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

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Chapter 7 Long-term Consequences of Non-intentional Flows of Substances: Long Term Consequences of Substances Presence in Utilized Secondary Materials*

Abstract

In addition to the substances' intentional or functional use, substances exist in applications as contaminants. This non-intentional presence is either due to the natural occurrence of substances in ores or due to anthropogenic sources. The presence of substances in applications as contaminants may have environmental and economic consequences.

This chapter investigates the long-term environmental and economic consequences of the existence of substances in applications as contaminants using a dynamic substance flow-stock model. The model is illustrated by non-intentional flows and stocks of lead in roads, buildings, and agricultural soil.

The model estimates the non-intentional flows of lead into different applications based on the utilized flow of the relevant materials and lead content in these materials.

The model shows that the supply of secondary material and consequently the availability of lead in non-intentional applications is increasing as the demand for electricity and other heavy metals (zinc, iron and steel) are increasing. Moreover, the reuse of road construction and building materials is leading to an increase of the availability of lead. The increase generation of secondary materials and recycling of demolished construction materials combined with possible market saturation may have environmental and economic consequences in the future. The increase availability of lead and other materials will prevent the use of secondary materials in other applications, thus increasing the stock of lead in landfill sites.

The model also shows that the monetary value of lead in the generated secondary materials is considerable. If combined with other materials that are possible to recover, the recovery of metals might be economically visible.

Key words: Substance Flow Analysis, Dynamic Modelling, Non-intentional Applications, and Lead

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7.1 Introduction

Large quantities of secondary materials are generated from energy and materials production related activities as a result of an increasing consumption of energy and materials and recycled demolished construction materials.

Currently secondary materials are either utilized in the construction industry or disposed in landfill sites. In the future, the market of construction material might not be able to absorb the increasing amount of secondary materials, consequently an increase in the disposal to be expected and thus an increase in the environmental and economic burden. Alternatively, a new utilization option should be found, however, the availability of substances non-intentionally in secondary materials may limit their use. On the other hand, the increase generation of secondary material can be seen as a possible solution for the expected shortage in the availability of some metals. Secondary materials contains several metals such as Lead, Zinc, Copper, Germanium, Gallium and Indium. For some metals the concentration in secondary materials is more than their concentration in their mineral resources, which make them a potential secondary sources for these metals.

This has raised the concern about the potential environmental and economic consequences of the utilization and disposal activities of secondary materials mainly due to their constitutes.

Recently, the environmental and economic consequences of the existence of substances non-intentionally in applications and the applicability of secondary materials for utilization in different areas have been the focus of several studies. The environmental and economic consequences of non-intentional flows of substances in general and the utilization of secondary materials are evaluated by the leaching test (Kosson, et al., 1996 and Nunes et al., 1996), Substance Flow Analysis (Van der Voet et al., 1994) and Life Cycle Assessment (Mroueh et al., 2001). Although, the leaching test can contribute to the study of pollution aspects related to the utilization of secondary materials, it cannot contribute to the resource aspects (Roth and Eklund, 2003). It is argued by Roth and Eklund that the leaching tests have to be complemented by the broader system boundary used in SFA and LCA to evaluate the resource and environmental impacts of the reuse of by-products in construction materials. Moreover, it is argued by Iyer and Scott, that to evaluate the applicability of secondary materials in the current utilization options and the possible new options in the future, a long-term analysis is required (Iyer and Scott, 2001).

This chapter is aimed at evaluating the long-term environmental and economic consequences of the presence of lead non-intentionally in applications using a dynamic substance flow-stock model.
SFA system represents the substance chain from cradle to grave. SFA is widely used in the study of both pollution and resources aspects. It is used to describe and analyze substance flows and stocks in the environment and the economy, identify major flows and accumulations, identify causes of pollution problems and assess the effectiveness of measures (Van der Voet, 1996). Moreover, the dynamic modelling of SFA allows for the analysis of the long-term development of the stocks and flows, the forecasts of future emissions and waste streams from built-up stocks in society and the inclusion of loops and cycles within the system (Elshkaki et al., 2004).

Lead is chosen due to its extensive use (intentionally and non-intentionally) and due to its toxic characteristics.

Environmental consequences

Non-intentional flows find their way into the environment via several roads. Via phosphate fertilizer, lead enters the agricultural chain and accumulates there, leading to significant concentrations in manure. As a result of processing other heavy metals ores (zinc and iron ores), lead is accumulated in landfill sites, and is applied in roads materials. As a result of processing fossil fuels (coal and oil) in electricity production, lead accumulates in roads and in buildings via the use of ashes in building materials. As a result of processing lead containing waste, lead accumulates in roads, in landfill sites and in agricultural soil. The accumulated lead in roads, buildings, agricultural soil and landfill sites may leach to the soil or ground water.

Economic consequences

The supply of secondary materials such as fly ash, bottom ash, slag, sewage sludge is not dependent on the demand, they are by-products of other processes. On the other hand, they are somehow inter linked within the economic system. The supply of the incineration residues (bottom and fly ashes) is ultimately linked to the demand for the intentional applications. The supply of coal-fired power plants by-products (fly and bottom ashes) and iron and steel slag is ultimately linked to the electricity demand and the demand for iron and steel. Moreover, if these materials weren't there, others would have been used which would have to be purchased. They thus replace resources. The use of fly ash in road construction materials is replacing the use of natural mineral aggregate and the use of fly ash in agriculture is replacing commercial fertilizers (Ferreira et al., 2003).

Secondary materials generated from incineration plants, coal fired power plants, production of metals, and wastewater treatment plants contain a variety of metals. These heavy metals are valuable resources that can be recovered and put to use again (Krook et al., 2004 and Tateda et al., 1997). Therefore, the remaining lead in the utilized and landfilld secondary materials without recovery can be regarded as an economic loss. On the other hand, the utilization of secondary materials in roads and buildings could reduce the economic burden associated with waste dumping. It can also reduce the use of primary resources (natural gravel and crushed rock) and the energy cost associated with their use. The presence of lead and other heavy metals in secondary materials, however, may limit their use.

Utilization of secondary materials

Secondary materials generated from coal-fired power plants, incineration plants and metallurgic industry (fly ash, bottom ash and slag) are used in several applications in the area of construction industry, material recovery and agriculture. Fly ash generated from coal fired power plants, fly and bottom ash generated from the incineration of mixed solid waste and slag generated form the metallurgic industry are utilized mainly in road and building construction materials, however, these secondary materials can also be utilized in several other applications. Coal fired power plants fly ash can be utilized in the production of zeolites which is suitable for application as an immobilizer for air pollutants, the production of Glass materials and composite materials, adsorbent for waste management, waste stabilization, and materials recovery (Iyer and Scott, 2001). Coal-fired power plants fly ash can also be used in land applications with and without sewage sludge (Sajwan et al., 2003). Fly ash generated from the incineration of mixed solid waste can be utilized in agriculture either as fertilizer or amendment, in the production of adsorbing materials, and as sludge conditioning (Ferreira et al., 2003).

Recovery of metals

Several studies are conducted to examine the recovery of metals from fly ash generated from the incineration plants (Nagib and Inoue, 2000 and Izumikawa, 1996). Nagib and Inoue reported the possibility of recovering more than 97% of lead and 68% of zinc from fly ash generated from municipal incineration plants by acid and/or alkaline leaching and Izumikawa reported the possibility of recovering almost 100% of the heavy metals (Izumikawa, 1996).

Metals such as Iron, gallium, vanadium, nickel and magnesium can also be recovered from coal fly ash (Fang and Gesser, 1996 and Murase et al. 1998).

Tateda et. al estimated the losses of lead from municipal solid waste incineration ash, thermal power station coal ash, and sludge incineration ash from wastewater treatment facilities in Japan to be 22162 ton of lead/year and the monetary losses of 10.4 million dollar/year (Tateda et al., 1997).

7.2 Methodology

The non-intentional flows and stocks of lead originate from coal fired power plants, production of heavy oil, iron and steel, zinc and copper, waste water treatment, and the incineration of lead intentional applications are shown in figure 1.

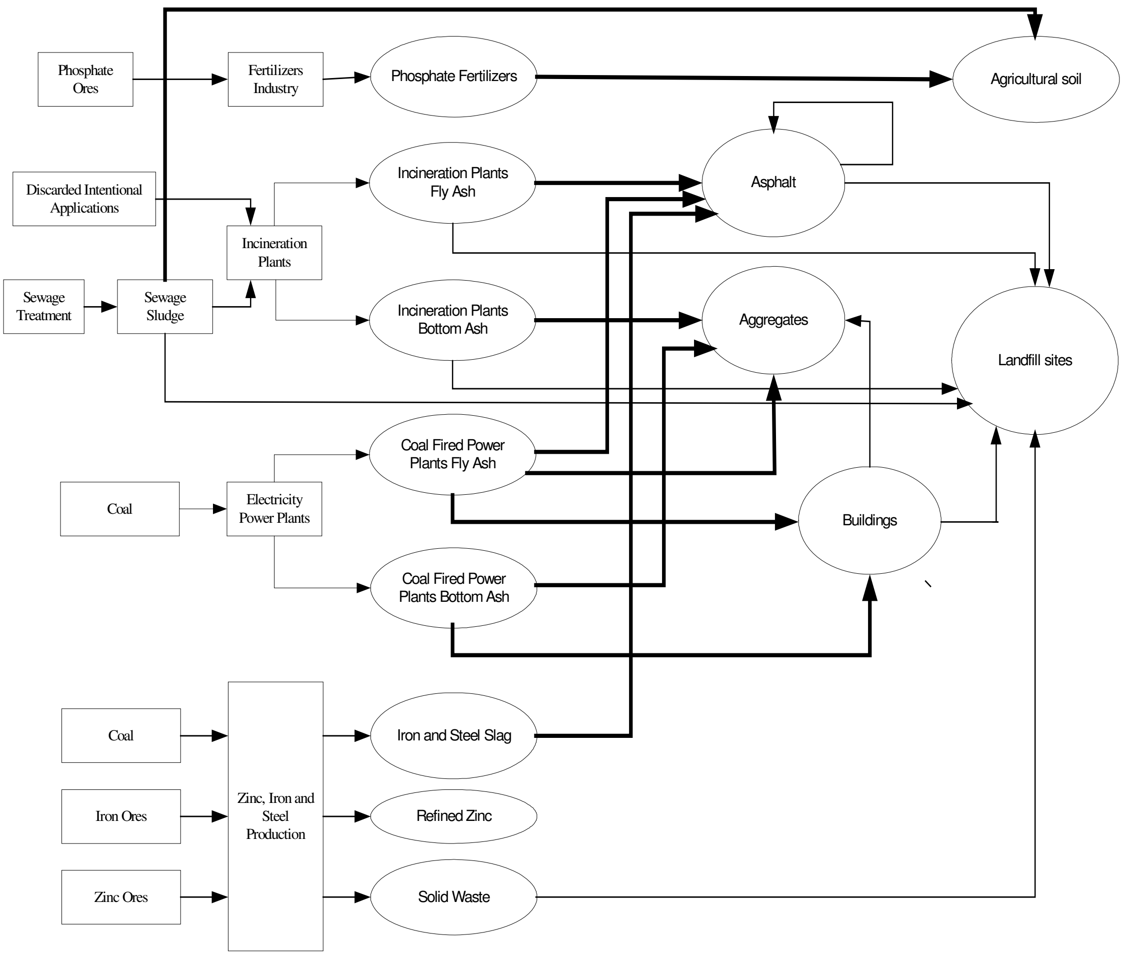

Fig. 1: Lead non-intentional flows and stocks in the Dutch economy and environment

7.2.1 General setup of the model

Modelling lead inflow into the stock of non-intentional application s

The inflow of lead into the stock of a certain non-intentional application (road construction materials) or landfill sites from a specific secondary materials (fly ash, bottom ash) is estimated based on the amount of lead in the generated stream of secondary material and the utilized fraction of this stream as given by Eq. 1.

$$F^{in}_{L,x,app}(t) = \beta_x(t) \cdot F^{out}_{L,x}(t) \quad (1)$$

$F^{in}_{L,x,app}(t)$ is the inflow of lead from a certain secondary material into the application at time t, $F^{out}_{L,x}(t)$ is the outflow of lead in the generated secondary material from a certain process at time t and β_x is the utilization factor at time t.

The inflow of lead through a specific secondary material into landfill sites is estimated as given by Eq. 2.

$$F^{in}_{L,x,L}(t) = F^{out}_{L,x}(t) - F^{in}_{L,x,app}(t) \tag{2}$$

$F^{in}_{L,x,L}(t)$ is the inflow of lead from a certain secondary material into the landfill sites at time t

Modelling lead outflow from the stock of non-intentional application

The outflow of lead out of the stock of road construction materials takes place through two processes: leaching and delay. Leaching may occur during use and delay is related to the discarding of products after use.

The discarded outflow of a certain product depends mainly on the product inflow and its life span. The discarded outflow is estimated as a delayed inflow, corrected for the leaching that have taken place during use, as given by Eq. 3:

$$F^{out}{}_{D}(t) = F^{in}{}_{C}(t - L_U) - \sum_{i=1}^{L_U} C \cdot F^{in}{}_{C}(t - L_U) \cdot (1 - C)^{i-1} \tag{3}$$

Where $F^{out}{}_{D}(t)$ is the outflow due to the delay mechanism at time t and L_U being the life span of the product in use.

The leaching outflow is estimated as a fraction of lead stock as given by Eq. 4.

$$F^{out}{}_{E}(t) = C \cdot S(t) \tag{4}$$

Where $F^{out}{}_{E}(t)$ is the leaching outflow at time t, C being the emission factor and S is the stock

Modelling lead accumulation in non-intentional application

The change of the magnitude of the stock over time is the difference between the inflow and the outflow as given by Eq. 5.

$$\frac{dS}{dt} = F^{in}(t) - F^{out}(t) \tag{5}$$

$F^{in}(t)$ is the inflow of lead through the utilized streams at time (t), $F^{out}(t)$ is the outflow of lead at time (t).

7.2.2 Estimation of lead inflows into stock-in-use of non-intentional applications

Road construction materials (aggregates and asphalt)

Road construction materials (Aggregate)

The inflow of lead into the stock of road aggregates originates from two sources: bottom ash generated from the incineration of lead intentional applications and sewage sludge (BAIN) and bottom ash and fly ash generated from coal fired power plants (BAC and FAC).

$$F^{in}_{agg}(t) = F^{in}_{UBAIN}(t) + F^{in}_{UBAC}(t) + F^{in}_{UFAC}(t) \tag{6}$$

The past inflow of lead into the stock of road construction materials (aggregates) through the utilized stream of bottom ash generated from the incineration plants (UBAIN) from 1980 through 2001 is estimated based on the incinerated mixed solid waste stream and the quantity of BAIN being applied in road construction materials (aggregates), combined with data on the lead content of this stream. Data on the

utilized stream of BAIN from 1988 through 2001 are available (VVAV, 2001). Before 1988, no data are available. We assume that the use started in 1980, and that the utilized amount of BAIN in the Netherlands before 1988 is the same as the amount in 1988. The lead content in BAIN is assumed to be 1500 mg lead/kg ash (Kosson, et al., 1996).
The future inflow of lead into the stock of road construction materials (aggregates) from BAIN is estimated as given by Eq. 1. The partitioning of lead to BAIN and the utilization factor, which are estimated based on (Sloot, 1996), are given in table1. The utilization factor of BAIN in the past is assumed to be valid for the future.

Table 1: The amount of lead in the generated secondary materials and their utilization fractions

Flow	Partitioning of lead	Utilization factors
BAIN	68%	90% as aggregate
FAIN	32%	50% as asphalt
BAC	4%	47% as aggregate
		53% as building materials
FAC	95.6%	20% as aggregate
		20% as asphalt
		60% as building materials
SPIS	12.1%	100% as asphalt
SS	80%	15% for land preparation

The past and future inflow of lead (from 1987 onwards) into the stock of road construction materials (aggregates) through the utilized stream of bottom ash generated from coal fired power plants (UBAC) is estimated as given by Eq. 1. The partitioning of lead to BAC (Sandelin and Backman, 2001 and Sandelin et al. 1999), and the utilization factor (VVAV, 2001), are given in table 1. From 1980 through 1987, the inflow of lead is assumed to be the same as the inflow in 1987.

The past and future inflow of lead (from 1987 onwards) into the stock of road construction materials (aggregates) through the utilized stream of fly ash generated from coal-fired power plants (UFAC) is estimated as given by Eq. 1. The partitioning of lead to FAC (Sandelin and Backman, 2001 and Sandelin et al. 1999), and the utilization factor of FAC (Eymael and Cornelissen, 1996), are given in table 1. From 1980 through 1987, the inflow of lead is assumed to be the same as the inflow in 1987.

Road construction materials (Asphalt)

The inflow of lead into the stock of road construction materials (asphalt) originates from three sources: fly ash generated from the incineration of lead non-intentional applications and sewage sludge (FAIN), fly ash generated from coal fired power plants (FAC) and iron and steel slag (SPIS). Recycling might further influence the stocks. When old asphalt is reused to produce new, a closed loop might evolve leading to ever increasing concentrations of lead.

$$F_{asph}^{in}(t) = F_{UFAIN}^{in}(t) + F_{UFAC}^{in}(t) + F_{USPIS}^{in}(t) + F_{UR}^{in}(t) \qquad (7)$$

The past inflow of lead into the stock of road construction materials (asphalt) through the utilized stream of fly ash generated from the incineration plants (UFAIN) from 1980 through 2001 is estimated based on the incinerated mixed solid waste stream and the quantity of FAIN being applied in road construction materials (asphalt), combined with data on the lead content of this stream. Data on the utilized stream of FAIN from 1988 through 2001 are available (VVAV, 2001). Before 1988, no data is available. We assume that the use started in 1980, and that the utilized amount of FAIN in the Netherlands before 1988 is the same as the amount in 1988. The lead content in FAIN is assumed to be 4000 mg lead/kg, based on (Kosson, et al., 1996).

The future inflow of lead into the stock of road construction materials (asphalt) from FAIN is estimated as given by Eq. 1. The partitioning of lead to FAIN (Sloot, 1996) and the utilization factor (Sakai et al., 1996) are given in table 1. The utilization factor of FAIN in the past is assumed to be valid for the future.

The past and future inflow of lead (from 1987 onwards) into the stock of road construction materials (asphalt) through the utilized stream of fly ash generated from coal fired power plants (UFAC) is estimated as given by Eq. 1. The partitioning of lead to FAC and the utilization factor of FAC are given in table 1. From 1980 through 1987, the inflow of lead is assumed to be the same as the inflow in 1987.

The past and future inflow of lead into the stock of road construction materials (asphalt) through the utilized stream of the slag generated from iron and steel production (USPIS) from 1980 onwards is estimated as a fraction of lead input through iron ores and coal used in steel production.
The inflow of lead through iron ores is estimated as 0.2 kg of lead per ton of iron and the inflow of lead through coal is estimated as 8.32E-3 kg of lead per ton of steel.

Building materials

The inflow of lead into the stock of buildings materials originates from bottom ash (BAC) and fly ash (FAC) generated from coal fired power plants.

$$F_{build}^{in}(t) = F_{UFAC}^{in}(t) + F_{UBAC}^{in}(t) \qquad (8)$$

The past and future inflow of lead (from 1987 onwards) into the stock of building materials through UBAC is estimated as given by Eq. 1. The partitioning of lead to BAC and the utilization factor of BAC are given in table 1. From 1980 through 1987, the inflow of lead is assumed to be the same as the inflow in 1987.

The past and future inflow of lead (from 1987 onwards) into the stock of building materials from through UFAC is estimated as given by Eq. 1. The partitioning of lead to FAC and the utilization factor FAC are given in table 1. From 1980 through 1987, the inflow of lead is assumed to be the same as the inflow in 1987.

Materials used in agricultural soil

The inflows of lead into the agricultural soil originate from four sources: air, phosphate fertilizers, sewage sludge, and manure.

$$F_{agrsoil}^{in}(t) = F_{ag,air}^{in}(t) + F_{ag,fert}^{in}(t) + F_{ag,SS}^{in}(t) + F_{ag,manure}^{in}(t) \qquad (9)$$

The past and future non-intentional flow of lead through phosphate fertilizers is estimated on the basis of the past and future use of phosphate fertilizers and the amount of lead in fertilizers. The amount of lead in fertilizers is estimated as 0.135 kg of lead per ton of fertilizer (Annema et al., 1995).

Lead in sewage sludge is partly ends up in agricultural soil due to the use of sewage sludge in land preparation. The inflow of lead into the agricultural soil through sewage sludge is estimated as 15% of the total lead in sewage sludge. Lead in sewage sludge is estimated as 80% of total lead input to sewage treatment plants.

The inflow of lead as a result of using manure is treated as internal loop in the agricultural sector.

7.2.3 Estimation of non-intentional outflows of lead from stock-in-use

Road construction materials (aggregates and asphalt)

The outflow of lead out of the stock of road construction materials takes place through two processes: leaching and delay.
Leaching may occur during use of road construction materials as a result of processes in the soil, which may free the lead out of the road materials. The release of lead from road construction materials is determined by the availability of lead, fill depth, infiltration rate, lead solubility as a function of residue PH (Kosson, et al., 1996). Kosson et al. evaluated the cumulative release of lead over 100 years for several management options (road construction materials and disposal). They report a release of small amount of lead, below the maximum level of increasing the soil concentration over 100 years (85mg Pb/kg). Using liner system and leachate collection reduces the actual environmental impact of the disposal or utilization. Although there is a release of small amount of lead from road construction materials, the leaching flow will be ignored due to the conclusions of several studies that this flow does not have environmental consequences and due to the fact that the flow is too small to effect the discarded outflow.
Delay is related to the discarding of products after use. The discarded outflow of a certain product depends mainly on the product inflow and its life span. The discarded outflow is estimated as a delayed inflow, corrected for the leaching that have taken place during use, as given by Eq. 3:

For road aggregates, we assume that the aggregate is not being replaced but stays in place as long as the road is there. That implies that the stock of lead in aggregates is treated as a sink: no outflow takes place at all. Road asphalt is replaced frequently in the process of maintenance and repair of the roads. The average life span of asphalt on the Dutch roads is unknown. We assume, arbitrarily, an average life span of 10 years. Therefore, the only outflow accounted for in road construction materials is the outflow of lead in asphalt due to the delay mechanism as given by Eq. 3. The discarded outflow of asphalt is reused in road construction materials with almost 100% (Schimmoller, 2000).

Buildings materials

The outflow of lead out of the stock of building materials takes place through two processes: leaching and delay. The yearly emissions of lead from buildings material is ignored due to the same reasons mentioned for road construction materials (Ferreira et al., 2003). The discarded outflow is estimated as given by Eq. 3. The average life span of building materials is assumed to be 50 years.
The discarded outflow of building materials is reused in road construction materials with almost 100% (Schimmoller, 2000).

Materials used in agricultural soil

The outflows of lead from the agricultural soil take place through the uptake of lead by food and fodder and the leaching to the ground water. The three outflows are estimated as a fraction of the lead stock in agricultural soil as given by Eq. 4. The uptake coefficients for food and fodder are estimated as 0.0018 and 0.0142 respectively. The leaching rate is estimated as 0.0182.

7.2.4 Estimation stocks of lead in the economy

The change of the magnitude of the stock over time is the difference between the inflow and the outflow as given by Eq. 5.

Road construction materials (aggregates and asphalt)

The stock of lead in road construction materials (aggregates) from 2003 onwards is estimated as given by Eq. 5. The initial stock of lead in aggregates in 2002 is estimated based on the utilized stream from 1980 through 2001 of BAIN, BAC and FAC as given by Eq. 10.

$$ISAG(t) = \sum_{t=1980}^{2001} F_{UBAIN}^{in}(t) + F_{UBAC}^{in}(t) + F_{UFAC}^{in}(t) \tag{10}$$

The stock of lead in road construction materials (asphalt) from 1991 onwards is estimated as given by Eq. 5. The initial stock of lead in asphalt in 1990 is estimated based on the utilized stream from 1980 through 1990 of FAIN, FAC, and SPIS as given by Eq. 11.

$$ISAS(t) = \sum_{t=1980}^{1990} F_{UFAIN}^{in}(t) + F_{UFAC}^{in}(t) + F_{USPIS}^{in}(t) \tag{11}$$

The stock is further influenced by recycling. The discarded asphalt is reused with almost 100% in the Netherlands [24].

Buildings materials

The stock of lead in building materials from 1991 onwards is estimated as given by Eq. 5. The initial stock of lead in buildings in 1990 is estimated based on the utilized stream from 1980 through 1990 of FAC and BAC as given by Eq. 12.

$$ISB(t) = \sum_{t=1980}^{1990} F_{UFAC}^{in}(t) + F_{UBAC}^{in}(t) \tag{12}$$

Materials used in agricultural soil

The stock of lead in agricultural soil from 2002 onwards is estimated as given by Eq. 5. The initial stock of lead in agricultural soil in 2001is estimated based on the accumulated amount of lead from 1980 through 2000 (CBS, 2003).

7.2.5 Estimation of the economic consequences

The economic consequences of the presence of lead and other metals in secondary materials are not limited to the value of these metals but also to the economic benefit due to the saving in the costs associated with materials dumping and the use of primary materials. The analysis presented here is limited to the economic value of the recovered lead from secondary materials, however, to estimate the economic benefit of metals recovery, the value of the other metals exist in secondary materials, which could have a higher value than lead such as indium, germanium, and gallium, and the cost of their recovery should be included. Several authors proposed extraction processes of metals from secondary materials which believed to be economically feasible and the cost of the end products compete with market price for the same primary compounds (Fang and Gesser, 1996, Basir and Rabah, 1999 and Nagib and Inoue, 2000).

The value of the metals in the utilized flows of secondary materials

The amount of lead in the utilized flows of secondary materials (UFAIN, UBAIN, USS, USPIS, UFAC and UBAC) is estimated as described in section (2.2). The economic losses due to the remaining lead in the utilized secondary materials are estimated on the basis of the amount of lead in these streams multiplied by lead price as given by Eq. 13.

The monetary losses = lead price * (UFAIN + ULBAIN + USS + USPIS + UFAC+ UBAC) (13)

7.3 Model results

7.3.1 Non-intentional inflows of lead into stock-in-use

Past inflows of lead into road construction materials (asphalt) through the utilized stream of the incineration fly ash (UFAIN), coal fired power plants fly ash (UFAC), iron and steel slag (USPIS) are shown in figure 2 and the future inflows of lead from FAIN, FAC, SPIS and the recycled asphalt (RAS) are shown in figure 3. The main flow of lead into road construction materials (asphalt) originates from the recycled asphalt, which is increasing due to the past development in the utilized streams in asphalt. The second largest flow originates from SPIS, which is increasing as a result of increasing demand for iron and steel. The third flow originates from FAIN, which is decreasing from 2002 through 2010 and stabilizing from 2002 onwards as a result of lead input into the incineration plants. Small contribution to lead in asphalt from FAC, which is slightly increasing as a result of increasing demand for electricity.

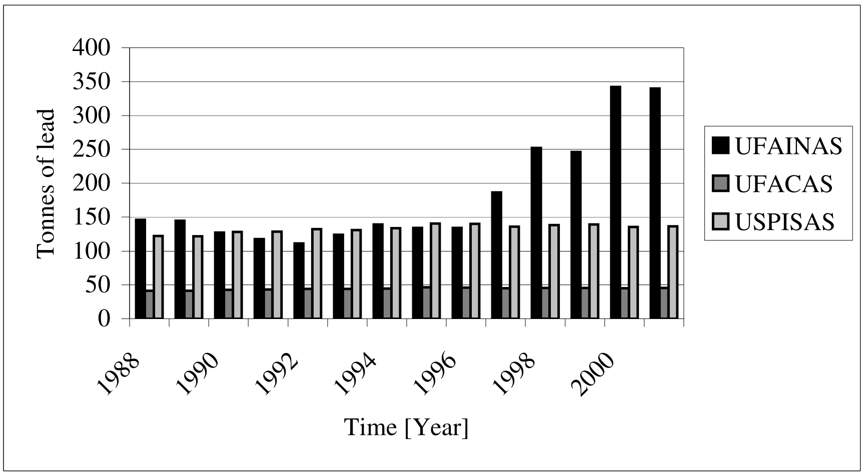

Fig. 2: Lead inflows into the stock of road construction materials (asphalt)

Future inflows of lead into road construction materials (aggregates) through the utilized stream of the incineration bottom ash (UBAIN) and coal fired power plants fly and bottom ashes (UBAC and UFAC) are shown in figure 3. The main flow of lead into road construction materials (aggregates) originates from BAIN. The inflow is decreasing from 2002 through 2010 and stabilizing from 2010 onwards. This is ultimately a result of the input of lead into the incineration plants. Although the input of lead into the incineration plants from the sewage sludge is increasing, the input from the discarded intentional applications is decreasing as a result of increasing recycling. The second largest flow of lead originates from FAC, which is increasing as a result of increasing demand for electricity. A small contribution to lead in aggregates from BAC.

Future inflows of lead into building materials from coal fired power plants fly ash (FAC) and bottom ash (BAC) are shown in figure 3. The main flow of lead into building materials originates from FAC followed by BAC. Both are increasing as a result of increasing demand for electricity.

The total future inflows of lead into the stock of road construction materials and building materials from different sources are shown in figure 3. The model shows that the inflow of lead into the stock of road construction and building materials vary by secondary materials sources.

Lead inflows into the agricultural soil from air, fertilizers, sewage sludge, and manure are shown in figure 4. The main flow of lead into agricultural soil originates from manure, which is increasing as a consequence of both the intentional and non-intentional applications.

Although, the inflow of lead originates from phosphate fertilizers is decreasing due to the policy in the NL, the inflows of lead from sewage sludge and manure are increasing.
The landfilled stream of incineration residues (bottom and fly ashes) is decreasing from 2002 through 2010 and then stabilizing. This is due to the input of lead into the incineration plants.

The landfilled stream of sewage sludge is increasing from 2002 through 2016 and from 2017 onwards slightly decreasing. This is mainly due to the development in the sources of lead in sewage treatment plants, the production of other heavy metals, consumption of animal and food products, and the emissions from the use of lead intentional applications.

The landfilled flow of solid waste generated from the production of other heavy metals is increasing due to an increase demand for other heavy metals.

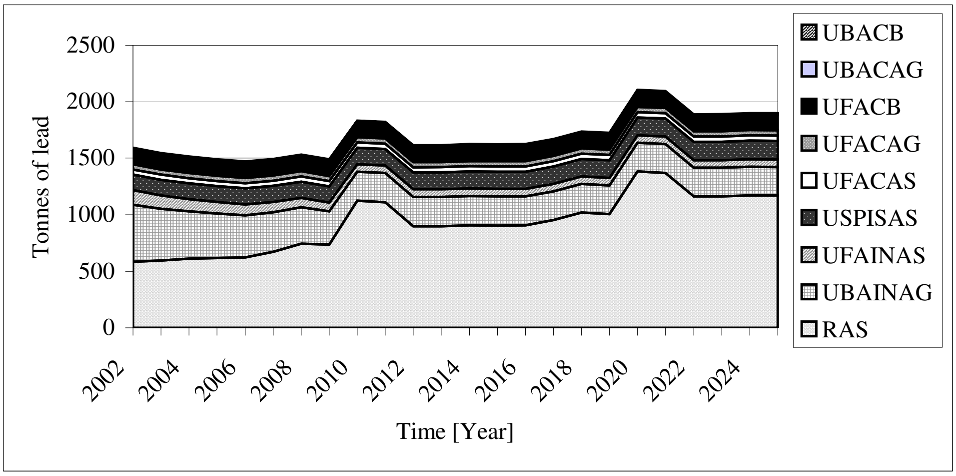

Fig. 3: Lead inflows into road construction and building materials

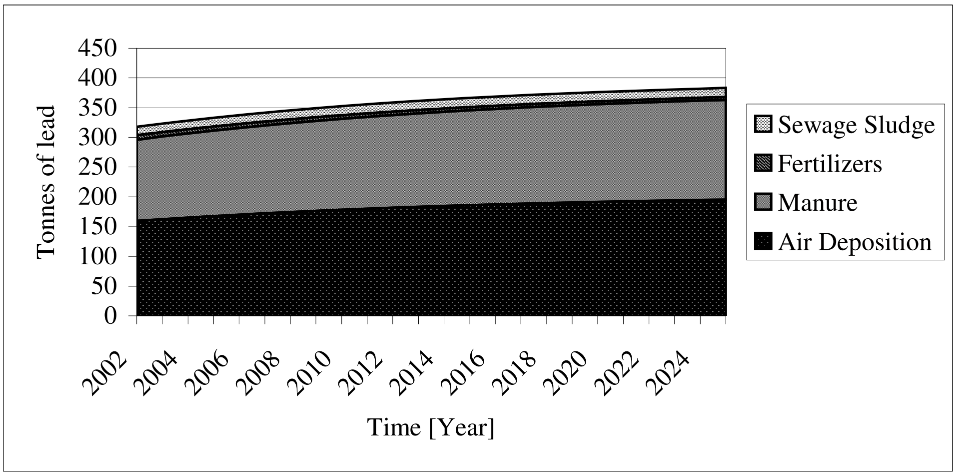

Fig. 4: Lead inflows into agricultural soil

7.3.2 Non-intentional lead outflows from stock-in-use

The only outflow of lead from road construction and building materials in the studied time is the discarded outflow of asphalt, the discarded outflow of building materials will start to come out of buildings in 2030.

Lead discarded outflow from road construction materials (asphalt) is shown in figure 5. The outflow is increasing overtime due to the past development in the utilized streams in asphalt.

Lead uptakes by food and fodder from agricultural soil and the leaching flow are shown in figure 6. The outflows from agricultural soil are the uptakes by food and fodder. Both are increasing as a result of the increasing stock of lead in agricultural soil.

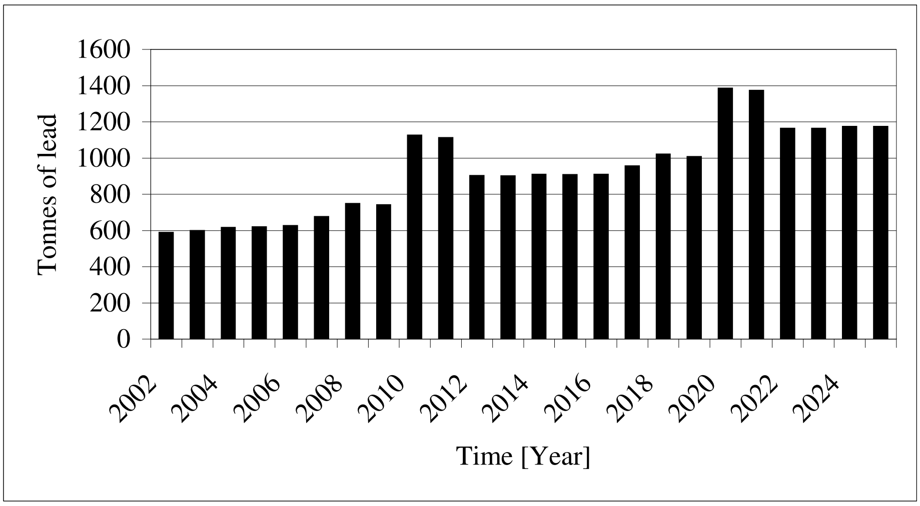

Fig. 5: Lead discarded outflow from the stock of road construction materials (asphalt)

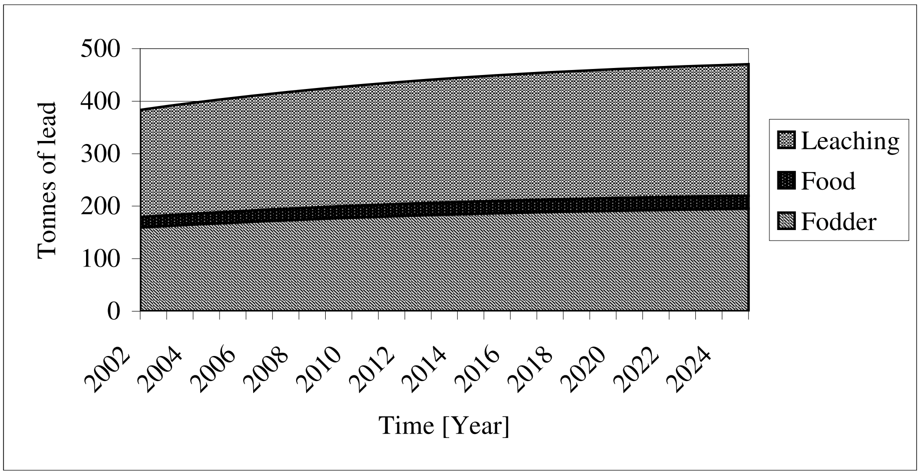

Fig. 6: Lead outflows from the agricultural soil

7.3.3 Stocks of lead in the economy

Stocks of lead in road construction materials (aggregates and asphalt) and building materials are shown in figure 7 and the stock of lead in agricultural soil is shown in figure 8.
Stocks of lead in road construction and building materials are increasing due to the long life span of some of these materials and the high level of recycling. Lead stock in agricultural soil is increasing. The increase in the stock of lead in agricultural soil is partly related to the intentional applications of lead.

7.3.4 Long-term economic consequences of non-intentional lead flows

The largest stream containing lead and therefore the largest economic value, is the one generated from the incineration plants. The second largest stream is the generated secondary materials from coal fired power plants. Although, the monetary value of lead in the utilized streams of SS, SPIS, FAC and BAC is increasing overtime due to the increase generation of these materials, the overall monetary value of lead is decreasing from 2002 through 2010 and increasing slightly afterwards. This is mainly due to the development in the incineration of lead intentional applications.

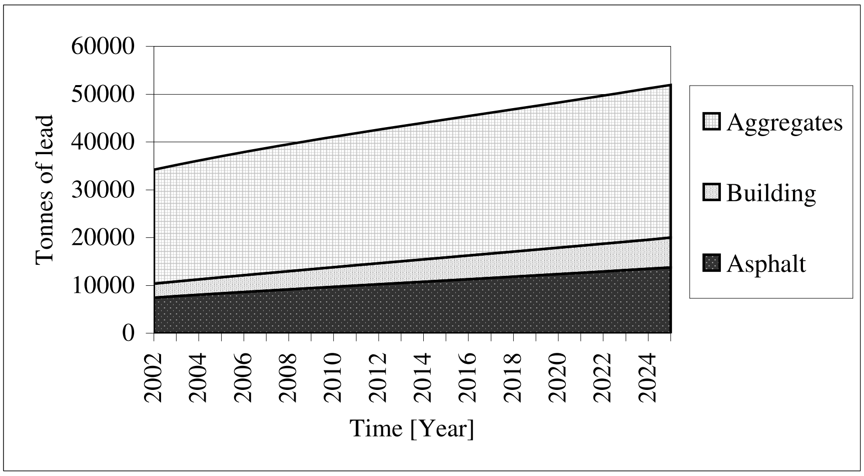

Fig. 7: Lead stocks in road construction and building materials

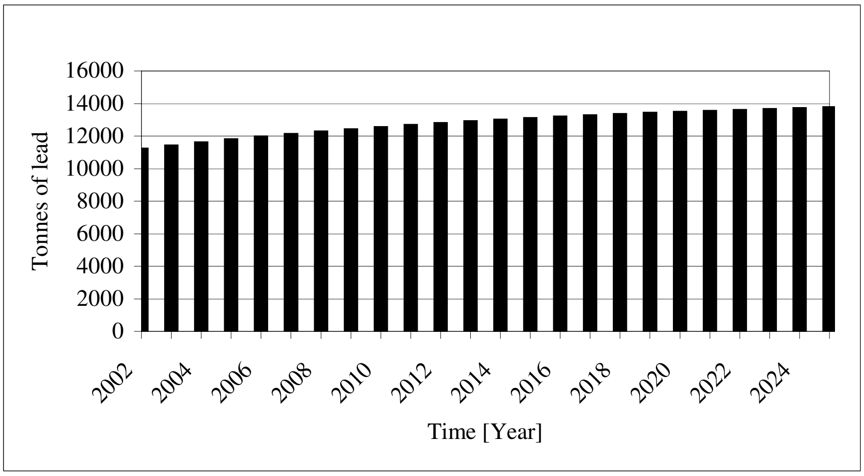

Fig. 8: lead stocks in agricultural soil

7.4 Discussion and conclusions

The model presented in this chapter is a dynamic substance flow-stock model of lead non-intentional applications.

The inflows of lead into the stock of road construction materials and building materials are mainly determined by the generation of secondary materials and the utilized stream of these materials. The generation of secondary materials is determined by the demand for lead intentional applications, electricity, petroleum products and other heavy metals. The utilization of secondary materials is mainly determined by technical, environmental and economic factors.

The outflows of lead from the stock of road and building construction materials are those related to the discarded asphalt and building materials. The leaching flows is ignored due to the conclusions by several studies that these flows are too small and below the toxicity level and due to the fact that these flows are too small compared to the discarded outflows.
The stocks of lead in road and building construction materials are increasing due to the increase utilization of secondary materials and the reuse of the discarded materials. The increase of lead in the stock might limit the future utilization of secondary materials and the recycalability of the discarded materials.

The main source of lead in the utilized streams of secondary materials is the generated fly and bottom ashes from the incineration plants followed by those generated from coal fired power plants.
The main source of lead in landfill sites is the solid waste stream generated from the production of zinc followed by the landfilled streams of fly ash and bottom ash generated from the incineration.

The inflows of lead from secondary materials generated from coal fired power plants and the production of other heavy metals are increasing overtime and those generated from the incineration plants are decreasing from 2002 through 2010. The increase in secondary materials generated from coal fired power plants and the production of other heavy metals is mainly due to the increase demand for electricity, zinc, iron and steel and the decrease of those generated from the incineration plants is due to the waste management policy, which is leading to an increase in the recycling of lead intentional applications.

At present, the generated streams of secondary materials BAIN, FAIN, BAC, FAC, and SPIS are utilized with almost 90%, 50%, 100%, 100%, 100% respectively in road and building construction materials due to their technical and environmental acceptance. This is might not be the case in the future.
The generation of secondary material and the recycling of discarded construction materials are increasing overtime. If this combined with a possible market saturation for construction material, the amount of secondary materials to be landfilled is going to increase. Otherwise, alternative utilization options for secondary materials should be found, however, the presence of lead and other heavy materials might limit the possibility of utilizing secondary materials in other areas.
The recovery of substances from secondary materials will allow for the utilization of secondary materials in other areas, consequently minimizing the environmental and economic burden associated with landfilling.

The monetary value of lead in the utilized streams is considerable, if combined with other heavy metals in mixed solid waste, coal, oil and other metals ores, which also can be recovered from secondary materials (Fang and Gesser, 1996, Murase et al, 1998, Nagib and Inoue, 2000 and Izumikawa, 1996), the recovery of these metals might be economically visible. Moreover, the losses of lead in landfilled streams are 7 times more than the losses of lead in the utilized streams.
The economic analysis is limited to the value of lead in secondary materials, however, a more detailed cost benefit analysis is needed in which the value of all materials that can be recovered and the costs of their recovery, in addition to the other benefits in terms of reducing the demand for the land required for landfill and primary materials are included.

The analysis present in this chapter is made for lead flows and stocks in the NL, however, the generation of secondary materials in the NL from coal for example is small compared to other countries, which rely more on coal for their electricity production. From resource prospective, the analysis should be extended for other metals and other countries.

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