The input from sewage sludge is discussed in (2.6.3).

$$F_{inc}^{in}(t) = \sum_{i=1}^{n} F_{inc,DC,i}^{in}(t) + F_{inc,SS}^{in}(t) \tag{6}$$

where $F^{in}{}_{inc}(t)$ is the inflow of lead into incineration plants, $F^{in}{}_{inc,DC,i}(t)$ is the inflow of lead into incineration plants originating from discarded product i at time t, and $F^{in}{}_{inc,SS}(t)$ is the inflow of lead into incineration plants originating from incinerated sludge at time t.

The future inflow of lead into incineration processes from the discarded outflow of the stock-in-use is estimated from assumptions for the distribution over incineration, landfill and recycling.

The incinerated flow of lead out of the discarded outflow of the different applications of lead is estimated as a fraction of the total amount of the substance going to be incinerated and landfilled, as given by Eq. 7.

$$F_{inc,DC,i}^{in}(t) = \alpha_{1,i}(t) \cdot F_{inc,land,i}^{in}(t) \tag{7}$$

where $F^{in}{}_{inc,land,i}(t)$ is the amount of lead to be incinerated and landfilled at time t.

The total amount of lead to be incinerated and landfilled is estimated as the difference between the total discarded outflow and the flow collected for recycling as given by Eq. 8.

$$F_{inc,land,i}^{in}(t) = F_{C,D,i}^{out}(t) - F_{SC,i}^{in}(t) \tag{8}$$

where $F^{out}{}_{C,D,i}(t)$ is the total discarded outflow from the stock-in-use of product i at time t and $F^{in}{}_{SC,i}(t)$ is the scrap of product i collected for recycling at time t.

The collected flow for recycling is estimated as a fraction of the discarded outflow, as given by Eq. 9. The model uses a general function (Eq. 10) to describe the collection rate (CR), whose fit is based on past trend data for some applications, such as lead sheet. For other applications, assumptions are made about future collection rates.

$$F_{SC,i}^{in}(t) = CR_i(t) \cdot F_{C,D,i}^{out}(t) \tag{9}$$

$$CR_i(t) = \beta_0 + \sum_{i=1}^{n} \beta_i X_i(t) + \varepsilon(t) \tag{10}$$

The discarded outflow from the stock-in-use is estimated as the inflow at a given point in the past as given by Eq. 11 (see Elshkaki et al., 2004).

$$F^{out}{}_{C,D,i}(t) = F^{in}{}_{C,i}(t - L_{U,i}) - \sum_{i=1}^{L} C_i \cdot F^{in}{}_{C,i}(t - L_{U,i}) \cdot (1 - C_i)^{i-1} \tag{11}$$

where $F^{out}{}_{C,D,i}(t)$ is the outflow due to the delay mechanism at time t, C_i is the emission factor of product i and $L_{U,i}$ is the life span of product i in use.

Output of lead from different processes

Outflows of lead from the production processes of oil, electricity and other heavy metals and incineration processes are determined mainly by technical factors. Lead flows associated with disposal routes of sewage sludge are determined mainly by policy aspects. These outflows are modelled as a fraction of the input, as given by Eq. 12. Mass balance is enforced by modelling one flow per process as a balancing item, in this case landfill.

$$F_{L,x}^{out}(t) = \alpha_x(t) \cdot F_{L,Y}^{in}(t) \tag{12}$$

where $F^{out}{}_{L,x}(t)$ is the outflow of lead to a specific destination at time t, $\alpha_x(t)$ represents the emissions factor, the partitioning of lead between fly and bottom ashes, and the different disposal routes of sewage sludge at time t.

Emissions factors are mainly determined by technological development. These can be assumed either to be constant or to change overtime and are modelled by either linear or exponential functions. Data for some of the emissions factors are available. The emissions data are fitted with a linear function, similar to the one given by Eq. 1, using time as a proxy of technological development and other time-related variables or they are fitted to an exponential function as given by Eq. 13.

$$\alpha_x(t) = \beta_0 \cdot e^{\beta_1 \cdot t} \tag{13}$$

The partitioning of lead between bottom ash and fly ash during incineration processes and electricity production is determined by technical factors (Hasselriis and Licata, 1996, Sandelin et al., 1999 and Sandelin and Backman, 2001). In the model the partitioning of lead is estimated, based on different sources, and is assumed to be constant.
The disposal routes of sewage sludge are determined mainly by policy aspects. They can be assumed constant, with the most recent values being used, or they can be assumed to change over time and modelled based on Eq. 1. Time can be used as a proxy of the policy aspects and other time-related variables.

6.2.2 The production of electricity

Input of lead into the production of electricity

Electricity is generated from different sources such as coal, oil, natural gas, nuclear and others. The inflows of lead into the production of electricity are mainly due to the use of coal and heavy oil. The lead inflow is estimated from the demand for electricity, the amount of coal and oil used in electricity production and the lead content in coal and oil.

Data on past electricity production in the Netherlands are available (CBS, 2003). For the future, a general function (Eq. 1) is used to describe electricity production, which is fitted based on past trend data using regression analysis. Electricity price, GDP, per capita GDP, and population size are the primary determinants of demand for electricity.
The amounts of coal and oil used in electricity production can be estimated either by using Eq. 1 and the factors determining the use of different sources, such as the price of different fuels, technology development and policy, or by using developed scenarios.
The input of lead from coal (L_x in Eq. 2) is estimated based on the total inflow of lead due to the use of coal in electricity production in 1990 (Annema et al., 1995) and the electricity produced from coal in the same year (CBS, 2003).
Data on the amount of lead related to the use of oil was difficult to find, therefore the outflows of lead are taken as being directly related to the production of electricity from oil, which is better known.

Output of lead from the production of electricity

The outflows of lead from the production of electricity from coal (lead emissions to air, lead in fly ash and lead in bottom ash) are estimated as fractions of the total input of lead into coal fired power plants as given by Eq. 12. These factors are estimated from work by Sandelin et al., (1999) and Sandelin and Backman (2001). The only flow related to the use of oil in electricity production is the lead emitted to the air, which is estimated as a fraction of electricity produced from oil. The factor is estimated using CMLCA software (Heijungs, 2000).

6.2.3 The production of other heavy metals

Input of lead into the production of other heavy metals

The inflow of lead into the production of other heavy metals originates from the ores of zinc and iron and the coal used in steel production. The inflow of lead is estimated based on the amounts of zinc, iron and steel produced and the lead content in these ores and in coal.
Data on the past production of zinc, iron and steel are all available (USGS, 1980-1990, British Geological Survey, 1988-2000 and Metallgesellschaft Aktiengesellschaft, 1990). For the future, a general function (Eq. 1) is used to describe the production of these metals, which is fitted based on past trend data using regression analysis. The prices of these metals, GDP, per capita GDP, population and world demand are the primary determinants of the production of these metals.
The input of lead from zinc and iron ores (L_x in Eq. 2) is estimated from the total input of lead through iron and zinc ores in 1990 (Annema et al., 1995), lead in zinc concentrates, pre-refined zinc and refined zinc (Ayres et al. 2003) and the amount of zinc and iron produced in the NL in 1990. The input of lead due to the use of coal (L_x in Eq. 2) is estimated based on the total input of lead from coal in 1990 (Annema et al., 1995) and the amount of steel produced in the NL in 1990.

Output of lead from the production of other heavy metals

The outflows of lead from the production of other heavy metals are in the form of emissions of lead to air and water, the flow of lead to sewage treatment plants, the lead remaining in iron and steel slag, in refined zinc, and in landfilled solid waste generated by all these production processes.
Data on the past emissions of lead to air and water during the production processes of iron and steel are available (VROM, 1990). These data are tested with linear and exponential functions as given by Eq. 1 and Eq. 13 for the best correlation of the emission factor (α_x in Eq. 12) using time as the explanatory variable.
The outflows of lead in slag and wastewater from the production of iron and steel are estimated as fractions of the lead input through iron and coal, as given by Eq. 12. The outflow of lead in refined zinc from the production of zinc is estimated as a fraction of the input of lead through zinc, as given by Eq. 12. The factors are estimated based on the work of Annema et al. (1995) and assumed to be constant.

The outflow of lead in solid waste stream is estimated as the difference between the total input of lead into the production of other heavy metals and the other outflows.

6.2.4 The production of oil

Data on the past inflow of lead into the Dutch economy from the production of refined oil was difficult to find. Therefore the outflows of lead are estimated directly, based on the production of refined oil. Data on the past production of refined oil are available (CBS, 2003). For the future, a general function (Eq. 1) is used to describe the production of refined oil, which is fitted based on past trend data using regression analysis. GDP, per capita GDP, and population are the primary determinants of oil production. The outflows of lead from the production of refined oil are emissions of lead to the air, water and soil. These outflows are estimated as fractions of the produced oil. The factors are estimated using CMLCA (Heijungs, 2000).

6.2.5 The use of phosphate fertilizers

Lead occurs as a contaminant in chemical fertilizers, due to its natural existence in the ores from which these fertilizers are made, especially phosphate ores. The inflow of lead is estimated based on the use of fertilizers and the lead content of phosphate fertilizers. Data on the past consumption of phosphate fertilizers are available (FAO, 2003). For the future, a general function (Eq. 1) is used to describe the consumption of fertilizers, which is fitted based on past trend data using regression analysis. The use of fertilizers is determined by several factors, including economic growth, population growth, fertilizer prices, the price of agricultural products, the relative price of fertilizers with respect to the price of agricultural outputs, lagged agricultural output price and policy measures. The input of lead (L_x in Eq. 2) is estimated based on the use of phosphate fertilizers in the NL in 1990 (FAO, 2003) and the inflow of lead to agricultural soil through fertilizers in the same year (CBS, 1993).

6.2.6 Sewage treatment

Estimation of the inflows of lead into sewage treatment plants

The input of lead into sewage treatment plants originates mainly from emissions of lead during the use phase of lead sheets. Of these emissions, roughly 50% are emitted directly to the soil and the other 50% enter the sewage system. The other inputs of lead to the sewage system originate from the production of other heavy metals and the consumption of food and animal products.

Estimation of the outflow from sewage treatment plants

The outflows of sewage treatment plants are sewage sludge and effluent. The input of lead into sewage treatment plants will end up in one of these two media, depending on the efficiency of the process. It is estimated that 80% of lead input into sewage treatment plants ends up in sewage sludge (Annema et al., 1995) and 20% in the effluent.

The disposal routes of sewage sludge

Sewage sludge is disposed of in different manners. Some is used as a soil improver, some is incinerated and the remainder is landfilled. Data on the past disposal routes of sewage sludge are available (CBS, 2003). The future development in the disposal routes of sewage sludge can be estimated either by the general equation (Eq. 1) and the time as proxy time-related variables, or by assuming that the most recent values of different disposal routes are valid for the future.

6.2.7 Incineration processes

Input of lead into incineration plants

The input of lead into incineration plants originates from the waste stream of products containing lead that have been discarded from the stock-in-use, together with the fraction of sewage sludge that is incinerated. Data on the past incinerated mixed solid waste and bottom and fly ash are available (VVAV, 2001). The lead content of bottom ash and fly ash is assumed to be equal to estimates made by Kosson et al. (1996). The future inflow of lead into incineration processes from the discarded outflow from the stock-in-use is estimated, based on Eqs. 7, 8, 9, 10, and 11. The input of lead into incineration processes from sewage sludge is discussed in 2.6.3.

Output of lead from the incineration plants

The outflows of lead from incineration plants in bottom ash, fly ash and emissions from incineration process are estimated as fractions of the total inflow of lead into incineration plants, as given by Eq. 12. The partitioning of lead (α_x in Eq. 12) amongst the incineration residues is estimated as 85% in the bottom ash and 15% in the fly and combined ash (Van der Sloot, 1996), with the lead content in bottom ash being 1500 mg lead/kg and 4000 mg lead/kg in the fly ash.

6.3 Quantification of model relations - Results of the analysis

6.3.1 The production of electricity

The total electricity produced in the NL between 1975 and 2000 (Fig. 2) (CBS, 2003) has been tested for correlation with all the expected influential explanatory variables such as the population size, GDP, per capita GDP, and electricity own price. The results are shown in table 1. The results indicate a positive correlation between all the tested variables and the production of electricity, significant at the 99% probability level. The coefficient of determination (R^2) associated with the correlation is fairly high. The highest coefficient of determination (R^2=0.95) is the one associated with population and GDP. On this basis the following equation is used to calculate total electricity production:

$$TEP(t) = -47018 + 0.00713 \cdot pop(t) + 5.4E - 9 \cdot GDP(t) \qquad (14)$$

where TEP (t) is the total electricity production at time t.

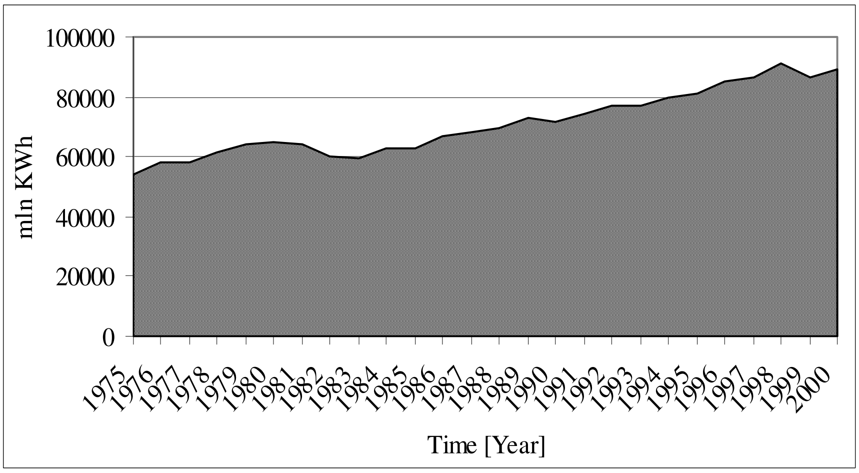

Fig. 2: Total electricity production in the NL 1975-2000

The share of the main sources used for electricity generation from 1987 through 2000 (Eurostat, 1987-2000) is shown in Fig. 3. The future share of the main sources in electricity generation is estimated from Eq. 1 and time is used as a proxy of all time-related variables. The following model relations are used to calculate the future share of coal and gas and other sources. The share of oil is estimated by Eq. 17.

Table 1: Analysis of the production of zinc, iron, steel, electricity, oil and fertilizer use in the Dutch economy

Variable	B_0 (t-value)	B_1 (t-value)	β_2 (t-value)	B_3 (t-value)	R^2	F-statistics
Zinc						
Population	-87610(-1.6)	0.01947(5.5)			0.62	31.3
GDP	178998(28.2)	9.54E-9(4.2)			0.48	18.0
Per capita GDP	177161(25.7)	0.15521(4.1)			0.47	17.2
Price	175418(13.9)	25.2351(2.3)			0.22	05.5
Pop, GDP	-293577(1.8)	0.03478(3.0)	-8.87E-9(1.3)		0.65	17.3
GDP, price	169363(16.5)	8.29E-9(3.3)	11.3575(1.1)		0.52	09.9
Pop, price	-71204(1.3)	0.01768(4.6)	9.12402(1.1)		0.64	16.4
Pop, GDP, price	-293880(1.9)	0.03416(3.0)	-9.69E-9(1.5)	10.34(1.3)	0.68	12.6
Iron						
Population	-6.8E6(-2.5)	0.77(4.3)			0.49	18.6
GDP	3.78E6(13.8)	4.4E-7(4.5)			0.52	21.0
Per capita GDP	3.68E6(12.6)	7.3(4.6)			0.52	21.2
Price	1.09E6(0.6)	6730(2.1)			0.19	04.4
Pop, GDP	1.9E6(0.2)	0.13(0.2)	3.7E-7(1.1)		0.52	10.0
GDP, price	2.53E6(1.7)	4E-7(3.7)	2359(0.9)		0.54	10.7
Pop, price	-6.6E6(-2.4)	0.73(3.3)	1192(0.4)		0.49	08.9
Pop, GDP, price	4.5E6(0.5)	-0.16(-0.2)	4.8E-7(1.3)	2727(0.8)	0.54	06.8
Steel						
Population	-6.14E6(-2.4)	0.78(4.7)			0.53	21.7
GDP	4.45E6(17.2)	4.4E-7(4.8)			0.54	23.1
Per capita GDP	4.36E6(15.5)	7.21(4.7)			0.54	22.3
Price	1.3E6(0.8)	7404(2.4)			0.24	06.1
Pop, GDP	741375(0.1)	0.27(0.47)	2.96E-7(0.9)		0.55	11.2
GDP, price	2.7E6(2.0)	3.86E-7(3.8)	3219(1.3)		0.58	12.7
Pop, price	-6.1E6(-2.4)	0.7(3.4)	2066(0.7)		0.54	10.8
Pop, GDP, price	4.06E6(0.5)	-0.11(-0.2)	4.38E-7(1.3)	3459(1.16)	0.58	08.0
Electricity						
Population	-156373(-12.3)	0.0154(17.9)			0.93	323.0
GDP	48170(36.5)	9.7E-9(19.0)			0.94	363.0
Per capita GDP	46208(29.8)	0.158(17.4)			0.92	302.0
Pop, GDP	-47018(-1.4)	0.00713(2.8)	5.413E-9(3.4)		0.95	236.0
Oil production						
Population	-125323(-5.9)	0.01173(8.4)			0.85	71.0
GDP	35547(18.6)	5.63E-9(8.9)			0.86	79.4
Per capita GDP	34286(16.5)	0.09212(8.7)			0.86	76.8
Pop, GDP	-29504(-0.4)	0.00472(0.9)	3.46E-9(1.44)		0.87	39.8
Fertilizers						
Population	272694(22.6)	-0.013(-15.5)			0.86	241
GDP	106568(62.4)	-1.2E-7(-14.9)			0.85	224
Per capita GDP	107936(62.4)	-1.93(-15.4)			0.86	237
Population G	47552(6.5)	0.351(5.5)			0.45	30
Price	174785(21.8)	-195(-11.0)			0.81	122
Time	114932(57.2)	-1386(-16.2)			0.87	263
Time, PopG	114075(16.4)	-1375(-11.2)	0.005(0.13)		0.87	128

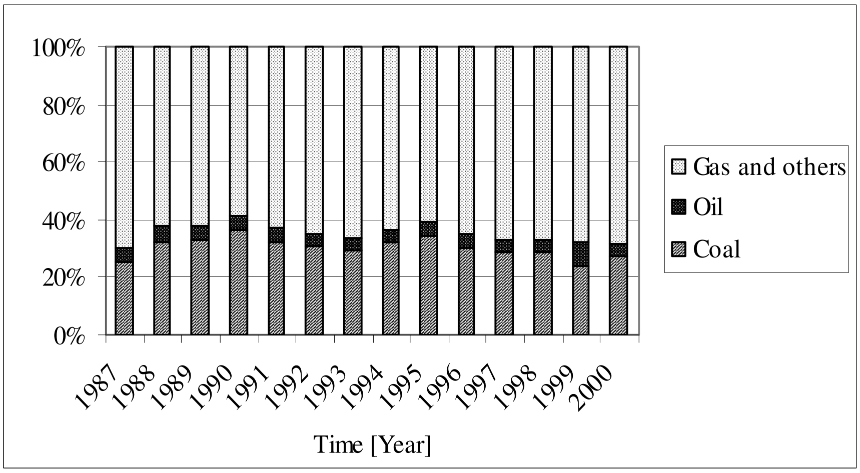

Fig. 3: The share of different sources for electricity production in the past 1987-2000

$$GOSS(t) = -6.621 + 0.0036 \cdot t \quad (15)$$

$$CS(t) = 6.7203 - 0.0032 \cdot t \quad (16)$$

$$OS(t) = 1 - [GOSS(t) + CS(t)] \quad (17)$$

where GOSS (t) is the share of gas and other sources at time t, CS (t) is the share of coal at time t and OS (t) is the share of oil at time t.

Alternatively, the future share of the main sources for generating electricity can be estimated using different scenarios. National Institute of Public Health and the Environment (RIVM) has developed four scenarios for the future use of different sources in electricity production for OECD Europe based on different economic, environmental and social assumptions (Image team, 2001). Two of these scenarios (A2 and B2) are used in the estimates of lead flows from using coal in electricity production and compared with the outcome of the model.

6.3.2 The production of other heavy metals

The amounts of refined zinc, iron and steel from 1980 through to 2000 (USGS, 1980, British Geological Survey, 1988-2000 and Metallgesellschaft Aktiengesellschaft, 1990) have been tested with the all expected influential explanatory variables, such as the population size, GDP, per capita GDP, and metals price. The results are shown in table 1.

The results indicate a positive correlation between the production of these metals and all the tested variables. The correlation between the tested variables and zinc, iron and steel production is significant at the 99% probability level. The coefficient of determination (R^2) associated with the correlation is fairly high, with the exception of the correlation with the price. For zinc, the highest coefficient of determination (R^2=0.62) occurs with population and, for iron and steel the highest coefficients of determination (R^2=0.52 for iron, R^2=0.54 for steel) occur with per capita GDP. When the variables are combined, the coefficients of determination do not change significantly from those associated with the population in the case of zinc and per capita GDP in the case of iron and steel. Therefore, the following models will be used to calculate the production of the three metals:

$$ZP(t) = -87610 + 0.01947 \cdot pop(t) \quad (18)$$

$$IP(t) = 3.68E6 + 7.3 \cdot GDP / C(t) \tag{19}$$

$$SP(t) = 4.36E6 + 7.21 \cdot GDP / C(t) \tag{20}$$

where *ZP (t)* is the production of zinc at time t, *IP (t)* is the production of iron at time t and *SP (t)* is the production of steel at time t.

6.3.3 The production of oil

The production of refined oil in the NL between 1985 and 1998 (CBS, 2003) has been tested for correlation with all expected influential variables, such as the population size, GDP, and per capita GDP. The results are shown in table 1. The results indicate a positive correlation between all the tested variables and the production of oil, significant at the 99% probability level. The coefficient of determination (R^2) associated with the correlation is fairly high. The highest coefficient of determination (R^2=0.86) occurs with GDP and per capita GDP. When variables such as GDP and population were combined, the coefficient of determination does not change significantly from those associated with GDP or per capita GDP and both variables turn out to be insignificant. Therefore, the following model will be used to calculate oil production in the NL:

$$OP(t) = 35547 + 5.63E - 9 \cdot GDP(t) \tag{21}$$

where *OP (t)* is the production of oil at time t.

6.3.4 The use of phosphate fertilizers

The inflow of phosphate fertilizers into the Dutch economy between 1961 and 2000 (FAO, 2003) has been tested for correlation with all expected influential variables. The explanatory variables used in the analysis are population size, GDP, per capita GDP, agricultural output price, population growth and time as a proxy of the effect of other influential variables on the inflow of phosphate fertilizers. The analysis covers the period 1961 to 2000. The relation between the price and the inflow of phosphate fertilizer is analyzed from 1966 to 1995. The results are shown in table 1. It is clear from the analysis of the inflow that all the independent variables correlate negatively with the inflow, except population growth. This is to be expected because fertilizer use is declining and the variables are increasing. This means that it is difficult to explain developments in fertilizer use from variables such as GDP, population, per capita GDP or price. Instead, we use the time variable to model the inflow. Using time as the explanatory variable, the coefficient of determination (R^2) associated with correlations is fairly high. The time variable correlates negatively with the inflow. This indicates that other factors have influenced the use of fertilizers in the NL and it is clear that policy has had a large influence on the decline in fertilizer use. Therefore, the following model will be used to calculate the future demand for phosphate fertilizers in the NL:

$$F_{fert}^{in}(t) = 114932 - 1386 \cdot t \tag{22}$$

where $F^{in}_{fert}(t)$ is the inflow of fertilizers at time t.

The future use of fertilizer can be estimated using time as the explanatory variable since this can capture the influence of the policy on fertilizer use.
The linear function estimated by regression analysis gives a good fit for the past. However, for the future the same equation lead to a considerable reduction in the use of fertilizers. A scenario developed by RIVM (Egmond et al., 2001) shows that the use of phosphate fertilizer will be stabile in the future at 38 million kg p.a.. Therefore, this value is taken as the minimum value for the use of fertilizer in the model.

6.4 Results of the model

6.4.1 Non-intentional inflows of lead

The production of electricity

The input of lead through coal used in electricity production (L_x in Eq. 2) is given in table 2. The inflow of lead based on Eqs. 14, 16, and 2 and the value given in table 2 is shown in Fig. 4.

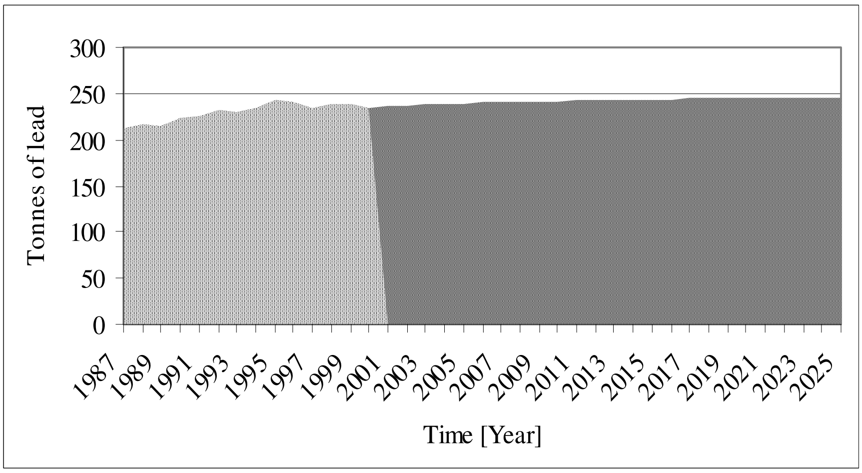

Fig. 4: The inflow of lead into the Dutch economy through the coal used in electricity production

As shown in Fig. 4, the non-intentional flow of lead from the production of electricity from coal is slowly increasing until 2017; and stabilizes thereafter. This is mainly due to the expected increase in the demand for electricity combined with the expected decrease in the use of coal in the generation of electricity.

Table 2: Lead content in different flows (L_x in Eq.2)

Flow	Lead content (L_x)
Production of other heavy metals	Kg of lead per ton of metal produced
Zinc	26.0
Iron	0.2
Coal	8.32 E-3
Electricity production	Kg of lead per mln kWh electricity produced
Coal	9.13
Use of fertilizers	Kg of lead per ton of phosphate fertilizers
Phosphate fertilizers	0.135

Fig. 5 shows the non-intentional flow of lead from the production of electricity from coal, based on two scenarios. Although the share of coal is decreasing, its use is increasing, due to the increase in electricity demand. The total use of coal in electricity production estimated based on A2 scenario is less than that estimated from the model to 2020, but more after that date. The estimated use of coal based on the B2 scenario is less than that estimated from the model.

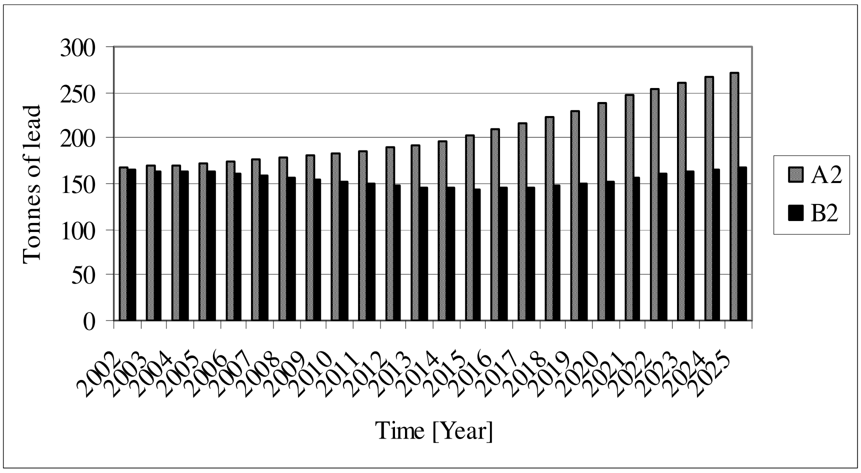

Fig. 5: The inflow of lead through the coal used in electricity production based on two scenarios

The production of other heavy metals

The inputs of lead through zinc, iron and steel (L_x in Eq. 2) are given in table 2. The past and future inflows of lead based on Eqs. 18, 19, 20, and 2 and the values given in table 2 are shown in Fig. 6.

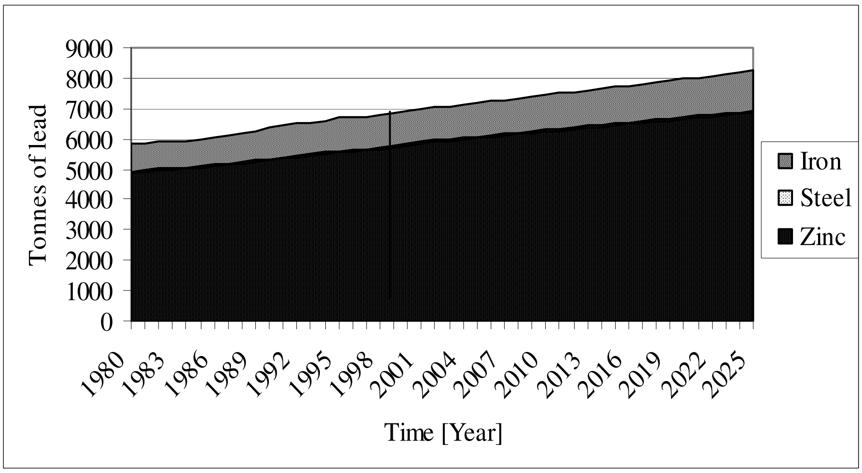

Fig. 6: The past and future inflow of lead in other metals

As shown in Fig. 6, the non-intentional flows of lead due to the production of zinc, iron and steel are increasing overtime. This is mainly due to the expected increase in the demand for these metals. Although the production of iron and steel in the Netherlands is greater than the production of zinc, the input of lead from zinc production is higher, due to the high content of lead in zinc ores.

The use of phosphate fertilizers

The input of lead through phosphate fertilizers (L_x in Eq. 2) is given in table 2. The past and future inflow of lead through phosphate fertilizers based on Eq. 22 and the RIVM scenario and the value given in table 2 is shown in Fig. 7.

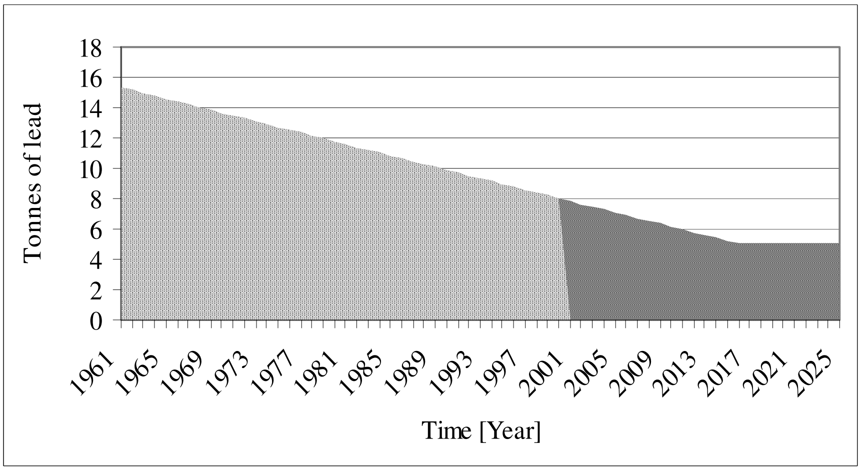

Fig. 7: The inflow of lead in the past and the future into Dutch agricultural soil

As shown in Fig. 7, the inflow of lead into agricultural soil from the use of phosphate fertilizers is decreasing overtime and is expected to stabilize in 2017 at 5.13 tonnes. This is mainly due to policy, which aims to reduce fertilizer use.

Sewage treatment plants

The input of lead into sewage treatment plants from different sources is shown in Fig. 8.

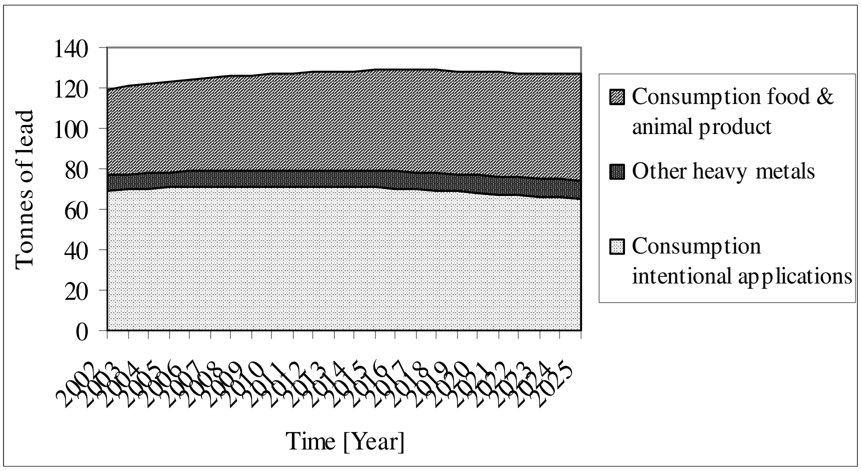

Fig. 8: The inputs of lead into sewage treatment plants

The main source of lead in sewage sludge is from emissions from the consumption of intentional lead applications. These are decreasing over time, due to the decrease in lead stocks in use. The second largest source of lead is the consumption of food and animal products, which is increasing over time due to the increase of lead inputs into agricultural soil and consequently its uptake in food and fodder. The third flow originates from the production of other heavy metals, which is increasing due to the increase in the production of iron and steel.

The disposal routes of sewage sludge

The disposal routes of sewage sludge in the past are shown in Fig. 9.

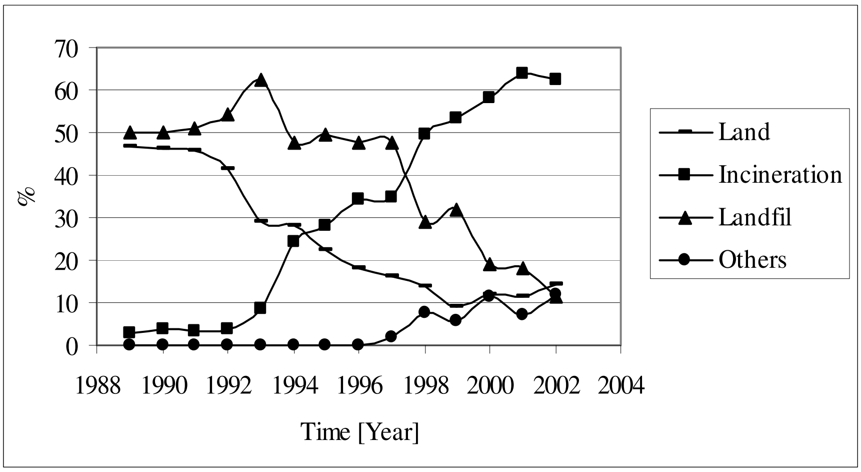

Fig. 9: Past disposal routes of sewage sludge

It is clear that the incineration of sewage sludge is increasing over time and the other disposal routes are decreasing. This is mainly due to the policy influences in the NL. Two future options for these different disposal routes are investigated. First, the values of different disposal options in the year 2001 are assumed to be constant in order to evaluate the current situation on the management of sewage sludge. The landfilled stream is assumed to be the difference between the total lead within sewage sludge and the lead in other disposal routes (incineration, land, others). Second, the incineration is modelled based on Eq. 1 with time being used as a proxy of time-related variables. If the current trend continues, the incineration of sewage sludge will reach 100% by the year 2009. If the current practice of sewage sludge management continues, 12% of lead in sewage sludge will end up in landfill sites and 62% of it will enter incineration plants. Due to the current management of incineration residues, about 15% of the lead entering incineration plants will also end up in the landfill sites, meaning that 27% of lead in sewage sludge will end up in landfill sites.
If the current trend of increasing incineration of sewage sludge continues and reaches 100% in the year 2009, the landfilled lead, including the landfilled streams of bottom and fly ash will account for 23% of the total lead contained in sewage sludge.

Incineration processes

The input of lead into incineration plants from discarded applications and sewage sludge is shown in Fig. 10. By far the largest source is the outflow of discarded applications of lead out of the stock of products in use. This is decreasing over time, due to an increase in the recycling of intentional lead applications. The second largest flow is the stream of incinerated sewage sludge, which is increasing over time.

6.4.2 Non-intentional outflows of lead

Some of the non-intentional outflows of lead, in particular those from the production of electricity, other heavy metals, refined oil, together with the flows from incineration plants and wastewater treatment plants, are released directly to the environment. Other outflows either enter new economic applications such as parts of the fly ash, bottom ash and slag or are sent to landfill sites. The total non-intentional outflows of lead to the air, water, soil and to landfill sites are shown in Fig. 11.

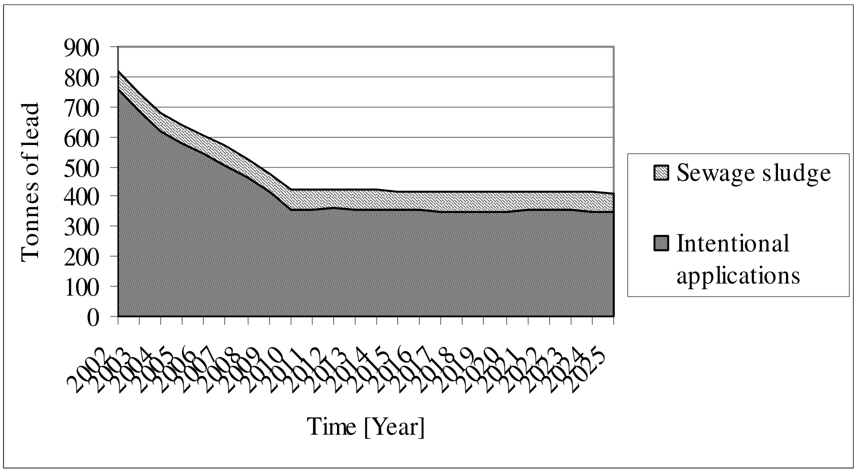

Fig. 10: The inputs of lead into incineration plants

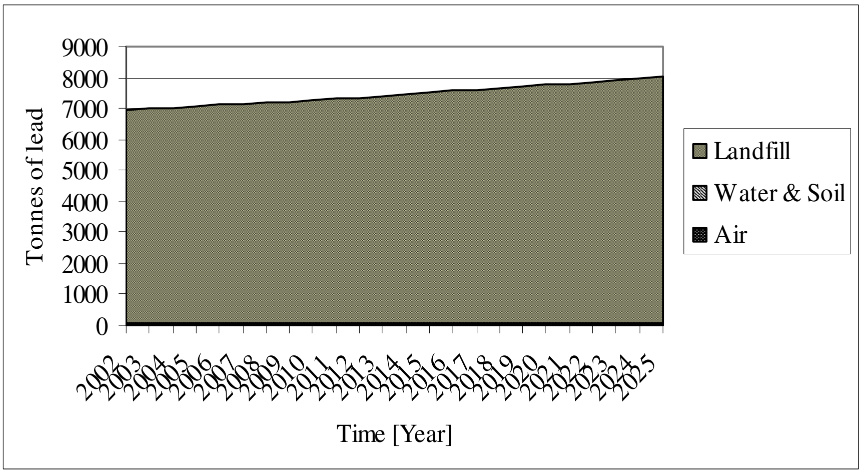

Fig. 11: Non-intentional outflows of lead to air, water, soil and landfill sites

Sometimes, it is not clear where exactly to draw the border between the economy and environment. A landfill exists in the environment but is under human control. However, the choice of treating a landfill as part of the environment or of the economy does not make any difference in modelling terms or to the outcome of the SFA model. This is in contrast to, for example, LCA where the boundary between the technical system and the environment has to be drawn as one of the system boundaries (Guinée et al. 1993), as it determines what to call "emissions"). It is generally accepted that the emissions from landfill sites should be included in the inventory and therefore, that landfill sites should be included in the economic system (Heijungs et al. 1992 and Finnveden et al. 1995).

Lead in secondary materials

Table 3 shows the partitioning of lead to bottom ash and fly ash during the production of electricity from coal, the factors used to estimate lead outflows from the production of other heavy metals and the partitioning of lead to fly ash and bottom ash during incineration processes (α_x in Eq. 12). Figure 12 shows the future outflows of lead in secondary materials based on the figures provided in Table 3 and Eq. 12. These lead outflows arising from the production of electricity from coal, of other heavy metals and from incineration plants. The flows in secondary materials are coded as follows: lead in fly ash and bottom ash from electricity production (FAC and BAC respectively), lead in iron and steel slag (SPIS), lead in refined zinc (RZP) lead in the bottom ash and fly ash from incineration (BAIN and FAIN respectively) and lead in sewage sludge (SS).

Table 3: Factors used for different flows (α_x in Eq. 12)

Flow	Factors (α_x)
Production of other heavy metals	
Emissions of lead to air	3E73exp(-0.0863*t)
Emissions of lead to water	3E182exp(-0.214*t)
Lead in iron and steel slag	12.1%
Lead in wastewater	0.675%
Lead in refined zinc	2.7%
Electricity production	
Coal – emissions of lead to air	0.4%
Coal – lead in fly ash	95.6%
Coal – lead in bottom ash	4%
Oil – emissions of lead to air	0.128 kg of lead per TJ of produced electricity
Oil production	Kg of lead per ton of produced oil
Emissions of lead to air	1.65 E-4
Emissions of lead to water	3.38 E-4
Emissions of lead to soil	3.45E-5
Sewage sludge disposal routes	
Incineration	62%
Land	15%
Others	11%
Incineration processes	
Emissions of lead to air	0.07%
Lead in fly ash	31.93%
Lead in bottom ash	68%
Landfilling	
Fly ash generated from incineration	50%
Bottom ash generated from incineration	10%
Sewage sludge	27%

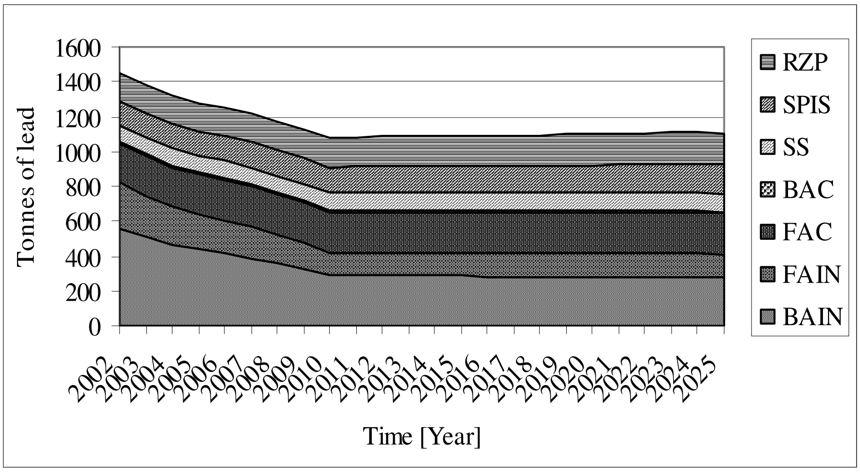

Fig. 12: Lead in secondary materials

Figure 12 shows that the total non-intentional flows of lead within secondary materials decreasing from 2002 to 2010 and slightly increasing thereafter. The initial decrease is largely is due to the decreasing stream of lead in fly and bottom ash from incineration plants, which constitute the largest flows of lead in secondary materials. The outflows of lead generated from the production of electricity from coal will increase due to an increase electricity production. The outflows of lead in slag and refined zinc will increase due to increases in zinc production. Possible ways of utilizing these secondary flows will be discussed in more detail in the following chapter.

Emissions of lead to the air

Air emission factors (α_x in Eq. 12) are given in table 3. Based on these figures and Eq.12, Figure 13 shows future emissions of lead to the air from: coal and oil fired power plants (AEEPC and AEEPO respectively), the production of other heavy metals (AEOHM), oil refining (AEOP) and incineration plants (AEIN).
The Figure shows total emissions of lead to the air to be decreasing over time due to the decline in emissions from the production of other heavy metals, which is the largest source of lead emissions to the air from non-intentional sources. Although, the demand for these other heavy metals is increasing, emissions of lead from their production are decreasing due to the assumed reduction in emission factors.
By contrast, atmospheric emissions of lead from electricity and oil production are increasing due to increase in demand for electricity and the increased production of refined oil in the NL and assumed constant emission factors for these processes.

Emissions of lead to water and soil

The factors used to estimate the water and soil emissions factors (α_x in Eq. 12) are given in table 3. These provide the basis for estimating future outflows of lead to water and soil from: the production of other heavy metals (WEOHM and WWOHM) and oil refining (WEOP and SEOP respectively), and the outflow of lead to water from sewage treatment plants (WEST).

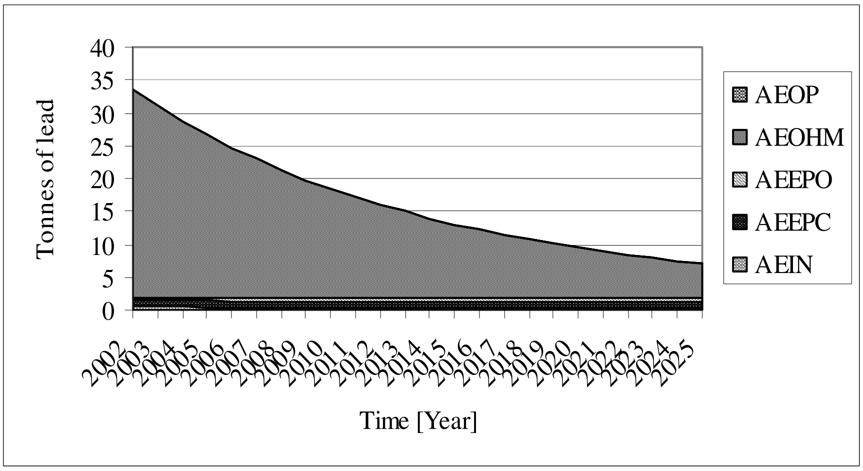

Fig. 13: Emissions of lead to air

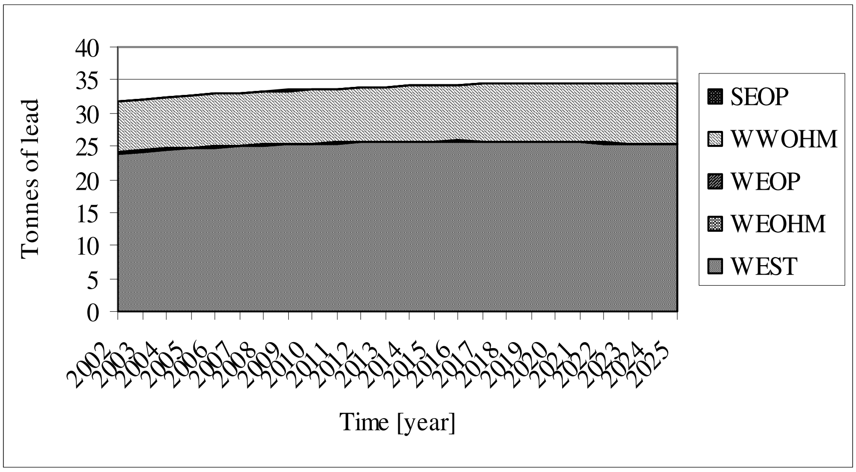

Fig. 14: Emissions of lead to water and soil

Figure 14 shows a slight overall increase in the total emissions of lead to water. The outflow of lead to wastewater from the production of other heavy metals is increasing due to an increase in lead input and assumed constant factor for this flow. Although, the input of lead is increasing, the emissions of lead to water from these processes are decreasing due to the assumed emission factors. The emissions of lead to water and soil from oil refining are increasing over time, due to increased activity in the NL and assumed constant emissions factors.

Lead in landfilled streams

The factors used to estimate the lead in landfilled streams (α_x in Eq. 12) are given in table 3. Based on these factors and calculations, Figure 15 shows the predicted future streams of lead in landfilled waste from several sources: the production of other heavy metals (LOHM), secondary materials (fly and bottom ashes) generated by incineration plants (LSM) and sewage sludge (LSS).

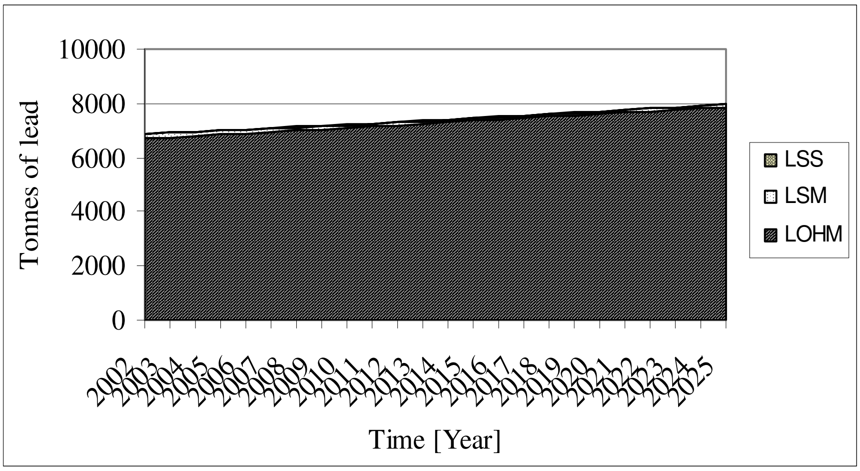

Fig. 15: Lead in the landfilled streams

Figure 15 shows that the outflow of lead in the landfilled stream is increasing, due to an increase in lead inputs and assumed constant factors. This figure includes the landfilled streams of secondary materials (fly ash, bottom ash and slag) generated from the production of electricity and heavy metals and incineration processes (see 4.2.1) and the landfilled stream of sewage sludge.

Leakage from landfill sites depends on many parameters, including the stock of materials (composition and amount) present at the site, the weather and hydrological conditions and the management of the site (covered or uncovered, treatment of waste water from the site etc.). The increase in lead in the landfill sites might lead to an increase in leaching of lead to the environment if these sites are not properly controlled.

6.4.3 Intentional and non-intentional flows of lead

Lead enters the economy and the environment through both intentional and non-intentional flows. These inflows of lead into the economy are partly released to different environmental media and partly re-used again. The following sections compare the inflow of lead into the economy and the release of lead to the environment from its intentional and non-intentional uses.

Intentional and non-intentional inflows of lead into the economy

The intentional inflow of lead into the Dutch economy is estimated as the inflow of lead through the inflow of its main applications into the stock in use. These applications include, batteries, lead sheet in buildings, cathode ray tubes, cable sheathings, small vehicle applications, gasoline and ammunition. The non-intentional inflow of lead into the Dutch economy is estimated as the amount of lead in the coal and oil used in electricity production, in zinc and iron ores processed in the NL, in phosphate fertilizers applied to Dutch agricultural soil, in sewage sludge and in incineration residues, as discussed in 4.1.
Fig. 16 shows the inflow of lead into the economy, distinguishing between intentional use and two forms of non-intentional use, mixed primary resources (MPR) which contain lead as a contaminant and the waste streams from intentional lead applications (WSIA).

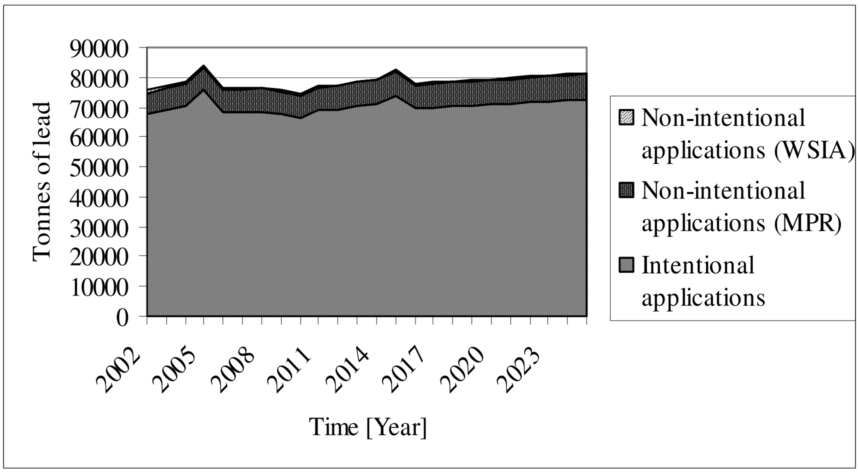

Fig. 16: The intentional and non-intentional inflows of lead into the economy

The figure shows that overall inflows of lead into the economy are slightly increasing over time. About 90% of the inflow of lead into the economy is related to intentional use. Non-intentional inflows of lead from the other two sources (MPR and WSIA) account for almost 10% of the total inflow. In 2002 about 90% of this fraction is related to the use of mixed primary resources and this is predicted to rise to 95% in 2025. The remaining 10-5 % is related to waste streams from intentional applications.

Intentional and non-intentional outflows of lead to the environment

The outflows of lead to the environment from its intentional inflows are estimated as the amount of lead released to environmental compartments (air, soil and water) during the production of lead and the production, consumption, recycling and disposal of lead-containing products. The outflows of lead to the environment from non-intentional inflows are related to emissions of lead to the air, water and soil from the

production of other heavy metals (zinc, iron and steel), the production of electricity from coal and oil, the production of refined oil, the use of phosphate fertilizers, and the treatment of waste water as discussed in sections 4.2.2, to 4.2.4. Fig. 17 shows the emissions of lead to the air from both intentional and non-intentional applications. Figure 18 shows the same for landfilled streams of lead.
As shown in Fig. 17, the emissions of lead to the air from its intentional applications are greater than those related to its non-intentional applications from 2002 to 2006, but from 2006 onwards this situation is reversed. Figure 18 shows the landfilled stream of lead related to its non-intentional applications to be far greater than the stream related to the intentional applications of lead. In 2002, the landfilled stream of lead related to its non-intentional flows was 76% of the total, increasing to 87% in 2025.

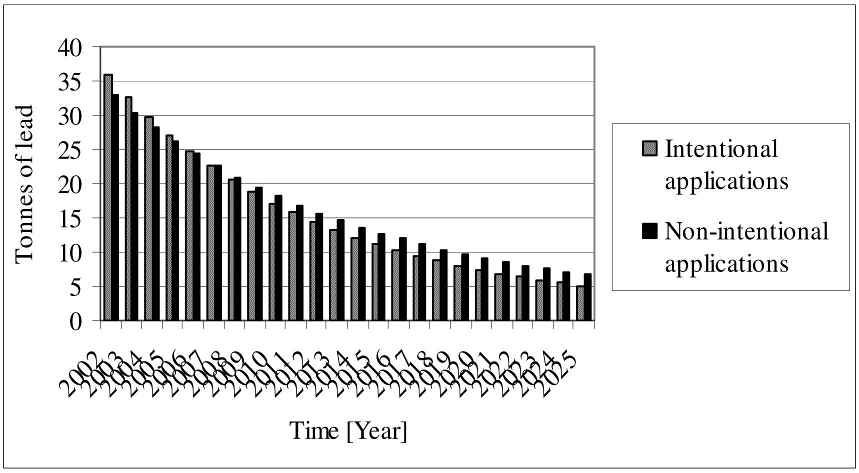

Fig. 17: Emissions of lead to the air as a result of intentional and non-intentional applications

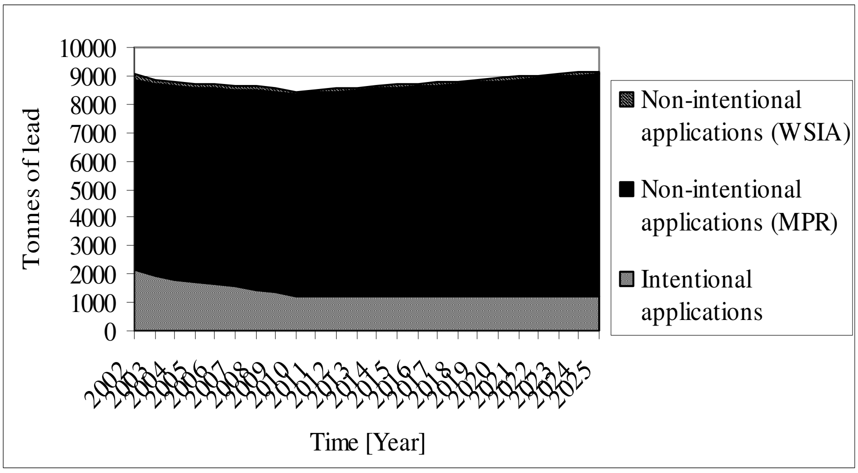

Fig. 18: Landfilled streams of lead as a result of intentional and non-intentional applications

6.5 Discussion and conclusions

In this chapter the non-intentional flows of lead have been modelled, their direct environmental consequences have been evaluated and a comparison made with the intentional flows of lead. The analysis was conducted using a dynamic model for the non-intentional flows of lead that combines non-intentional flows originating from waste streams from the intentional use of lead together with those originating from mixed primary resources that contain lead as a contaminant.
Regression analysis was used to determine the most variables with the greatest influence on the demand for different applications and the derived equations from the analysis were used to estimate future

developments. The expected explanatory variables, GDP, population, per capita GDP and prices, appeared to adequately explain the trends of production for electricity, oil and metals and the outcome of the regression analysis is comparable to those from other studies for the demand for these products. In the case of phosphate fertilizers, it was not possible to explain the trend of the use of fertilizers by the tested variables, due to the impact of policy. Therefore time was used as the explanatory variable since it was able to capture the influence of other time-related variables on fertilizer use.

In some cases, time is used as a proxy for technological change, policy aspects and other time-related variables. This approach is also used in the linear and exponential time models used for the analysis of the intensity of use of metals (Tiltone, 1990, Guzman et al., 1960 and Roberts, 1996). Although these models give good empirical results, they have some limitations, mainly due to the assumption that the net effect of all time related variables is constant over the time examined (Guzman et al., 1960).

The overall input of lead into the economy through a combination of direct routes (intentional flows) and indirect routes (non-intentional flows) is expected to increase in the future. The non-intentional flows of lead originating from the waste streams of intentional applications are expected to decrease over time, due to more effective recycling. However, flows of lead as a contaminant in mixed primary resources appear to be increasing. The only non-intentional inflow related to mixed primary resources that is decreasing over time is the one associated with phosphate fertilizers. This decrease is due to the policy aiming to reduce the use of chemical fertilizers in the Netherlands.

The total non-intentional outflow of lead to the air, water, soil and landfill sites is expected to increase in the future. The total emissions of lead to the air from the direct routes and indirect routes are expected to decrease in the future, while emissions of lead to water are expected to increase. In terms of pollution, the most important source of emissions of lead is the production of other heavy metals followed by sewage treatment plants. The production of iron and steel accounts for the most emissions of lead to the air, although these are decreasing due to assumptions about the emission factor. The second largest flow of lead to the air is emissions from coal-fired power plants. The incineration of the waste stream of intentional applications of lead, electricity production from oil and the production of oil make small contributions to atmospheric lead emissions.

The largest flow of lead to water originates from sewage treatment plants, followed by emissions from the production of other heavy metals and then the production of oil. All these flows are increasing over time.

The total landfilled stream of lead from the direct and indirect routes is expected to increase in the future due to the increase in the landfilled stream of lead from indirect routes. The main source of lead in landfill sites is the solid waste generated by zinc production, which is increasing over time.

The total non-intentional flow of lead in secondary materials will decrease from 2002 to 2010. This is due to the declining volumes of streams of fly ash and bottom ash generated by incineration plants, which constitute the largest flows of lead in secondary materials. The other flows of lead in secondary materials (fly ash and bottom ash from coal fired power plants, lead remains in zinc products, iron and steel slag, sewage sludge) are increasing over time.

Bottom and fly ash from incineration are the main source of available lead for possible recovery, followed by fly ash from coal fired power plants. The environmental and economic consequences of utilizing the secondary materials (fly ash, bottom ash and slag) generated from incineration plants, coal fired power plants and heavy metals production processes will be investigated in the following chapter.

Lead inputs into the economy through indirect routes (non-intentional flows) account for about 10% of the total input of lead into the economy. However these flows account for a far higher proportion of lead emissions to the environment: almost half of the emissions to air and water originate from non-intentional flows of lead, and this fraction is expected to rise in the future. Approximately three quarters of the flow of lead to landfill sites comes from non-intentional applications and this fraction is expected to increase further in the future, to 87% in 2025. Therefore in terms of both waste and emissions, the non-intentional flows are the most important ones.

The non-intentional flows of lead originating from mixed primary resource applications, especially those related to the production of zinc, iron and steel and electricity generation from coal, are larger than those originating from the waste streams of intentional applications of lead. Thus particular attention should be given to the management of the residues generated from these processes. In terms of metals, the policy aimed at increasing the incineration of sewage sludge in an attempt to minimize the amount of sludge being used on the soil or landfilled might not be effective if the incineration residues continue to be partly landfilled without the removal of the metals.

References

Annema, J.A., Paardekoper, E.M., Booij, H., Oers, L.F.C.M. van, Voet, E. van der, Mulder, P.A.A. Stofstroomanalyse van zes metalen (Substance flow analysis of six metals). RIVM report No. 601014010, Bilthoven, The Netherlands. 1995.

Ayres, R., Ayres, L., Rade, I. The life cycle of copper, its co-products and byproducts. Kluwer Academic Publishers, Dodrecht, The Netherlands, 2003.

Bauer, G., Deistler, M., Gleiß, A., Glenck, E., Matyus, T. Identification of material flow systems. Environ. Sci. & Pollut. Res. 1997; (2): 105 – 12.

Bouwman, A. F. Hoek, K.W. van der. Scenarios of animal waste production and fertilizer use and associated ammonia emission for the developing countries. Atmosphere Environment1997; 31 (24): 4095-102.

Bringezu, S., Fischer-Kowalski, M., Kleijn R., Palm, V. Regional and national material flow accounting: From paradigm to practice of sustainability. Proceedings of the ConAccount workshop. Leiden, The Netherlands, 1997.

British Geological Survey. World Mineral Statistics: Production: Exports: Imports. 1988-2000.

Burney N. Socioeconomic development and electricity consumption. Energy Economics 1995; 17 (3): 185-95.

Central Bureau of Statistics NL (CBS). Environmental Statistics of the Netherlands 1993. The Hague, sdu/Publisher, 1993.

Central Bureau of Statistics NL (CBS), 2003. http://statline.cbs.nl/StatWeb/start.asp?lp=Search/Search

Crompton, P. Future trends in Japanese steel consumption. Resources Policy 2000; 26 (2): 103-14.

Egmond, P.M. van, Hoogervorst, N.J.P., Van den Born, G.J., Hage, B. Van Tol, S. De Millieu Effecten van de Integrale Aanpak Mestproblematiek (IAM). Report No. 773004009. RIVM, Bilthoven, The Netherlands, 2001.

Elshkaki, A., Voet, E. van der, Holderbeke, M. van, and Timmermans, V. The environmental and economic consequences of the developments of lead stocks in the Dutch economic system. Resources, Conservation and Recycling 2004; 42: 133-154.

Eurostate. Eurostat yearbook. Office for official publications of the European communities Luxembourg, Luxemburg, 1987-2000.

Finnveden, G., Albertsso, A., Berendson, J., Eriksson, E., Hoglund, L., Karlsson, S., Sundquist, J. Solid waste treatment within the framework of life cycle assessment. J. Cleaner Production 1995; 3 (4): 189-99.

Food and Agriculture Organization of the United Nation (FAO), 2003. http://faostat.fao.org/faostat/collections?subset=agriculture

Guinée, J.B., Bergh, J.C.J.M. van den, Boelens, J., Fraanje, P.J., Huppes, G., Kandelaars, P.P.A.A.H., Lexmond, Th.M., Moolenaar, S.W., Olsthoorn, A.A., Udo de Haes, H.A., Verkuijlen, E., Van der Voet, E. Evaluation of risks of metal flows and accumulation in economy and environment. Ecological Economics 1999; 30 (1): 47-65.

Guinée, J.B., Udo de Haes, H.A., Huppes, G. Quantitative life cycle assessment of products: 1: Goal definition and inventory. J. Cleaner Production 1993; 1: 3-13.

Guzman, J., Nishiyama, T., Tilton J. Trends in the intensity of copper use in Japan since 1960. Resource Policy 2004. In press.

Hasselriis, F., Licata, A.. Analysis of heavy metals emissions data from municipal waste combustion. Jornal of Hazardous Materials 1996; 47: 77-102.

Heijungs R. Chain Management by Life Cycle Assessment (CMLCA): http://www.leidenuniv.nl/cml/ssp/index.html, CML, Leiden University, The Netherlands. 2000.

Heijungs, R., Guinée, J.B., Huppes, G., Lankreijer, R.M., Udo de Haes, H.A., Wegener Sleeswijk, A., Ansem, A.A.M., Eggels, P.G., Duin, R. van, Goede, H.P. Environmental life cycle assessment of products. Guide and background. CML, Leiden University, Leiden, The Netherlands, 1992.

Image team. The Image 2.2 implementation of the SRES scenarios: A comprehensive analysis of emissions, climate change and impacts in the 21st century. RIVM CD-ROOM publication 481508018, National Institute of Public Health and the Environment, Bilthoven, The Netherlands, 2001.

Kleijn, R., Huele, R., Voet, E. van der. Dynamic Substance Flow Analysis: the delaying mechanism of stocks, with the case of PVC in Sweden. Ecological Economics 2000; 32 (2): 241-54.

Kosson, D.S., Sloot, H.A. van der, Eighmy, T.T. An Approach for Estimation of Contaminant Release During Utilization and Disposal of Municipal Waste Combustion Residues, Journal of Hazardous Material 1996; 47: 43-75.

Mergos, G.J. and Stoforos Ch.E. Fertilizer Demand in Greece. Agricultural Economics 1997; 16: 227-35.

Metallgesellschaft Aktiengesellschaft (annual). *Metallstatistik*. Frankfurt am Main.

Ministerie Van Volkshuisvesting (VROM). Emissies in Nederland : Bedrijfsgroepen en regio's. Directoraat Generaal Milieubeheer, Hoofdinspectie Milieuhygiëne, Afdeling Emissieregistratie en Informatiemanagement, Den Haag, Netherlands, 1990-1999.

Mohamed, Z., Bodger, P. Forecasting electricity consumption in New Zealand using economic and demographic variables. Energy2004; article in press

Moore, D. J., Tilton, J. E., Deborah J. Shields. Economic growth and the demand for construction materials. Resources Policy 1996; 22 (3): 197-205.

Patra, M., Bhowmik, N., Bandopadhyay, B., Sharma, A. Comparison of mercury, lead and arsenic with respect to genotoxic effects on plants systems and the development of genetic tolerance. Environmental and Experimental Botany 2004; 52: 199-223.

Ranjan, M., Jain, V.K. Modelling of electrical energy consumption in Delhi. Energy 1999; 24: 351-61.

Roberts, M. C. Metal use and the world economy. Resources Policy 1996; 22 (3): 183-96.

Sandelin, K., Backman, R., Kouvo, P. A simple method for predicting distribution of trace elements in pulverized coal-fired power systems. Proceeding of the 5th international conference on technology and combustion for a clean environment. Lisbon, Portugal, 1999.

Sandelin, K., Backman, R. Trace elements in two pulverized coal-fired power stations. Environmental Science and Technology 2001; 35: 826-34.

Singh, R.P., Tripathi, R.D., Sinha, S. K., Maheshwari, R., Srivastava, H.S. Response of higher plants to lead contaminated environment. Chemosphere 1997; 34 (11): 2467-93.

Tiltone, J. World Metal Demand – Trends and Prospects, Resources for the Future, Washington D.C., 1990.

USGS 1980-1990. http://minerals.usgs.gov/minerals/pubs/commodity/

Van der Sloot, H.A. Present Status of Waste Management in the Netherlands, Waste Management 1996; 16 (5/6): 375-83.

Van der Voet, E. Substances from cradle to grave. PhD thesis, Leiden University, 1996.

Vereniging Van Afvalverwerkers (VVAV), 2001. Jaarverslag.

Wu, C.M.L., Yu, D.Q., Law, C.M.T., Wang, L. Properties of lead free solder alloys with rare earth element addition. Material Science and Engineering 2004; Ru4, 1-44.

Xiong, Z. Bioaccumulation and physiological effects of excess lead in a roadside pioneer species Sonchus Oleraceusl. Environmental Pollution 1997; 97 (3): 275-9.