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# A dynamic analysis of environmental losses from anthropogenic lead flow and their accumulation in China

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**Abstract:** Substance flow analysis was applied to analyzing the lead emissions in 2010. It turns out that in 2010, for every 1 kg of lead consumed, 0.48 kg lead is lost into the environment. The emissions in 2010 were estimated to be $1.89\times10^6$ t, which were mainly from use (39.20%) and waste management & recycling (33.13%). The accumulative lead in 1960−2010 from the anthropogenic flow was estimated and the results show that the total accumulative lead in this period amounted to $19.54\times10^6$ t, which was equivalent to 14.26 kg and 2.04 $g/m^2$ at the present population and territory.

**Key words:** substance flow analysis; emission; historical accumulation; dissipative uses; life cycle

## 1 Introduction

In recent decades, lead pollution incidents have happened frequently in China [1]. Specially, the children lead poisoning is extremely severe and has attracted much attention [2]. Therefore, the research concerning lead is arousing more and more concerns and thus treatment of lead pollution is highly pressing at present.

Probably as the earliest metal to be used on the earth [3], the manufacturing history of lead is more than several thousand years. Lead is mined as lead ores, and enters the anthropogenic flow by coming into the human society, which is dominated by human activities [4]. And then it is released from the flow as emissions. It can even accumulate in the environment, threatening the ecological security. Many studies on lead emissions have been carried out from different perspectives. For example, with the help of monitoring techniques, environmental geosciences mainly focus on recognizing the changes in resources or environment and the impacts imposed by human activities. Undeniably, it is challenging to evaluate pollution sources and quantities in geosciences. In this work, to address this key issue, a quantitative flow model will be established based on the substance flow analysis (SFA). This can greatly help to change the ineffective management pattern, which means remedying the existing pollutions, and therefore remarkably improve the potentials for source controlling. Meanwhile, the implementation of quantitative measures, which obeys the rules of lead life-cycle, can greatly promote the efficiency and scientificity of environmental management.

Substance flow analysis (SFA) is one of the most widely used techniques in the analysis of material flow which is confined to a specific boundary. Until now, detailed frameworks for cycles such as iron, zinc and lead have already been established [5−7]. SFA is not only an important tool to identify the pollution sources [8], but can help people to get a better understanding of resources utilization, and even explore the disciplines, which reflect the impacts of natural resources or socio-economic situation on lead emissions. In a word, the application of SFA will help to guide the waste management and evaluate the sustainability of resources in a long time.

Although there have already been a great deal of studies on lead emissions, unfortunately those studies only cover some of all life-cycle stages as to production, manufacture, use or recycling [9−12], or just report on a static study at a specific time as a snapshot of the cycle [5], without a clear idea of the historical characteristics or accumulative effects of lead emissions. It encourages us to wonder how much processed lead has been released

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into the environment in various ways over the years; this issue can only be satisfactorily addressed from a quantitative and comprehensive flow analysis [13]. In this work, lead emissions covering all life stages and the historical accumulation will be studied on the anthropogenic lead flow in China. The situation in 2010 will be analyzed to obtain the characteristics of national emission intensity, and accumulative lead in the environment is to be estimated during the period of 1960−2010.

## 2 Methodology

### 2.1 Model of lead emissions in anthropogenic cycle

Anthropogenic lead flow consists of four stages: production, fabrication & manufacture (F&M), use and waste management & recycling (WMR). Lead is extracted from lead ore in the lithosphere, which is the source of lead in anthropogenic cycle, and ends in the environment as landfills or sediments. Therefore, environment acts as both the source and sink of lead cycle. Specifically, lead cycle starts with the mining of ore resources in production, and then lead is transformed into products or semi-products in F&M, after which lead enters use stage and offers services to human. Finally, it is obsolete after use in WMR and some is reclaimed as secondary resources while the other is left in the environment. Especially, the production of lead can be further divided into primary and secondary lead production. The virgin material supplies of primary lead are lead ores after the processes of mining, concentration and smelting while the secondary lead is refined from scrap which contains relatively high amount of lead. Compared with primary lead from ores, the cost of the secondary lead from scraps is less expensive [14], which promotes the recycling of resources and improves environmental protection as well.

The wastes discharged in production include tailings after mining, slag from refining and smelting, clinker and smoke dust containing lead. During manufacturing, dross and lead ash are emitted, together with leftovers or offcuts from fabrication [15]. At use stage, lead products such as petrol additives, soldering alloys and ammunition are regarded to be permanently lost into the ambient environment and are not recyclable. Finally, many obsolete lead products are recycled or enter the environment as landfills. Lead acid batteries dominate the raw materials of the secondary lead, accounting for over 85% of the wastes, followed by cable sheeting, lead clad and alloys [16].

This research was based on the established framework of lead anthropogenic cycle in 2008 [5,17] (Fig. 1, Table 1). In this work, we will further study the lead cycle by focusing on the quantitative estimation of lead emissions. We make the following assumptions when carrying out our study: the international market is relatively stable in a long period of time; there is a certain quantitative relationship among lead imports, exports and lead consumption; the recycled lead scraps go through the process of secondary refining.

The historical data for a long period of time are not always available for us, with only some known or easy to

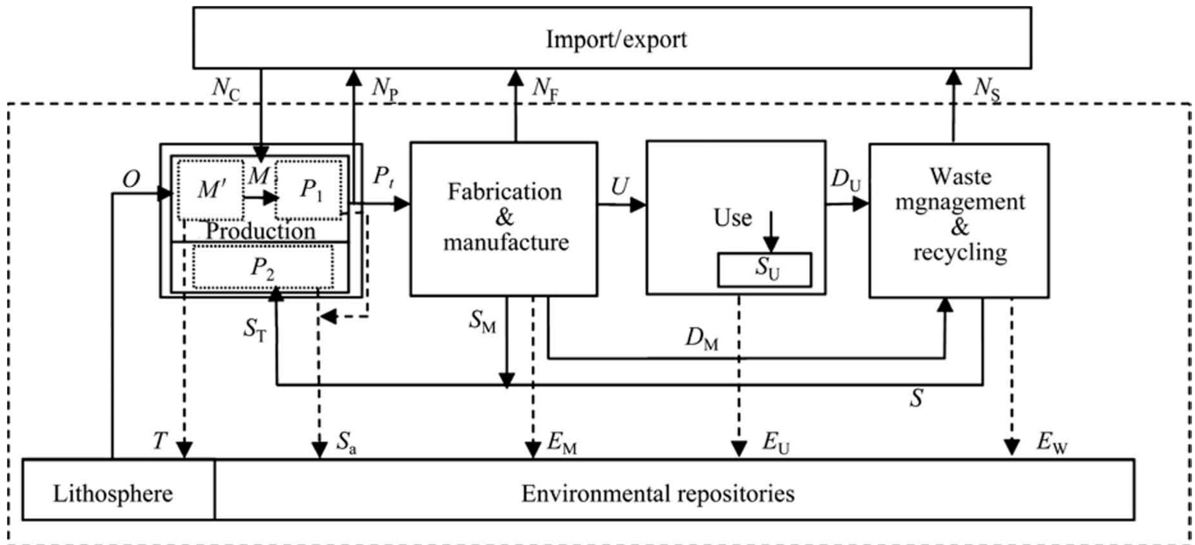


**Fig. 1** Framework of lead emissions from anthropogenic cycle: $O$—Lead from ore; $M$—Lead in total lead concentrate; $M'$—Lead in domestic lead concentrate; $P_t$—Refined lead in the year of $t$; $U$—Lead entering use; $S_U$—Lead entering in-use stock; $D_U$—End-of-life lead to waste management and recycling; $D_M$—Lead in F&M discards to WMR; $S_T$—Lead in total scrap to production; $S_M$—Lead in new scrap from manufacture; $S$—Lead in scrap from WMR; $T$—Lead in tailings; $S_a$—Lead in lag; $E_M$—Lead in F&M emissions; $E_U$— Lead in use emissions; $E_W$—Lead in WMR missions; $N_C$—Lead in net export of concentrate; $N_P$—Lead in net export of refined lead; $N_F$—Lead in net export of semi- or finished products; $N_S$—Lead in net export of scrap