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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

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ABSTRACT

Substances may enter the economy and the environment through both intentional and non-intentional 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. On the other hand, these flows have the potential to be a secondary source of substances.

This article aims to quantify and model the non-intentional flows of lead, to evaluate their long-term environmental consequences, and compare these consequences to those of the intentional flows of lead. To meet this goal, the model combines all the sources of non-intentional flows of lead within one model, which also includes the intentional flows.

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 application, lead flows are increasing as demand for these applications is increasing.

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.

The consequences of the intentional flows of these substances have been studied extensively and several policies have been implemented to minimize their negative impacts (Van der Voet, 1996). Less attention has been given to the consequences of the non-intentional flows, especially to the long-term consequences. This article 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 US Environmental Protection Agency (US 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 behavioral problems and 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; Patra et al., 2004). Due to its 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 (Guinée et al., 1999).

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 equipment containing lead, mercury, cadmium, chromium VI, and PBB or PBDE to be put on the market (European Commission, 2006). 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 (Tukker et al., 2001). However, despite effective management of these intentional applications, lead may still threaten human health through indirect routes of non-intentional flows. For example, lead enters the agricultural chain via phosphate fertilizer and accumu-

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lates there, leading to significant concentrations in manure (Guinée et al., 1999). The processing of metal ores and the use of fossil fuels leads to emissions of lead to the environment. Both intentional and non-intentional applications of lead 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 groundwater.

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 article is to evaluate the long-term direct environmental consequences of the non-intentional flows of lead, and compare these with the consequences of the intentional flows of lead. In meeting this goal, 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 a subsequent article.

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, 2005; Roberts, 1996; Moore et al., 1996; Crompton, 2000; Mergos and Stoforos, 1997; Bouwman et al., 1997) and technological factors describe that process efficiency, with specific detailed models for the intentional applications of lead (Elshkaki et al., 2004).

This article 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.

2. Methodology

2.1. General setup of the model

The core of the model used is based upon substance flow analysis (SFA), which 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; 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; 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 setup 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 non-intentional flows, stocks and processes of lead are shown in Fig. 1.

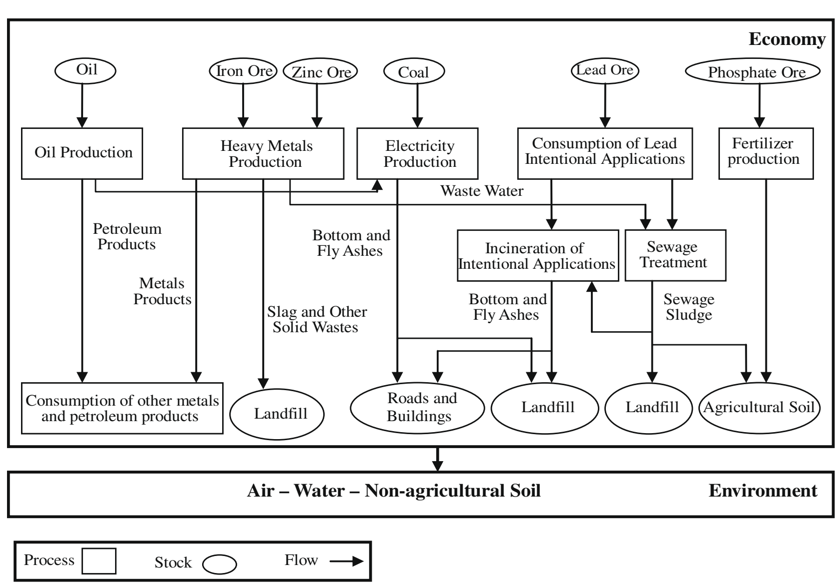

Fig. 1. Non-intentional flows, stocks and processes of lead in the economy and the environment.