The Economy of Chemicals: combining Substance characteristics with Socio-economic information in a Dynamic SFA model

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ABSTRACT

CML and Vito are developing a dynamic material flow model wherein economic and physical / chemical aspects are integrated. The model aims at analysing and forecasting flows and stocks of a certain substance (group). It operates at two levels: the product level and substance level. On the product level, all applications of the substance are included. For each product, the inflow into the consumption phase is described as a function of socio-economic variables such as price, GDP, population size and suchlike. The outflow is basically determined by physical mechanisms: during use, emissions may take place through corrosion or volatilisation, and after a certain lifespan the product will enter the waste stage. The combined products determine the dynamics on the substance level, but separate forces are at work there as well, most importantly connected to recycling. Whether or not recycling will take place depends both on physical and on socio-economic considerations. Parts of the model are already operational and are applied to the case of lead in the Netherlands and CFCs in Belgium. Some of the results for lead in the Netherlands are presented in this paper.

INTRODUCTION

Forecasting future waste streams and emissions is useful for environmental policy, but difficult. Economically oriented models usually ignore physical laws, such as mass balance and stockbuilding over time. The predictions from these models blindly follow economic forecasts, at best based on growth forecasts for different economic sectors. In some cases, this leads to erratic predictions. Material flow models on the other hand are limited to physical considerations and ignore economic mechanisms of supply and demand. These models have no rationale for predicting any future developments, other than applying mass balance. To obtain more accurate predictions, elements from both types of models should be combined. CML and Vito started a project to develop a dynamic model for Material Flow Analysis (MFA) that combines economic and physical variables. In this paper, some preliminary results of this project are presented.

MATERIAL AND SUBSTANCE FLOW ANALYSIS

Material and Substance Flow Analysis (SFA) can be placed in the scientific field of Industrial Ecology, as one way to operationalize the concept of industrial metabolism (Ayres 1989). The core principle of MFA and SFA is the mass balance principle. This allows for various types of analysis, a.o. the studies of biogeochemical cycles including the human interference. The study of flows in the economic system starts in the late 1960s, sometimes connected to the availability of specific resources (Meadows et al. 1972), but more specifically to pollution problems (Stigliani and Solomons 1993). Since roughly a decade, different efforts in this field are becoming more harmonized and there is a certain development towards a general methodology (Bringezu et al. 1997; Hansen and Lassen 2000). So far, the emphasis has mostly been on data collection and organisation: accounting for material flows. Modelling has had less attention, especially dynamic modelling needed for forecasting.

DYNAMIC MFA: THE CENTRAL POSITION OF THE STOCK

Although mass balance always applies, it cannot be applied always in a straightforward manner. Assessing future inflows is not sufficient for predicting future emissions and waste streams: waste and emissions in a certain year in many cases do not correspond with supply and demand in the same year. This is due to the fact that chemicals sometimes have a long residence time in society, when they are locked in applications with a long life-span such as building materials or durable user goods. The dynamics of such stocks are very important for the generation of future waste and emissions, but so far are no part of models, not even of MFA or SFA models, and consequently are left out of environmental forecasts altogether. Scattered information regarding the importance of considering stocks is arising:

- The generation of PVC waste in future will be orders of magnitude larger than the present amount, not as a result of increased demand but due to the delay of PVC applications in the economy (Kleijn et al., 2000)
- Heavy metal emissions have been reduced over the last decades, but at the same time an increased stock building in society takes place, and a subsequent increase of emissions can be expected in the future (Bergbäck & Lohm, 1997; Guinée et al., 1998).

In order to control emissions in the long run, a stock management appears to be essential. Stocks therefore must have a central place in a dynamic SFA model.

MODELLING STOCKS

Substance or material stocks are composed out of all the products that contain the substance or material. This could be a large number of products with widely different behaviours. This implies that a stock model should at least contain two layers: the substance level and the product level. Products are associated with a demand; products have a life span which may or may not be influenced by the substances it contains. A substance in a product may be substituted without changing the demand for the product. The substance in a waste product may be extracted and recycled, and subsequently applied in different products. As a result, the substance leaves the specific product stock but not the economy, and the life span of the substance may differ considerably from the life span of each of its applications. This means that even if the behaviour of the individual product stocks is not very complicated, the development of the substance stock may be complex and counter-intuitive.

Modelling the stocks's inflow

The inflow of a certain substance into a stock-in-use is primarily determined by economics, namely by the demand for the products containing the substance. In the model, a general function is used to describe the inflow, which is fitted for each product separately based on past trend data (Elshkaki et al., 2002):

$$F_{in}(t) = \beta_0 + \beta_1 x_1(t) + \beta_2 x_2(t) + \beta_3 x_3(t) + \beta_4 x_4(t) + \varepsilon \qquad (1)$$

$F_{in}(t)$ is the inflow into the product stock at time t. The variables x_1 to x_4 are socio-economic variables explaining the demand, such as GDP, the intersectoral and intrasectoral share in GDP, population size, price of the product or material, and variables representing technology development, substitution, fashion trends etc. This approach is taken among others by Tilton (1990) and Moore & Tilton (1996) to describe the demand for products or materials. The advantage is that if a significant relationship between the inflow and one or more of the explanatory variables is established, it can also be used for forecasting. Projections of GDP, population etc. then can be used to derive projections for the future inflow of the product into the product stock.

The inflow into the substance stock can be calculated as the sum of all product inflows, multiplied by the fraction of the weight that is taken up by the substance. Figure 1 shows, as an example, the inflow of lead in different products in the Netherlands.

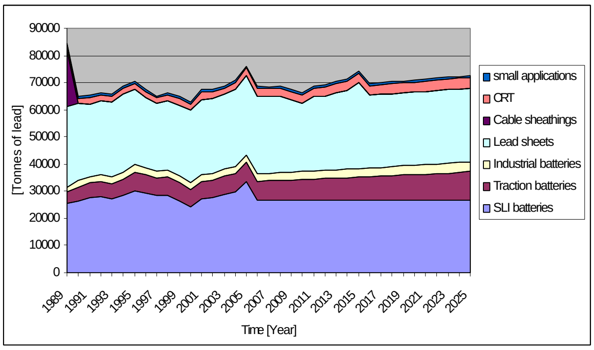

Figure 1. Inflow of lead in different applications into the stock of products-in-use in the Netherlands, 1989-2025.

The largest flows are related to SLI batteries and lead sheet used in buildings. These are expected to remain constant, if no specific policy is defined. Traction batteries used in industry are still expected to increase, as is the application of lead in CRT.

Modelling the stock's outflow

The outflow out of the stocks depends generally on two mechanisms: *delay* and *leaching* (van der Voet et al., 2002). Both of them are technical mechanisms, hardly related to economics. The term *delay* is used to describe the outflow of waste due to the discarding of products after use. The delay thus is determined by the life span of the products. The outflow from the product stock due to the delay mechanism is given by equation 2:

$$F_{out,\,delay}(t) = F_{in}(t - L) \qquad (2)$$

$F_{out,\,delay}(t)$ is the outflow of discarded goods at time t, $F_{in}(t - L)$ is the inflow of goods at an earlier moment, namely at time t - L, and L is the life span of the product.

Leaching refers to the emissions of the substance from the products during use. These emissions, which can occur as a result of volatilisation or corrosion, can be described as a fraction of the stock:

$$F_{out,\ leaching}(t) = c * S(t) \qquad (3)$$

$F_{out,\ leaching}(t)$ is the outflow due to emissions during use at time t, S(t) is the size of the stock at time t and c is a leaching factor, to be established per product / material.

To calculate the outflow out of the stock-in-use, the two outflow models must be combined. Figure 2 shows the outflow thus calculated for the stock of lead products in the Netherlands.

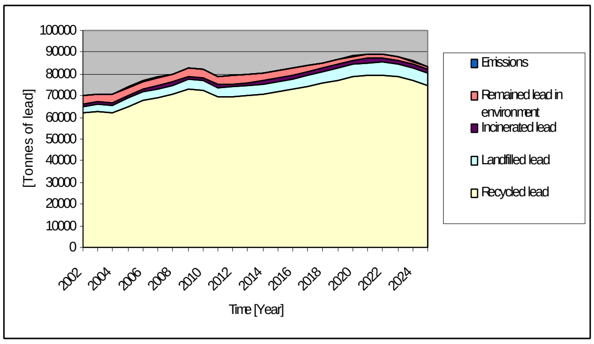

Figure 2. Outflow of lead out of the stock of products-in-use in the Netherlands, 2002-2025.

In this case, the emissions (top layer) are only a tiny fraction of the total outflow. When looking at other substances, this may be entirely different. From this picture, we can see two things: (1) the outflow of lead out of stock is for the most part larger than the inflow as pictured in Figure 1, and (2) most of the discarded lead is being recycled. The layer of lead "remaining in the environment" represents the cable sheathings no longer in use, which are being left into the soil. The total outflow of lead can also be broken down into the different applications. This is shown in Figure 3.

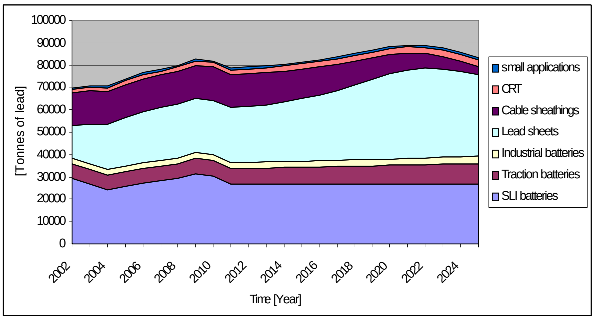

Figure 3. Outflow of lead out of the stock of products-in-use in the Netherlands, broken down to applications, 2002-2025.

A rise is expected for the discarding of lead sheets. This increase is the result of an increase in building activity some 50 years earlier, since the life span of lead sheets is very long. For cable sheathings, a slow decrease can be observed. Cable sheathings are phased out already, but the waste is expected to come out only after a very long delay.

Modelling the stock

The developments in the size of the stock can be calculated by adding yearly inflows to, and subtracting yearly outflows from, the stock in a starting year:

$$S(t+1) = S(t) + F_{in}(t) - F_{out}(t) \qquad (4)$$

This also must be done on the product level. The different products then again can be added on the basis of their lead content to a total substance stock. Figure 4 shows this, again for lead in the Netherlands.

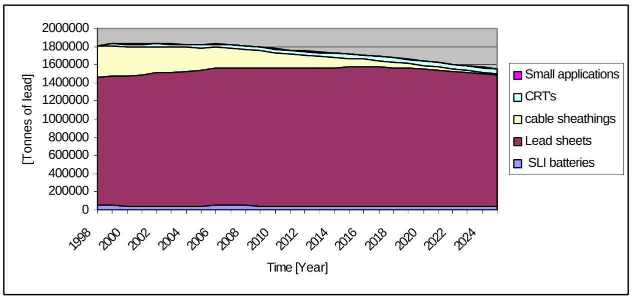

Figure 4. Stock of lead in products-in-use in the Netherlands, 1998 - 2025.

Lead sheet dominates the stock-in-use for a long time to come. Another observation is that the stock is decreasing in size. Instead of a sink, the stock thus is expected to become a source of lead in the near future.

RELEVANCE FOR A SUBSTANCE MANAGEMENT

For a substance management, the stock model may provide relevant information. Especially for applications with a long life span, the information is very much additional to any information obtained in another manner. If we remain with the case of lead in the Netherlands, the results of this model can be represented in different ways, depending on the policy issue at hand. For example, the contribution of the different applications to landfill or diffusive emissions can be specified over time, which is useful information for a waste prevention or pollution prevention policy. Another example is the future estimate of what will become available for recycling. For lead, Figure 5 shows this:

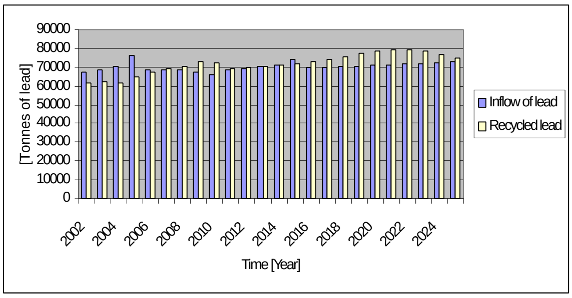

Figure 5. Lead available for recycling vs. the demand for lead in the Netherlands, 2002 - 2025.

Figure 5 shows that the amount of lead available for recycling is expected to become larger than the demand for lead in the near future. This means that at least in the Netherlands the demand will be more than covered by the supply of secondary lead only. If likewise developments can be found in other countries, it may imply that lead will become a similar case to the much smaller scale metals cadmium and mercury. For these metals, supply and demand are effectively disconnected. Supply is larger than demand, due to the availability of secondary and by-product sources and the reduction in demand. This has consequences for the price of these metals and thus also for the profitability of primary production and the recycling industry (for example, Maxson et al., 1991).

DISCUSSION AND CONCLUSIONS

The approach presented in this paper differs from other models used for forecasting in some aspects:

- the distinction between stocks and flows
- the inclusion of both socio-economic and physical data and model variables
- the differentiating between the product and the substance level, each with their own dynamics.

The distinction between stocks and flows enables to account for the impact of delay; this is not usually included in forecasting models but could be very important especially for materials applications with a long life span. The inclusion of socio-economic as well as physical information has so far only been applied either for single products or for single materials. In this model it is applied for all relevant products and linked together to form one model. The differentiation between the product level and the substance level enables to include both product related developments (such as product alternatives, product price, going out of fashion etc.) and substance/material related developments (such as alternative substances fulfilling the same function, the materials price, possibilities for recycling, substance oriented policies etc.). We think that the level of detail thus included in the model provides better forecasts of future total and primary demand on the one hand and waste streams on the other.

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