

# Feasibility assessment of using the substance flow analysis methodology for chemicals information at macro level

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# Executive summary

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This report examines the state and application of substance flow analysis (SFA) methodology in selected European Environment Agency (EEA) member countries. The objective is to explore if any of the existing practices could serve as a methodology framework for a macro level, Europe-wide application of the SFA methodology to gather information on chemical substances.

An increasing number of chemicals are in use today in Europe and around the globe. A sound and integrated information system has not yet been implemented to systematically monitor and trace these substances. Furthermore, knowledge about chemical substances with regard to their hazardousness is limited, as is the knowledge about the impacts of their production and consumption on human health and the environment.

The report gives a brief outline of the two main concepts for tracing materials and substances in the economy: material flow analysis/accounting; and substance flow analysis.

Austria, Denmark, Germany, the Netherlands, Norway, Sweden and Switzerland are among the countries considered to be the most advanced in the field of MFA and SFA applications. Therefore, the use of SFA for chemicals in these countries has been studied.

These country studies showed that SFA may provide a considerable amount of useful information for policy-making at national level. Moreover, such

studies have been used for different purposes in different fields. Several aspects of the following areas have been identified:

- Production, trade and consumption
- Regulation and policy support
- Tracing flows and understanding fate of substances
- Impact on human health and the environment
- General purposes

This report concludes that while European level SFA studies could provide useful information, substantial barriers should be overcome regarding this broader applicability of SFA. The most important barriers include non-standardised methodology, high data and resource demands, and the broad variety of substances and high variability in substance properties.

Two options have been proposed as possible first steps towards a broader applicability of SFA: (a) produce an inventory of the flows of a substance for Europe and/or (b) examine a number of indicator countries where the selected countries could represent a number of countries.

Furthermore, the applicability of the SFA methodology in support of a future European integrated environmental assessment (EU-IEA) has been assessed. SFA studies on substances or group of substances may provide helpful support both for general and specific modules of the EU-EIA.

# 1 Introduction

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## Objective

This report examines the state and application of substance flow analysis (SFA) methodology in selected European Environment Agency (EEA) member countries. The objective is to explore if any of the existing practices could serve as a methodology framework for a macro level, Europe-wide application of the SFA methodology to gather information on chemical substances. In this context, the report assesses how SFA could potentially support logical modules of an integrated environmental assessment in Europe.

## Background

Progress and innovations achieved by the chemical industry have led to the marketing and use, in different applications, of ever-increasing numbers and quantities of chemical substances. Consequently, ecological systems and human populations are now exposed to the pressure from vast numbers of chemicals present throughout society and the economy. More than 10 million chemical compounds, both natural and man-made, exist. Over 100 000 are industrial chemicals and potential subjects of concern. (A more detailed overview of the European chemical industry is presented in Annex I). Knowledge about these chemicals and their hazardousness is limited. Despite the large number of chemicals released into the environment, a sound and integrated information system has not

yet been implemented to systematically monitor and trace these substances. Finally, knowledge about the impacts of their production and consumption on health and the environment is limited. Therefore, the overall objective of this project is to assist in improving this knowledge about chemicals and how they impact upon the environment. This is carried out by using a feasibility study of the use of substance flow analysis to improve the information on chemicals.

## Structure of the report

The report is based on the approach of different material flow analyses (MFA) methodologies, which are identified as tools used to describe the concept of industrial metabolism at different levels of the economy (Section 2.1). A brief summary on general MFA concept and tools (Section 2.2) is provided, followed by an overview of the concept and applied methods of SFA (Section 2.3). Country profiles of selected EEA member countries are drawn up to provide a closer look at the applications of SFAs in practice. This covers the studied substances, methods and information sources used for the studies (Section 3). Finally, an assessment of the applicability of SFAs for gathering information on chemicals at European level is carried out. This applicability assessment is twofold: (a) a general approach for gathering information on chemicals at European level (Sections 4.1 and 4.2), and (b) an approach to supporting a future, Europe-wide, integrated environmental assessment (Section 4.3).



## 2 Tracing materials in the economy

Industrial metabolism is the way materials and energy are utilised by the economy, i.e. transforming them as inputs to products, services and other outputs such as waste and emissions to the environment. Figure 2.1 below illustrates the concept. Although the global economy has accounts to trace fiscal and product flows, tracing the material (and energy) flows in the economy and systematically describing and monitoring the industrial metabolism of national economies in a consistent manner is still lagging behind the practice of tracing goods or money in economic systems (Bringezu, 2003).

### 2.1 General concept of material flow analysis

The concept of material flow analysis (MFA) refers to a number of methodologies or MFA tools that can be used to provide information on industrial metabolism. MFA also refers to accounts in physical units (i.e. usually in terms of kilograms, as mass is

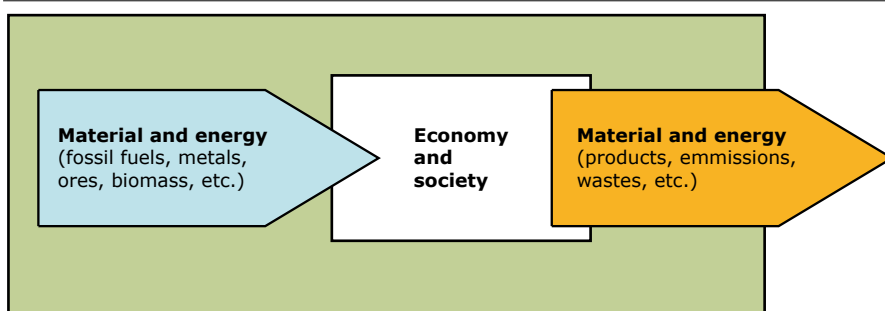
the basic physical unit to characterise materials, and kilograms or metric tonnes are the measurement units for mass) comprising the extraction, production, transformation, consumption, recycling and disposal of materials in the categories or notions of substances, raw materials, base materials, process flows, manufactured products, process residues and wastes, emissions to air, water and soil.

MFA can be carried out on different scales ranging from international, national and regional macro-down to the community or company micro level.

MFA-based analyses include approaches such as substance flow analysis, product flow accounts, material balancing, life cycle inventories and bulk material flow accounts. Figure 2.2 below characterises the relationship of MFA tools including SFA to product specific life cycle inventories (LCI).

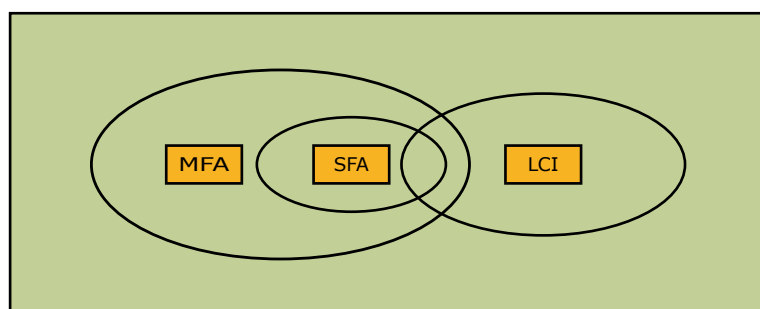
MFA tools are widely used for addressing different environmental problems as summarised in Table 2.1.

**Figure 2.1 The concept of industrial metabolism**



Source: Bringezu, 2003.

**Figure 2.2 Relation of SFA to MFA and LCI**



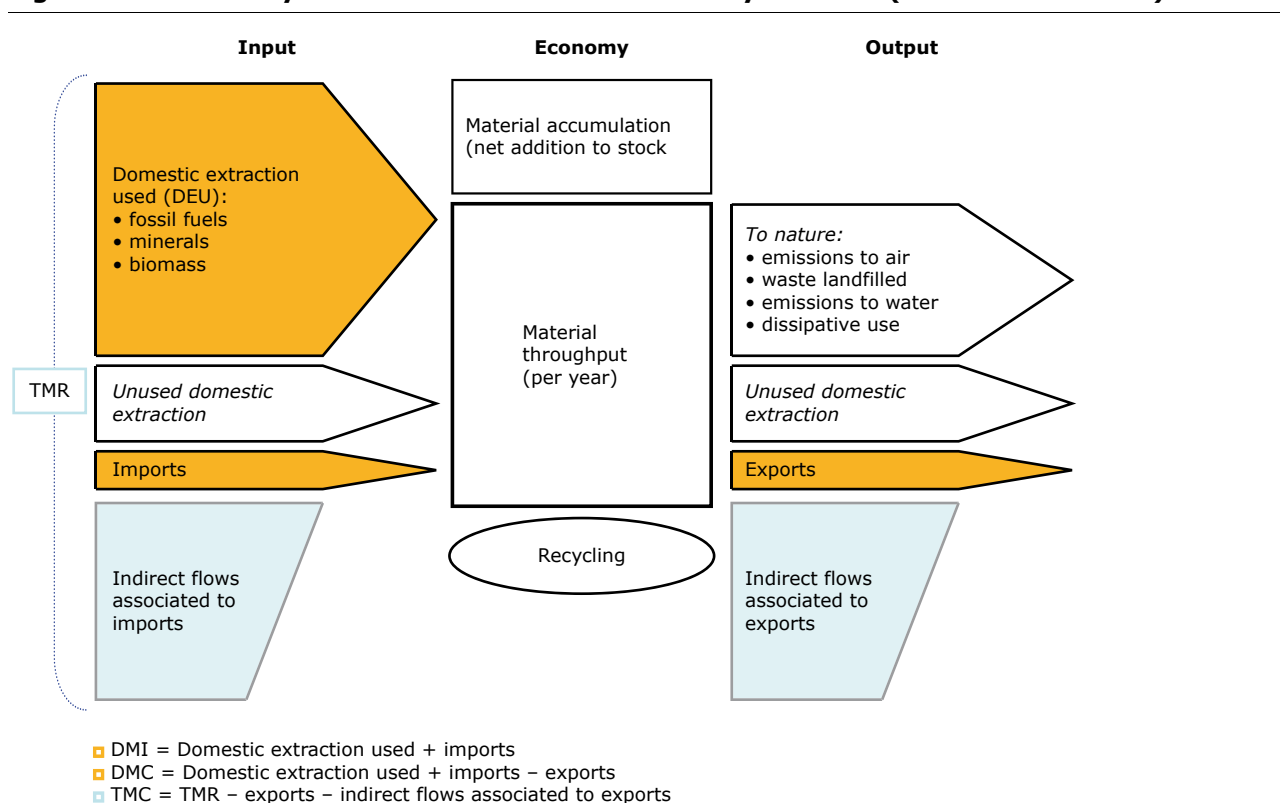
Source: Helias *et al.*, 1997.

**Table 2.1 Environmental problems where different MFA tools can be of help**

Environmental problem	Substances (chemicals) or materials
Climate change	Fossil carbon (C), bulk materials (e.g. oil)
Ozone depletion	Various substances (e.g. NO <sub>x</sub> , CFCs)
Eutrophication	Nitrogen (N), food production
Acidification	Sulphur (S), nitrogen (N)
Toxification chemicals	Metals, fuels
Resource depletion	Non-renewable and renewable resources
Land destruction through mining	Fossil fuel and metal
Waste management	Waste
Equity between generations	Total consumption
Equity between regions	Total consumption

Source: Bringezu *et al.* in Palm, 2002.

**Figure 2.3 Economy-wide material balance scheme by Eurostat (excl. water and air)**



**Note:** DMI: direct material input, TMR: total material requirement, DMC: domestic material consumption, TMC: total material consumption.

Source: Eurostat, 2001.

## 2.2 Economy-wide material flow accounts

Although the main focus of this report is on the SFA methodology, the economy-wide material flow accounts (EW-MFA) are also summarised briefly. The reason is that such accounts provide the macro level framework for the flows traced and data sets used by SFA studies. It should be kept in mind that bulk material accounts in EW-MFA may provide

helpful information when tracing individual substances by SFA. EW-MFA also provides the framework for setting up the basic concept of bulk material accounting. This gives a detailed insight into sectoral accounts, such as physical input-output tables or national accounting matrix including environmental accounts (NAMEA). The strength of MFA lies in its systematic and integrated view of the various physical interactions between environment and economy. The accounting rules for EW-MFA are

documented in a methodology guide published by the Statistical Office of the European Communities (Eurostat, 2001). It complements monetary accounts, such as the system of national accounts (SNA). EW-MFA can be used to derive indicators of the metabolic performance of national economies, e.g. resource inputs, and the efficiency of resource use. The general scheme of an EW-MFA is illustrated below in Figure 2.3. EW-MFA indicators (such as DMI, DMC, TMR and TMC) are discussed briefly in Section 7.

EW-MFAs systematically show the bulk material flows through society in a comprehensive way. The underlying principle of EW-MFA is to account for all materials entering and leaving the economic system, based on a mass-balancing approach. Material flow accounting has been prepared in a number of industrialised and developing countries for bulk materials, and represent part of the official statistics, for example, in Austria, Denmark, Finland, Germany, Italy, Japan, and the Netherlands.

The EW-MFA approach counts all material flows crossing the functional system boundary between 'environment' and 'economy' (Femia and Moll, 2005). The economy takes in raw materials — from the domestic environment and via imports from foreign countries — for further processing, manufacturing, production and consumption. Some materials, such as construction minerals, are stored in buildings and other infrastructure for many years. At the end of their useful life products become waste and may be recycled, disposed of in landfills or incinerated with or without energy recovery. Hence, the volume of the resource input also determines the amounts of subsequent waste and emissions.

### 2.3 Tracing substances: SFA

SFA is used for tracing the flow of a selected chemical (or group of substances) through a defined system. SFA is a specific type of MFA tool, dealing only with the analysis of flows of chemicals of special interest (Udo de Haes *et al.*, 1997). SFA can be defined as a detailed level application of the basic MFA concept tracing the flow of selected chemical substances or compounds — e.g. heavy metals (mercury (Hg), lead (Pb), etc.), nitrogen (N), phosphorous (P), persistent organic substances, such as PCBs, etc. — through society.

After having recognised the existence of environmental problems and making progress in environmental protection since the 1990s, SFA

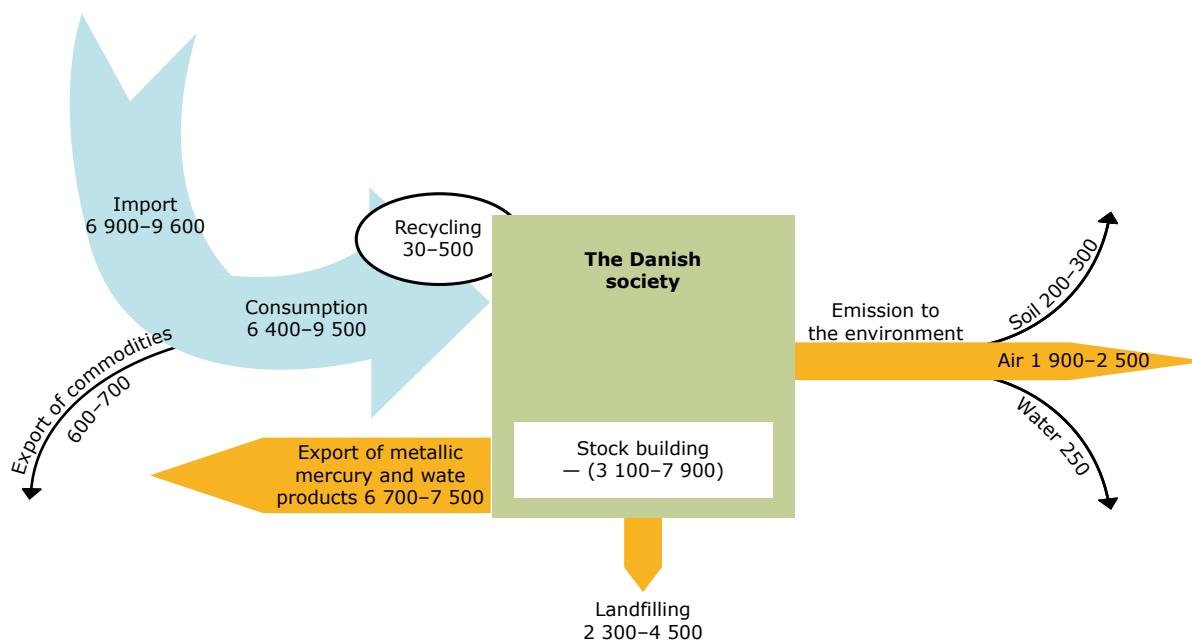
studies were first applied to trace and control the flow of hazardous substances. In the first instance, heavy metals were the focus. SFA has been used to determine their main entrance routes to the environment, the processes associated with these emissions, the stocks and flows within the industrial system, and the resulting concentrations in the environment.

Figure 2.4 shows the results of an SFA performed for mercury in Denmark. This figure illustrates the basic concept of SFA in practice. The objective of the study was to describe developments in the use of mercury, as well as establish the baseline consumption level prior to the enforcement of legislative restrictions on the use of mercury. The study covered a comprehensive analysis of the flow of mercury in Danish society, including identification of applications and quantification of consumption, losses to relevant waste fractions, and emissions to the environment (air, water, soil) for each field of application (Femia and Moll, 2005). As seen in Figure 2.4, SFA traces the substance pathway through the economic and natural systems by revealing information on the origin of a certain harmful substance, its applications in the economic system and where it ends up. Substances may cause a problem (e.g. adverse human health impacts) when they are released into the environment, for example through emissions or waste.

An SFA identifies these entry points and quantifies how much of and where the selected substance is released. Policy measures may address these entry points, e.g. by end-of-pipe technologies. Its general aim is to identify the most effective intervention points for policies of pollution prevention. According to Femia and Moll (2005), SFA aims to answer the following questions:

- Where and how much of substance X flows through a given system?
- How much of substance X flows to wastes?
- Where do flows of substance X end up?
- How much of substance X is stored in durable goods?
- Where could substance X be more efficiently utilised in technical processes?
- What are the options for substituting the harmful substance?
- Where do substances end up once they are released into the natural environment?

The conclusions of governmental policy based on substance flow analyses have been described for pollution control in some countries, such as the

**Figure 2.4 SFA for mercury, Denmark 1992/1993 (all figures in kg per year)**

**Source:** Maag et al. 1997 in Femia and Moll, 2005.

Netherlands and Denmark. Results which have contributed to policy-making include:

- an integrated view of the various types of data relevant for specific substance flows supported strategic and priority-oriented design of control measures;
- the analyses assisted in finding a consensus on the data, which is an important prerequisite for policy measures;
- SFA led to new insights and to changes in environmental policy (e.g. the abandonment of the aim of closed chlorine cycling in favour of controlling the most hazardous emissions);
- the analyses discovered new problems (e.g. the mercury stocks in chlorine plants);
- they also contributed to the discovery of new solutions (e.g. source-oriented input reduction in the case of non-degradable substances).

The impact of substance-specific findings is not restricted to government policy but includes industry itself, especially when related to certain products.

The strength of SFA is that it provides systematic, physical, quantitative information to design substance management strategies in order to keep a certain harmful substance under control. SFA may reveal opportunities to utilise substances more

efficiently in technical processes and help identify options for substituting the harmful substance. However, the application of SFA is limited because the substance needs to be identified as being relevant (i.e. it is not a tool to prioritise substances). Moreover, it does not consider any 'hidden flows' associated with foreign trade (Femia and Moll, 2005).

### Applied methods

Although there is no formally standardised methodology accepted so far, SFA methodologies established by academia are available. In general, SFA studies comprise the below three-step procedure (Van der Voet *et al.* in OECD, 2000) <sup>(1)</sup>.

#### (1) Definition of the system

The SFA system must be defined with regard to space (e.g. a city, province or country), function (e.g. processes), time horizon (e.g. a year) and materials (e.g. the studied substance). If necessary, the system can be divided into subsystems.

#### (2) Quantification of the overview of stocks and flows

The various related processes and stocks and flows (of the studied substance) belonging to the system must be specified.

<sup>(1)</sup> For a practical example, see Section 2.4. Case Study: Summary of the Danish paradigm, demonstrating a methodology applied in the Danish EPA.

### (3) Interpretation of the results

Finally, this results in a flow chart. The specification of the 'network of nodes' can be seen in Figure 4. This is an elegant method for visualising the often complex processes, tracing mass/volume of the substances in question.

When an SFA is to be carried out, it involves the identification and collection of data on the one hand, and modelling on the other. According to van der Voet *et al.* (OECD, 2000), there are three possible ways to 'model' the system:

**Accounting (or bookkeeping)** The input for such a system is the data that can be obtained from trade and production statistics. If necessary, further detailed data can be recovered on the contents of the specific substances in those recorded goods and materials. Emissions and environmental fluxes or concentration monitoring can be used for assessing the environmental flows. The accounting overview may also serve as an identification system for missing or inaccurate data.

Missing amounts can be estimated by applying the mass balance principle. In this way, inflows and outflows are balanced for every node, as well as for the system as a whole, unless accumulation within the system can be proven. This technique is most commonly used in material flow studies, and can be viewed as a form of descriptive statistics. There are, however, some examples of case studies that specifically address societal stocks, and use these as indicator for possible environmental problems in the future (OECD, 2000).

**Static modelling** is the process whereby the network of flow nodes is translated into a mathematical 'language', i.e. a set of linear equations, describing the flows and accumulations as inter-dependent. Emission factors and distribution factors over the various outputs for the economic processes and partition coefficients for the environmental compartments can be used as variables in the equations. A limited amount of substance flow accounting data is also required for a solution of the linear equations. However, the modelling outcome is determined largely by the substance distribution patterns.

Static modelling can be extended by including a so-called origin analysis in which the origins of one specific problematic flow can be traced on several levels. Three levels may be distinguished:

- direct causes derived directly from the nodes balance (e.g. one of the direct causes

of cadmium (Cd) load in soil is atmospheric deposition);

- economic sectors (or environmental policy target groups) directly responsible for the problem. This is identified by following the path back from node to node to the point of emission (e.g. waste incineration is one of the economic sectors responsible for the cadmium load in soil);
- ultimate origins found by following the path back to the system boundaries (e.g. the extraction, transport, processing and trade of zinc (Zn) ore is one of the ultimate origins of the cadmium load in soil).

Furthermore, the effectiveness of abatement measures can be assessed with static modelling by recording timelines on substances (OECD, 2000).

**Dynamic modelling** is different to the static SFA model, as it includes substance stocks accumulated in society as well as in various materials and products in households and across the built-up environments.

For SFA, stocks play an important role in the prediction of future emissions and waste flows of products with a long life span. For example, in the case of societal stocks of PVC, policy makers need to be supplied with information about future PVC outflows. Today's stocks become tomorrow's emissions and waste flows. Studies have been carried out on the analysis of accumulated stocks of metals and other persistent toxics in the societal system. Such build-ups can serve as an 'early warning' signal for future emissions and their potential effects, as one day these stocks may become obsolete and recognisably dangerous, e.g. as in the case of asbestos, CFCs, PCBs and mercury in chlor-alkali cells. As the stocks are discarded, they end up as waste, emissions, factors of risks to environment and population. In some cases, this delay between inflow and outflow can be very long indeed.

Stocks of products no longer in use, but not yet discarded, are also important. These stocks could include: old radios, computers and/or other electronic equipment stored in basements or attics, out-of-use pipes still in the ground, obsolete stocks of chemicals no longer produced but still stored, such as lead paints and pesticides. These 'hibernating stocks' are likely to be very large, according to OECD estimates (2000). Estimating future emissions is a crucial issue if environmental policy makers are to anticipate problems and take timely, effective action. In order to do this, stocks cannot be ignored. Therefore, when using MFA

or SFA models for forecasting, stocks should play a vital part. Flows and stocks interact with each other. Stocks grow when the inflows exceed the outflows of a (sub)-system and certain outflows of a (sub)-system are disproportional to the stocks.

For this dynamic model, additional information is needed for the time dimension of the variables, e.g. the life span of applications in the economy; the half life of compounds; the retention time in environmental compartments and so forth. Calculations can be made not only on the 'intrinsic' effectiveness of packages of measures, but also on their anticipated effects in a specific year in the future. They can also be made on the time it takes for such measures to become effective. A dynamic model is therefore most suitable for scenario analysis, provided that the required data are available or can be estimated with adequate accuracy (OECD, 2000).

### 2.4 Case study: summary of the Danish paradigm

The following Danish case study demonstrates SFA applicability and gives an overview of the possible data sources that can be used for such an analysis.

A paradigm was prepared by Lassen and Hansen (DEPA, 2000) to provide a general framework for SFAs to be carried out for the Danish EPA. This paradigm contains two main parts. Firstly, it describes the principles and procedures for the use of substance balances, uncertainty, detail and reliability, cross-checks, literature, statistics, etc. The second part provides a general outline of SFAs and includes a detailed description on a chapter by chapter basis.

#### Principles and procedures

Within this framework SFA consists of three steps:

- Goal and system definitions
- Inventory and modelling
- Interpretation of the results.

The overall goal of the analyses covered by this paradigm is to provide a comprehensive view of the flow of the substance in question through Danish society. This will help form the foundations for considerations regarding the need and instruments for risk minimisation for that substance. To meet the overall goal, the SFAs include determination of the main sources of discharges to the environment in

Denmark (including losses to waste deposits, etc.) and explanations about the uses of the chemical substance causing these discharges. A simplified model of the SFA system, developed by Lassen and Hansen (DEPA, 2000), is shown in Figure 2.5 below. Most of the arrows in the figure show different kinds of transport. This overview is useful when the inventory starts.

Within the phase of inventory and modelling, the collection of data takes place. This starts with the easily accessible data, e.g. statistical data, about the production, import and export of relevant raw materials, semi-manufactured goods and finished products. In addition, there will be monitoring data concerning finished products and waste streams, etc. The next step will contain a number of options depending on the types of information required. Besides conducting a desk study from available sources (see the section on information sources below), sometimes a questionnaire or personal interviews will be useful. During this inventory, the pieces of information building up the paradigm components are assembled. Some of the flows, due to the lack of monitoring data, can be estimated or determined by using different diffusion and flow models.

The final phase is the interpretation of the results. The basic part includes a discussion of the obtained flows chart, based on cross-checks of gathered information (e.g. substance mass) and flows. The main sources of emission to the environment and losses to waste are pointed out, and emissions of potential importance where more data are needed are flagged.

The interpretation of the results with regard to regulatory actions is kept out of the analysis and left to the authorities.

#### The general outline

The SFAs carried out at national level in Denmark used the following method:

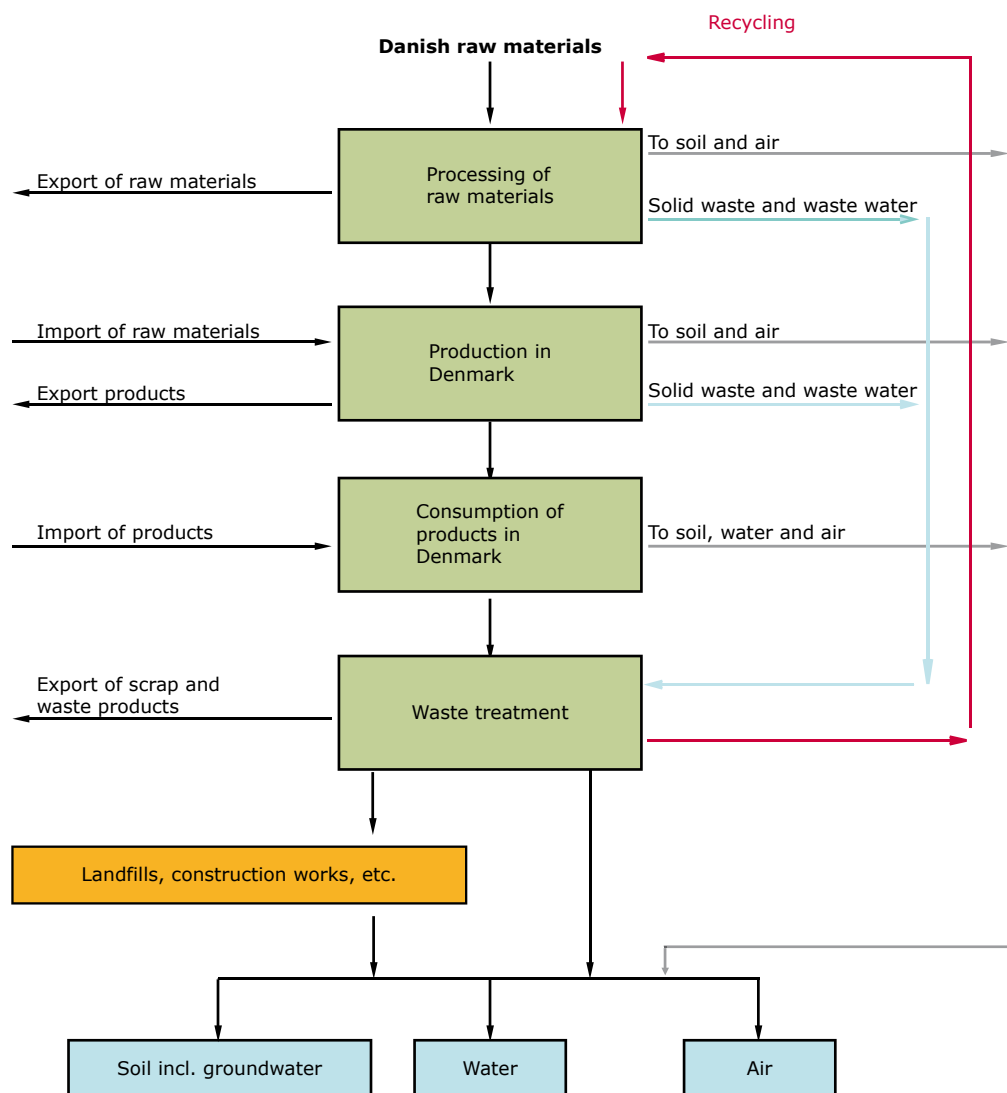
##### 1. Introduction

- 1.1 Purpose of the analysis
- 1.2 Methodology and limitations
- 1.3 What is <the substance>?
- 1.4 International market and trends in consumption

##### 2. Application in Denmark

- 2.2 Raw materials and semi-manufactured goods
- 2.2 Fields of application (eventually two sections)
- 2.3 Consumption as trace element and contaminant



**Figure 2.5** Diagram of principles of the transport and turnover of substances in Denmark

Source: DEPA, 2000.

### 3. Turnover with waste products

- 3.1 Recycling of the chemical substance
- 3.2 Other turnover with solid waste
- 3.3 Turnover with chemical waste
- 3.4 Turnover with waste water and sewage sludge
- 3.5 Summary

### 4. Evaluation

- 4.1 Application and consumption in Denmark
- 4.2 Discharges to the environment in Denmark
- 4.3 Substance balance in Denmark

### References

### Appendices

Furthermore, the paradigm distinguishes between what is designated as the 'core SFA' and a number

of optional 'extensions'. The core SFA includes an analysis of the total flow of a substance or a group of substances through Danish society over one year. In the extensions, the system boundaries are expanded either in space or time, i.e. by covering the monitoring data of the substance in different environmental compartments. Examples of extensions include:

- international market and trends in consumption;
- qualitative description of exposure to humans by use and disposal of finished products;
- scenarios for future emissions and loss of the substance;
- assessment of substitutes.

### *Information sources*

The paradigm provides a number of the most important sources of information to be used when carrying out an SFA. A technical encyclopaedia may be used to achieve an initial overview of the fields of industrial application of chemical substances. The encyclopaedia also provides a great deal of information about processes. This provides a solid background on which to foresee what losses to the environment are likely to be caused by those economic processes.

Information about Danish production, imports and exports of goods as well as foreign trade is available from The Danish Statistical Office. With regard to Danish EU trade, this is based on information declared monthly to the Office from importers and exporters. Trade with non-EU countries is based on the declarations submitted by the customs authorities. Among foreign tabular surveys the 'Mineral commodity summaries' and the 'Minerals yearbook', published by the US Geological Survey are of particular interest.

Additionally, a number of market reports for some substances have been carried out by consulting companies specialised in business communication. Eurostat provides a complete official foreign trade statistics as well.

The most important sources of information needed to explain the pattern of consumption of substances in Denmark are the manufacturers and

importers involved in trade with the products in which the substance occurs. Research institutions and their journals, periodicals, and the economic and environmental literature via various media constitute other sources of information.

A number of trade associations exist including associations covering/representing different parts of the economy. Many of them have regular information acquisition and recording that might be useful in some of the SFAs. Furthermore, the electricity companies can be approached for information regarding the use of coal for power generation and the resulting residual products. The 'Danish Product Register' contains information about the composition of a large number of chemical products marketed in Denmark. However, this register only contains information on chemical products that contain one or more substances that have been classified as dangerous.

Regarding information about consumption, waste, waste water and emissions from energy conversion etc., searches on already existing SFAs and other reports published by other environmental authorities and research institutions (both at national and international levels) are recommended.

Data on the presence of the substance in waste and residues from waste treatment often need to be obtained directly from the waste treatment facilities, solid waste incinerator enterprises and the Danish central treatment facility for hazardous waste.



### 3 Substance flow analysis in selected countries

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The following chapter examines the state of SFA applications in selected EEA countries. The goal is to offer an insight into the existing experience of SFA studies. Furthermore, it explores whether any SFA methodology could serve as a template or framework for a European level SFA. This would trace substances or be used in support of a European integrated environmental assessment. Austria, Denmark, Germany, the Netherlands, Norway, Sweden and Switzerland are among the countries that are considered to be the most advanced in the field of different MFA and SFA applications (Bringezu, 2005 and OECD, 2005). The following sections give a summary (including a tabular overview) on these countries:

#### 3.1 Austria

SFA methodology is used for studies on various substances and within some branches of the chemical industry. Some studies have been conducted on different chemicals as well as an overall assessment of the Austrian chemical industry (Hüttler, W., Schandl, H., Weisz, H., 1998).

The first study was on the material balance of PCB (polychlorinated biphenyls) in Austria by the Austrian Federal Environment Agency (UBA) in 1996. This UBA study gives an overview of the status of use and disposal of PCBs in Austria. Although they are no longer used in new technical installations, safe disposal of more than one tonne of PCBs until 2015 had to be planned. The study identifies and quantifies the relevant material fluxes of PCBs in Austria.

A project has been conducted to evaluate the feasibility of a National Accountancy, tested on zinc (Zn) by UBA (1998). Targets aimed to check the basic applicability of the methodology developed, while at the same time assessing its current limits and working out information about necessary prerequisites for a possible establishment of this kind of instrument.

The study examined the points at which the material flow system zinc (Zn) flows and deposits should be monitored for a national material accountancy. Points identified include the most important

production processes, residues from waste and waste water management as well as the big mass 'conveyor belts' of water (especially the river Danube) and air (air constituents and deposition). The methodology used to collect data (data sheets from companies) proved to be basically feasible.

The study concluded that it was only feasible for high priority substances. Regarding data quality it became evident that the data actually recorded about zinc (Zn) in water, soil and air is only suited for the analysis of material flows and deposits to a limited extent.

A few studies were carried out on substance flows at local level only:

- In 2000, a study was conducted to provide a silver (Ag) balance for Vienna. Special attention was paid to silver flows in the sewage systems (RMA, 2000). The purpose was to trace back the presence of silver (Ag) in waste water sludge. After incinerating the sludge, the bottom ash was landfilled. Since year 2004 the concentration of silver was legally limited to 50 mg/kg.
- A relevant study was carried out on the anthropogenic metabolism of the city of Vienna by Daxbeck *et al.* in 1997. The study included carbon (C), nitrogen (N), and lead (Pb) fluxes (flows) and balances.

Another study was conducted on the chemical sector by Windsperger and Schneider in 1999. This study focused on fibre, fertilizer and plastic industries. It attempted to estimate carbon losses.

#### 3.2 Denmark

The overview of substance flow analysis in Denmark is written mainly from the information stated in the article 'Experience with the use of substance flow analysis in Denmark' by Hansen and Larsen (2003). In Denmark, national-level SFAs have been carried out for heavy metals and hazardous organic compounds for more than two decades. Studies started with an SFA for mercury (Hg) in 1978. Today more than 35 SFAs have been completed, resulting in a well-defined methodology presented above in Section 2.4.

**Table 3.1 Summary on Austria**

Study criteria	Results in Austria
Substances and/or group of substances investigated	SFA studies exist for the chemical industry on: <ul style="list-style-type: none"> <li>• fibres</li> <li>• fertilizers</li> <li>• plastics</li> <li>• unverified mass balance exists for the chemical industry</li> </ul> SFA studies on individual substances: <ul style="list-style-type: none"> <li>• PCB, zinc (Zn)</li> <li>• silver (Ag) in waste water in the city of Vienna</li> <li>• lead (Pb), nitrogen (N) and biotic carbon (C) balance in Vienna</li> </ul> Main categories of MFA cover bulk materials
Main data/info sources used by the studies	Basic data for the MFA and chemical SFA methods are mainly from Statistics Austria <ul style="list-style-type: none"> <li>• statistics for production</li> <li>• statistics for consumption (ÖSTAT Industrie und Gewerbestatistik)</li> <li>• environmental statistics</li> </ul> Data sheets from companies
Methodologies	Data for SFAs are partly calculated stoichiometrically from chemical relations and processing and technology Most SFAs are rather substance balances or inventories National material balance was developed already in 1992 and standardised procedures are available on MFA

**Source:** Daxbeck *et al.*, 1997; Hüttler, W., Schandl, H., and Weisz, H., 1998; UBA, 1996; UBA, 1998; RMA, 2000; and Windsperger and Schneider, 1999.

SFAs have traditionally been initiated by the Danish Environmental Protection Agency (DEPA) either for substances or groups of substances that have been identified as posing actual or potential hazards to humans or the environment or for which regulatory actions were under consideration. SFAs in Denmark have had the following purposes:

- to provide a common understanding of the flows of the substance, including emissions and waste generation to all stakeholders;
- to ensure that regulatory actions directly address the main sources of emissions and wastes of the substance;
- to monitor the effects of regulatory actions on consumption, emissions and waste generation;
- to identify the need for further studies and regulation;
- to provide input to economic assessments regarding the cost of substituting the substances, economic consequences of new regulation, and the consequences of environmental taxes and fees;
- to provide information on reporting on releases of hazardous substances;
- to provide background information for regulatory actions to reduce hazardous substances in waste;
- to provide information on substances in waste used for development of life-cycle-based waste indicators.

Already during the 1980s, a number of national level SFAs were carried out, focussing primarily on heavy metals and chlorinated organic compounds, such as polychlorinated biphenyls (PCBs) and chlorofluorocarbons (CFCs). To ensure uniformity and comparability of SFAs carried out under DEPA's framework programme on hazardous substances in waste, a 'paradigm' or complete framework for SFA was developed in 1993 and further developed in 2000 (DEPA, 2000) (see Section 2.4).

The main objective of the update was to incorporate optional extensions of the SFA into the paradigm and to distinguish them from the core SFA. The core SFA addresses the following specific issues:

- international market and trends in consumption at an overall level (used as background information);
- production, import/export, and processing of raw materials and semi-manufactured goods;
- application and consumption of finished goods by use areas in Denmark;
- emissions and losses to air, soil, waste water, solid waste, and hazardous waste from manufacturing processes and use of finished goods by use areas;
- quantity disposed of into waste treatment systems and emissions from those systems;

**Table 3.2 Summary on Denmark**

Study criteria	Results in Denmark
Substances and/or group of substances investigated	SFA for individual substances: <ul style="list-style-type: none"> <li>metals and heavy metals: aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), tin (Sn)</li> <li>organic substances: azo colorants, AMPA, brominated flame retardants, CFCs, HCFCs, HFCs, chloroparaffins, chlorophenols, dichlorofemethane, dioxins, orghanotin, fluorocyclobutane, fluoroethane, fluoroethane, fluoropropane, formaldehyd, methylbromide, nonylphenols and nonylphenoethoxylates, PCB/PTB, phthalates, sulphur-hexafluoride, tetrachloroethylene, trichloroethylene</li> </ul>
Main data/info sources used by the studies	Technical reference books, statistical information, manufacturers, importers
Methodologies	Accounting (balancing) is a part of the Danish paradigm, and it is recommended to do it manually

**Source:** DEPA, 1996; DEPA, 1996a; DEPA, 1996b; DEPA, 1996c; DEPA, 1996d; DEPA, 1996e; DEPA, 1996f; DEPA, 1997; DEPA, 1997a; DEPA, 1998; DEPA, 1999; DEPA, 1999a; DEPA, 2000; DEPA, 2000a; DEPA, 2003; DEPA, 2003a; DEPA, 2003b; DEPA, 2004; DEPA, 2004a; DEPA, 2004b; DEPA, 2004c; and Hansen, E. and Lassen, C., 2003.

- consumption and emission resulting from the presence of the substance as a trace element or contaminant in fossil fuels, wood, cement etc.

In addition to the core analysis, SFAs often include parts of the substance flows outside the boundaries in space and time. Environmental and health hazard and risk assessments are not included in SFAs, as these assessments have, by tradition, been carried out in separate environmental assessment studies.

The following describes the extension of the core SFAs:

- detailed analysis of the international market and trends in consumption;
- qualitative description of human exposure through the use and disposal of unfinished products;
- scenarios for future emissions and loss of substance;
- occurrence and fate of the substance in the environment;
- national and international regulation on the use of the substance;
- assessment of substitutes;
- recycling and material deterioration.

With regard to the methodology used in Denmark, there is a tradition whereby the balancing element has been allocated many resources. Balancing the estimated flows (as discussed above in Section 2.3) is considered a very useful procedure for checking assumptions and estimates. If there is a discrepancy between the source and the turnover within the waste treatment system, the source has to be re-evaluated. The consistent use of balancing distinguishes the Danish SFAs from SFAs prepared for environmental authorities in many other countries.

### 3.3 Germany

Germany has the largest share of chemical industry output in Europe. Moreover, Germany was among the first countries implementing macro level Material Flow Accounting and also conducted SFA studies on different chemicals. Application of SFA methodology was used for studies on various individual substances or group of substances with specific impacts or risks. The flow of selected materials and substances through German industry and beyond has been studied by a variety of researchers. The overview on Germany is partly based on the work of and personal communication with Stephan Bringezu and Stephan Moll of the Wuppertal Institute in 2005.

SFA on selected substances was applied extensively in West Germany predominantly in the 1980s. In the late 1980s and early 1990s, the German UBA conducted/commissioned comprehensive SFA studies on chlorine (for the years 1987 and 1992). The results were published in the series called *UBA Texte*.

Beginning with the work of the Enquête Commission of the German Bundestag in the early 1990s on the 'Protection of humanity and the environment', some examples were presented (Friege, 1997) for material and substance flows, which were of high political importance. The flow of PVC was taken as an example of how to discuss possible criteria for the assessment and the main fields for materials management.

In the context of their work on chlorine chemistry, the Enquête Commission (1995) proposed a number of measures including the substitution of chlorinated solvents for nearly all uses. For the remaining applications, dry-cleaning with tetrachloroethene

being the most important among them, the Enquête Commission stated: 'Past experience has shown that there is a need for a standardised documentation of solvent flows which will have to be made available to the authorities upon request.' The Enquête Commission did not distinguish between so-called closed and open systems, because they will be destroyed or cleared out one day. Electric capacitors filled with PCBs are a fine example of this type.

Cadmium (Cd) has been phased out for many former applications. As to accumulators, cadmium (Cd) has only partly been substituted. The Enquête Commission proposed an eco-effective management of cadmium (Cd) by recycling accumulators after the introduction of a deposit-refund to optimise the re-distribution in 1994. Perfect recycling leads to a surplus of cadmium (Cd) because it is also a by-product of primary zinc (Zn) production. Surplus cadmium (Cd) must be removed to avoid diffuse applications, which cannot be controlled properly. Within this model, zinc (Zn) and cadmium (Cd) smelters and refineries have to separate surplus cadmium (Cd). If all relevant players (e.g. the manufacturers or importers of accumulators, the wholesalers and the smelters) document the cadmium flows, it is relatively simple for the authorities to follow the fate of this dangerous metal.

A study was carried out on the flow of aluminium (Al) through production and consumption and interlinked material flows with reference to the development of integrated environmental and economic statistics. Furthermore, a special research programme on resource-oriented analysis of metallic raw material flows was set up (Bringezu, 2002).

Nutrient flows, such as nitrogen (N), phosphorus (P) and potassium (Na) have been balanced to assess agricultural performance. Extended modelling was used to predict environmental loads.

Various studies have been integrated into an overall flow assessment of nitrogen (N) in order to support priority-oriented political action for which targets had already been formulated.

The flow of hazardous chemicals such as cadmium (Cd) and chlorinated substances, as well as flows for the production of textiles and cars, were studied on behalf of the Enquête Commission in 1994 and 1998.

SFA studies for important endocrine disrupting industrial chemicals (bisphenol A (BPA); dibutyl phthalate (DBP) or benzyl butyl phthalate (BBP); and nonylphenol (NP) or alkylphenol ethoxylates (APEO)) were conducted in 1997. The study addressed the production and domestic consumption (for further processing and in final

**Table 3.3 Summary on Germany**

Study criteria	Results in Germany
Substances and/or group of substances investigated	<p>SFA studies on individual substances:</p> <ul style="list-style-type: none"> <li>• endocrine disrupting industrial chemicals: bisphenol A, dibutylphthalat, benzylbutylphthalat, nonylphenol, alkylphenoethoxylate</li> <li>• metals: lead (Pb), copper (Cu), cadmium (Cd), aluminium (Al)</li> <li>• nutrients: nitrogen (N), phosphorus (P), potassium (Na)</li> <li>• chlorine (Cl) and PVC</li> </ul> <p>Main categories of MFA cover bulk materials</p>
Main data/info sources used by the studies	<p>SFA data are from statistics on transport, manufacturing, production, sales and environment from ministries and German Federal Statistical Office</p> <p>Data are often based on estimations</p> <p>Basic data for the MFA method are mainly the statistics of the German Federal Statistical Office. The statistical data on waste and waste water are collected as a rule every three and four years, respectively</p>
Methodologies	<p>Applied methodologies cover substance balances, dynamic and static SFA models</p> <p>Software support</p> <p>As part of the material and energy flow accounts (GEEA), three types of environmental burdens are examined on the output side: air emissions, waste and waste water. The calculation method for air emissions is based on both the energy balance, which is compiled by the working group 'energy balance' and the technical emission factors determined by the German UBA. The GEEA method is largely standardised. Compared to that, the method to calculate the amount of waste and waste water is in its development stage. It was used for setting up the first physical input-output table in Germany</p>

Source: Bringezu, 2002; Leisewitz, 1997; and Erdmann *et al.*, 2004.

products) of these three chemicals/groups in Germany in 1995. It took account of imports/exports, and also the pathways for release and disposal. The data acquired are used to assess emission paths and volumes of potential environmental relevance (Leisewitz, 1997).

In December 2004, a study on lead (Pb) and copper (Cu) was published. The report presents dynamic SFAs on these metals. The study goes beyond the figures in analysing the policy context (Erdmann *et al.*, 2004).

To assist on the 'bottom-up' analyses, physical inputs and outputs of certain (unit) processes have been provided in computer-based models, such as GaBi (<http://www.gabi-software.com>), GEMIS (<http://www.oeko-institut.de/service/gemis/index.htm>) and UMBERTO (<http://www.umberto.de>). UMBERTO was originally designed to simulate the emissions for certain process chains. However, it also includes some categories of resource requirements and may be used for LCA, form related accounts and MFA as well.

SFA studies contributed to the fact that the release of eco-toxic substances, such as heavy metals and chlorinated chemicals was limited to critical levels. In the 1980s end-of-pipe measures were increasingly substituted for integrated pollution control (i.e. by steering processes within the industrial metabolism). SFA has not yet been used for ex-ante assessment of new chemicals.

### 3.4 Netherlands

Although the Netherlands only accounts for 6 % of the output of the European chemical industry, the country is considered important for this report. This is due to the fact that MFA and SFA concepts are used in several nationwide instruments such as official statistics or policy support, and that SFA has been used as a tool for environmental policy-making.

A number of Dutch universities and research institutes (e.g. University of Leiden) have very solid experience in SFA, particularly in connection with life cycle analysis (LCA). In addition, various other institutes were engaged in conducting SFA studies at national level or at the following institutions:

- Environmental Studies of Free University Amsterdam;

- Copernicus Institute of University of Utrecht (especially materials like plastics);
- Institute for Energy and Environment of Groningen University.

Since the early 1990s, many studies have been carried out at different levels. Most of them have traced heavy metals (copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), mercury (Hg), cadmium (Cd)) and nutrients (nitrogen (N), phosphorus (P)). However, some also have traced organochlorine compounds (OECD report).

One of these was a comprehensive study on six heavy metals (cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn) and mercury (Hg)), carried out in 1990 and reported by Annema *et al.*, (1995). This study includes scenario calculations and the effect of current environmental policy measures. Additional measures on substance flows in 2010 are determined. This investigation has been commissioned by the Ministry of Housing, Physical Planning and the Environment (VROM) because the environmental norms of the selected heavy metals have been exceeded in different environmental compartments and products (e.g. in sewage sludge and incineration ashes).

The study showed that environmental policy leads to considerable reductions; however, not sufficient to reach the desired environmental quality. Therefore, the report gave a summary of additional policy measures that were considered effective according to scenario calculations. Another objective of the investigation was to determine the effectiveness of environmental policy, concerning the theme of squandering vs. the proper management of stocks of heavy metals.

Another comprehensive research work was carried out on flows of organic chlorine compounds, to support the societal debate on chlorine around 1995 (personal communication with Esther van der Voet).

Furthermore, the national Central Bureau of Statistics (CBS) used to make detailed studies regarding the economic flows of a number of heavy metals and nitrogen and phosphorus balance to support agricultural policy with data.

An assessment of the flows of plastics in the Netherlands for the reference year 1990 was conducted by the so called STREAMS method. This is a method for material flow analysis based on national supply and use tables (Jooesten *et al.*, 2000).



**Table 3.4: Summary on the Netherlands**

Study criteria	Results in the Netherlands
Substances and/or group of substances investigated	SFA for individual substances: <ul style="list-style-type: none"> <li>• heavy metals: copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), mercury (Hg), cadmium (Cd), nickel (Ni)</li> <li>• nutrients: nitrogen (N) and phosphorus (P)</li> <li>• chlorinated compounds and plastics (PVC)</li> </ul> NAMEA covers bulk materials
Main data/info sources used by the studies	Statistics from NAMEA by Central Bureau of Statistics (CBS)
Methodologies	Dynamic and static SFAs STREAMS method for plastics MFA is standardised under NAMEA. Accounts include information on the environment in physical units. In the NAMEA not only pollution caused by producers and consumers is shown, but also the entry of polluting substances in the Dutch environment: the domestically emitted pollution including the balance of cross-border pollution from and to the rest of the world

**Source:** OECD report, 2005; van der Voet, 1996; Joosten *et al.*, 2000; and Annema *et al.*, 1995.

SFA activities have also been conducted at other scale levels, in the European Union, and in a region within the Netherlands. There are studies for two cases at EU level (cadmium (Cd) and nitrogen (N)), from 1996 as well. For both, an account has been drawn up of the existing flows in, out and through the EU (van der Voet, 1996).

### 3.5 Norway

SFA is mainly carried out by the Norwegian Pollution Control Authority. A few ad-hoc studies were carried out by Statistics Norway (solvents, 1995; cadmium (Cd) and phthalates, 1997; wood products, 1998). The work from the Norwegian Pollution Control Authority started at the beginning of the 1990s and has covered many substances and products. The SFAs provide an inventory of the substances. They have focused on import, export, use, consumption and emissions of the substances to the environment (air, water and soil) as well as the amount of waste. Furthermore, the possibilities of more environment-friendly substitutes were analysed for some substances. In addition, the possibilities for recycling and/or recovery of the product in order to reduce the emissions of the substance to the environment were studied.

The results of the studies were to be used as background for decisions for action To Whom It May Concern: reduce the impact on the environment. The following substances were studied: tetra chloroethene (1991); chlorophenols (1991); chromium (Cr) (1992); carbon tetrachloride (1992); lead (1992); arsenic (As) (1992); zinc (Zn) (1993); nickel (Ni) (1993, 2002); trichloroethene (1993); absorbing substances (1993); tinorganic

substances (1994); dioxins (1994); nonylphenol and nonylphenoxyethoxylates, brominated flame retardants, phthalates and chloroparaffins (1995); environmentally hazardous substances in batteries (1995); substances which may have endocrine effects (1996, 1998); few chemicals with endocrine effects in consumer products in Norway (1996); hazardous substances in toner powder for laser printers and copying machines (1997); short chained chlorinated paraffins (1999); brominated flame retardants (1999, 2003); biocides and biocidal products (1999); environmentally hazardous substances in products (1996, 1997, 1998, 1999, 2000); PCB in building materials: grouting, concrete admixture, floor covering and paint/marine coating (1998); chemicals used in development and management of transport works (1999); endocrine disruptors in cleaning and car maintenance products (1999); and paints and varnishes (2001).

From 2000 to 2004, a number of studies were carried out for the substances: perfluoroalkylsulfonates (PFAS), brominated flame retardants (BFRs) and muskxylenes. The selection criteria and objectives were the:

- use of the group of substance;
- type of products in which the substance is present;
- amount of substance used;
- import and production volumes of the substance;
- main sources of emissions of the substances entering the environment.

The possible substitutes and the trends in development in the use of the substances were studied. Furthermore, inventories of hazardous substances in selected building materials and in selected textiles were carried out. Both inventories

**Table 3.5 Summary on Norway**

Study criteria	Results in Norway
Substances and/or group of substances investigated	Studies on: <ul style="list-style-type: none"> <li>• heavy metals: chromium (Cr), arsenic (As), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn)</li> <li>• tin organic substances and</li> <li>• organic compounds: tetra chloroethene, chlorophenols, carbon tetrachloride, trichloroethene, absorbing substances, dioxins, nonylphenol and nonylphenoletoxylates, brominated flame retardants, phthalates and chloroparaffins, short chained chlorinated paraffins, brominated flame retardants, biocides and biocidal products, muskxylenes, perflouroalkylsulfonates (PFAS)</li> <li>• others, e.g. a few chemicals with endocrine effects, hazardous substances in toner powder for laser printers and copying machines , PCB in building materials: grouting, concrete admixture, floor covering and paint/marine coating, chemicals used in development and management of transport works, endocrine disrupters in cleaning and car maintenance products, paints and varnishes</li> </ul>
Main data/info sources used by the studies	Data are collected from: <ul style="list-style-type: none"> <li>• statistical office</li> <li>• product register</li> <li>• industry/trade organisations</li> <li>• importers and users</li> </ul>
Methodologies	SFA and substance inventories

**Source:** SFT, 1991; SFT, 1992; SFT, 1992a; SFT, 1992b; SFT, 1992c; SFT, 1993; SFT, 1993a; SFT, 1993b; SFT, 1994; SFT, 2003; SFT, 2003a; SFT, 2004; SFT, 2004a; and SFT, 2004b.

focus on the use of the substances, their substitutes and development trends. For the studies from Norway, no accounting of the flows took place.

### 3.6 Sweden

Research in the field of SFA has focused on heavy metals and nutrients at local and national level. At national level, SFA studies commissioned by the Swedish National Chemical Inspectorate are closely linked to policy uses.

In order to assess the environmental impact from urban metal flows, a five-year research programme 'Metals in the Urban and Forest Environment' was carried out from 1994–1999. The financial support was provided by the Swedish EPA, the Stockholm County Council and the City of Stockholm. Here, studies of metal flows and accumulation in the anthroposphere and the biosphere of Stockholm were analysed. The work focused on the metals cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn). These metals were chosen due to their toxicity and/or frequent use in urban areas. The study covers a substance flow analysis, i.e. metal inflow to, metals in the stock of and metal outflow from the anthroposphere of Stockholm in 1995.

This work was comprehensive and resulted in about 20 scientific articles, which are mainly collected in *Water, Air, & Soil Pollution: Focus/Volume 1 (2001)*.

One of the main conclusions of the study was that the metal stock of Stockholm is large and still growing for Cr, Cu, Ni, Pb, and Zn. The large amount of metals in the solid waste fraction totally dominates the outflow from the city. From the results, a scenario has been designed for the sustainable use of metals. In future urban areas, cadmium (Cd) and mercury (Hg) are to be phased out; lead (Pb) use is to be restricted to a few applications, whereas chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn) may continue to be used in applications that are considered not to cause harmful effects in both the short and long term.

In addition, the study concluded that in future urban areas, monitoring of metal flows must be performed both in the anthroposphere and the biosphere in order to have a proactive approach to environmental problems. Since this comprehensive project, the work carried out on SFA/MFA is more scattered. The Environment and Health Administration of the city of Stockholm is currently starting up a project continuing the work on SFA for Stockholm with other substances such as polybrominated diphenyl ether (PBDE), polycyclic aromatic hydrocarbons (PAH), alkylphenolethoxylate

**Table 3.6 Summary on Sweden**

Study criteria	Results in Sweden
Substances and/or group of substances investigated	SFA for individual substances for Stockholm: <ul style="list-style-type: none"> <li>• heavy metals (cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn) and antimony (Sb))</li> <li>• organic substances (polybrominated diphenyl ether (PBDE), polycyclic aromatic hydrocarbons (PAH), alkylphenolethoxylate (APA), Di(2-ethylhexyl) phthalate (DEHP) and perfluorooctane sulfonate (PFOS) (currently ongoing study for Stockholm 2005–2007)</li> </ul>
Main data/info sources used by the studies	Monitoring data from soil, air and water. Statistical Office
Methodologies	Local and nationwide SFA studies

**Source:** Bergbäck, B., Johansson, K. and Mohlander, U., 2001.

(APA), Di(2-ethylhexyl) phthalate (DEHP) and perfluorooctane sulfonate (PFOS). Furthermore, studies have been carried out for antimony (Sb) as well as an updated SFA on cadmium (Cd) for Stockholm.

### 3.7 Switzerland

The basis for this overview of substance flow analyses in Switzerland is the website of BUWAL – the Swiss Agency for the Environment, Forests and Landscape, as well as completed SFAs, which can be downloaded from this site.

In 1992, the Swiss Parliament requested the Government to investigate the most important hazardous substance flows in the environment at national level. This was caused by the reorientation of the environmental policy from 'end-of-pipe' to a more holistic approach. BUWAL was commissioned with this task and has carried out a number of SFAs as well as producing a guideline on how to conduct SFAs.

These SFAs cover the following substances: nitrogen, vinyl chloride, halogenated solvents, cadmium, dioxins and furans, polybrominated flame retardants, chlorinated paraffins, and metallic/non-metallic substances in waste electronics. The purposes of the SFAs are:

- early appreciation of problematic substances;
- clarification of needs for action;
- identification of most successful measures;
- monitoring of effects of already introduced measures;
- projection of future developments.

As regards the methodology, data are balanced in the accounts. If input and output do not match, changes in stock, substance decomposition or substance build-up may have occurred. The SFAs do not contain evaluations and instruments. However, they do provide the basis for subsequent risk assessments or introduction of efficient instruments and measures.

**Table 3.7 Summary on Switzerland**

Study criteria	Results in Switzerland
Substances and/or group of substances investigated	SFA for individual substances: <ul style="list-style-type: none"> <li>• heavy metals: cadmium (Cd)</li> <li>• organic compounds: vinylchlorid, halogenated solvents, dioxins and furans, polybrominated flame retardants, chlorinated paraffins</li> <li>• other compounds: nitrogen (N) metallic/non-metallic substances in waste electronics</li> </ul>
Main data/info sources used by the studies	Statistical office, national waste statistics, national soil, air and water monitoring data
Methodologies	SFA guideline based on terminology and systematics of Professor Baccini, ETH, Zrich

**Source:** BUWAL, 1993; BUWAL, 1995; BUWAL, 1995a; BUWAL, 1996; BUWAL, 1997; BUWAL, 1999; BUWAL, 2002; BUWAL, 2003; and BUWAL, 2004.



## 4 Using SFA to provide information on chemicals

### 4.1 Discussion of the use of SFA on the European level

Country studies show that SFAs may provide much very useful information for policy-making at national level. This information has been influencing policy development at European level too. The practice of the selected countries shows that SFA studies have been used for several purposes in different fields. These possibilities allow for a promising number of potential application forms or benefits of SFA studies beyond the national scale. However, the feasibility of carrying out numerous SFA studies and applying the methodology at European level faces several problems.

#### 4.1.1 Areas where SFA may be useful

Overviews and the information gathered in selected countries indicate that SFA may be used in the following areas.

##### *Production, trade and consumption*

SFAs can:

- help carry out a detailed analysis of the international market and trends in consumption;
- provide information on international market and trends in consumption at an overall level (used as background information);
- help identify the products in which the substance is present;
- identify the overall amount of the substance used;
- help trace the consumption and emission resulting from the presence of the substance as a trace element or contaminant in fossil fuels, wood, cement, etc.;
- help identify emissions and losses to air, soil, waste water, solid waste, and hazardous waste from manufacturing processes and use of finished goods;
- help understand the use of a group of substance;
- provide information on the application and consumption of finished goods by areas of use;
- help trace substance import and production;
- provide information on production, import/export, and processing of raw materials and semi-manufactured goods.

There are several examples from selected countries for the above uses; e.g. PCB, lead (Pb) and zinc (Zn) studies in Austria and the Netherlands, studies on silver (Ag) in Vienna or SFAs on PCB, CFS, metals and heavy metals in Denmark.

##### *Regulation and policy support*

SFAs can:

- be used for the identification and the prediction of the effectiveness of potential pollution abatement measures as a basis for priority setting;
- assist the sound national and international regulation on the use of the substance;
- help clarify needs for action;
- help identify most successful measures;
- help control the effects of already introduced measures;
- help identify the need for further studies and regulation;
- help monitor the effects of regulatory actions on consumption, emissions and waste generation;
- assist the projection of future developments;
- help ensure that regulatory actions directly address the main sources of emissions and wastes of the substance;
- provide input to economic assessments regarding the cost of substituting the substances, economic consequences of new regulation, and consequences of environmental taxes and fees;
- provide background information for regulatory actions to reduce hazardous substances in waste;
- provide information for European policies on chemicals;
- provide information for the future European integrated environmental assessments.

Best examples from selected countries for the above uses are the studies on heavy metals in the Netherlands and Denmark.

##### *Tracing flows and understanding fate of substances*

SFAs can:

- help in the identification of missing flows;
- be applied for the analysis of substance flow trends and their causes;

- help identify major problem flows to the environment, together with an analysis of their causes by stepwise tracing them back to their origins in society;
- help trace hidden leaks from processes in society (technosphere);
- help assess the degree to which material cycles are closed;
- help analyse recycling and material deterioration;
- help assist the quantity disposed of into waste treatment systems and emissions from those systems;
- provide a common understanding of the flows of the substance, including emissions and waste generation, to all stakeholders;
- provide information on reporting on releases of hazardous substance;
- provide information on substances in waste used for development of life-cycle-based waste indicators.

As tracing substance flows is the core of different SFAs, most of the studies may serve as examples for all the above.

### *Human effects*

SFAs can:

- help explore the fate of substances, or explore unexpected exposure routes;
- provide a qualitative description of human exposure through the use and disposal of unfinished products.

The best examples for these uses are the studies on endocrine disrupting industrial chemicals, conducted in Germany (Leisewitz, 1997).

### *General purposes*

SFAs can:

- serve as a support for systematic data acquisition;
- be used as a screening tool, identifying issues for further investigation by other tools;
- help in the assessment of substitutes;
- help early appreciation of problematic substances;
- be used for building scenarios for future emissions and loss of substance.

Several examples show how SFA studies have served these general purposes: e.g. PCB, lead and zinc studies in Austria and the Netherlands, studies on silver in Vienna or SFAs on PVC in Germany.

### *4.1.2 Aspects of applicability*

It is evident that the information SFAs provides would also be very useful for policy-making at European level. However, careful investigation is required into whether SFAs can be carried out on a large scale, if at all. Aspects influencing the broader applicability of SFA are linked to the methodology, data and resource demands, and the great variety of substances and their properties.

#### *Non-standard methodology*

Firstly, SFA methodologies have not been put into a single standardised procedure. Therefore, one cannot easily expect comparative and consistent studies to trace chemicals in a consistent way. It is obvious that the need for standardisation would be the first step if SFA tool is to emerge as an officially applied tool in the same way as the standard monitoring and sampling methods. Standardisation may also stimulate consistent data acquisition (Helias *et al.*, 1997). There is a need for:

- standardisation of the terminology used (as in the case of Material flow accounting from Eurostat or for the System of integrated economic and environmental accounting (SEEA) methodology from the UN);
- the definition of a technical framework;
- procedural guidelines for sound use.

#### *Data requirements*

Data requirements of SFA studies are also very large. Databases or data sets needed are unavailable for a vast majority of the chemicals. Table 4.1 below summarises the sources used for SFA studies in the selected countries. Different sources of input-output databases (both at micro and macro levels) would be necessary if the current situation was to be improved. In this context it would be advisable to assess how the required SFA information could be gathered from MFAs or NAMEAs. Although these latter tools are standardised and could provide information at least on bulk materials, the low level of penetration to the national statistical systems makes these sources very limited, especially for some countries (e.g. Germany or the Netherlands). Unlike the MFA derived indicators, data would have to be disaggregated. Unfortunately, MFA does not take production and consumption into consideration; a factor which is also important for an SFA.

In relation to Eurostat's database, it would be feasible to carry out a substance flow account. For this, statistical data can be an important source, although additional information is required as well. The result would be an overview of flows in a specific year. Repeating the exercise every year could give an insight into trends and possibly the effects of policy.

For a dynamic model time series data and information on stocks are needed. This is time-consuming and would run into statistical difficulties. The study on lead carried out by Elshkaki *et al.*, (2004) in the Netherlands failed when the researchers tried to move to a Europe-wide level. This was due to a lack of data. Ester van der Voet, who was member of the Dutch study team, has emphasised in a personal communication that they faced the problem of continuously extending their information base from the originally 6 to 25 countries; many of them having no comparable data collection and management systems and capabilities.

For the dynamic model, time series should go back by 10–50 years. The problem is that the individual countries' statistics have not been harmonised. However, trade statistics and agricultural statistics actually proved to be quite good in the EU. Agricultural statistics from FAO and trade statistics from Eurostat were used. In addition, data are needed on production, waste management and on

the content of all kinds of products. Production statistics were also helpful, though often incomplete, e.g. waste data at EU level were not good. For the composition of products, statistics were of no help at all.

#### *Relation to fiscal accounts*

As SFA only deals with the physical economy, it does not include information about prices and the connection with steering forces in society. The reason is that many flows of a substance constitute only a small part of products. Products on the market have prices assigned, but it is often very difficult to attach monetary values to the flows of substances which build up the products. This is more so where substances constitute an undesirable part of a product, e.g. cadmium pollution of phosphate fertilizer (Helias *et al.*, 1997).

#### *Relation to EW-MFA*

Another important consideration related to data sets regards countries that have built capacities, systems and methodologies for other macro level MFA systems, such as EW-MFA or NAMEA (see Glossary for more details).

Both MFA and SFA result in rather similar methodological assumptions. Moreover, due to methodological correspondence SFA could be linked

**Table 4.1 Summary on data sources used for SFAs in selected countries**

Country	Main data/info sources
Austria	Basic data for the MFA and chemical SFA methods are mainly from the statistics of Statistics Austria <ul style="list-style-type: none"> <li>• statistics for production</li> <li>• statistics for consumption (ÖSTAT Industrie und Gewerbestatistik)</li> <li>• environmental statistics</li> </ul> Data sheets from companies
Denmark	Technical reference books, statistical information, manufacturers, importers
Germany	SFA data are from statistics on transport, manufacturing, production, sales and environment from ministries and German Federal Statistical Office <p>Data are often based on estimations</p> Basic data for the MFA method are mainly the statistics of the German Federal Statistical Office. The statistical data on waste and waste water are collected as a rule every three and four years, respectively
Netherlands	Statistics from NAMEA by Central Bureau of Statistics (CBS)
Norway	Data are collected from: <ul style="list-style-type: none"> <li>• statistical Office</li> <li>• product register</li> <li>• industry/trade organisations</li> <li>• importers and users</li> </ul>
Sweden	Monitoring data from soil, air and water; Statistical Office
Switzerland	Statistical Office, national waste statistics, national soil, air and water monitoring data

**Source:** See Tables 3.1 to 3.7.

to MFA rather easily. Information gathered by both analyses seems to ensure a better potential for proceeding with chemicals specific SFAs.

Austria has implemented the concept of MFA in the national statistics already after the first successful studies were carried out in 1992. A detailed conception of the accounting framework for a national material balance was also developed in 1992. This made standardised procedures available. The MFAs carried out have demonstrated that the methodology at an intermediate level of data quality is feasible. The results of the study were integrated into the national environmental plan for Austria. In 1998 the national material flow accounting was updated for 1996 and integrated into official statistics (Federal Statistical Office Austria website). National MFAs and material balances have constituted an essential element of environmental economic accounting in Austria ever since. They are indispensable sources of information with respect to the operationalisation of sustainable development. The Federal Central Statistical Office, together with the Federal Ministry of Agriculture and Forestry, Environment and Water Management, regularly update and periodically publish the material balance of Austria.

In Germany, the Federal Statistical Office developed the German Environmental-Economic Accounting (GEEA). The purpose of Environmental-Economic Accounting is to represent interdependencies between economic activities and the environment. GEEA shows what natural resources are utilised, used up, devalued or destroyed by production and consumption and the efficiency with which the economy and society deal with materials, energy, and land resources. The GEEA system allows the determination of the pressure put on nature by using it as a 'sink' for residuals and pollutants. It also permits information to be compiled on how the state of the environment changes and what level of expenditure for environmental protection is made. GEEA results are structured according to the following subject fields: material and energy flows, use of land and space, state of the environment, and environmental protection measures. The GEEA system has a modular structure. The subject fields are self-contained and at the same time connected to each other. Taken together they form the overall picture. Depending on the field examined, different methodological approaches are used, for example, accounting methods, indicators or geographical information systems. The results are presented in both physical and monetary values. Where appropriate, environment-related data are always compiled in a form enabling them to be linked to

economic data of national accounts or other statistics (Federal Statistical Office Germany website).

The official Dutch national accounts also include detailed supply and use tables, input-output tables, sector accounts, a social accounting matrix (SAM), an environmental module and many detailed tables on specific transactions, e.g. taxes and social contributions. In the 'national accounting matrix including environmental accounts' (NAMEA) a link has been established between the national accounts and environmental statistics. The NAMEA discloses the interrelation between macro indicators for the economy (i.e. net domestic product, net saving, external balance etc.) and the environment. The NAMEA consists of a conventional national accounts matrix (NAM) extended with two accounts on the environment, namely a substance account and an account for environmental themes. These accounts do not express transactions in monetary terms but include information on the environment, as it is observed in reality, i.e. in physical units. In the NAMEA, not only pollution caused by producers and consumers is shown, but also the entry of polluting substances in the Dutch environment, i.e. domestically emitted pollution, including the balance of cross-border pollution from and to the rest of the world. The Netherlands has produced NAMEA series since 1993 for air emissions, waste, waste water, use of oil and gas, and now also estimates environmental impacts (e.g. greenhouse gas effects, acidification, eutrophication) by sector of origin.

### 4.1.3 *Physico-chemical substance properties*

Most of the SFA studies are on substances such as heavy metals and persistent organic compounds that are stable and non-reactive in normal environmental conditions. However, this is not the case with most chemicals. Table 4.2 below summarises the studies by countries and (group of) substances studied. 'Bulk' substances, such as nutrients (phosphorus or nitrogen) flows have also been studied and assessed. However, these analyses may be less precise due to the huge amount and complex forms in which these materials are present in the environment and the technosphere.

It is important to stress that an SFA deals with a single substance. So, if measures are taken to reduce the use of the substance during the study by replacing it with another substance, problems connected with this other substance will go beyond the scope of that study unless the researchers adapt a more comprehensive approach.

**Table 4.2 Summary on substances studied by SFAs in selected countries**

Country	Substances and/or group of substances investigated
Austria	<p>SFA studies exist for the chemical industry on:</p> <ul style="list-style-type: none"> <li>• fibre,</li> <li>• fertilizer</li> <li>• and plastic industry</li> </ul> <p>Unverified mass balance exists for the chemical industry</p> <p>SFA studies on individual substances:</p> <ul style="list-style-type: none"> <li>• PCB, zinc (Zn)</li> <li>• silver (Ag) in waste water in the city of Vienna</li> <li>• lead (Pb), nitrogen (N) and biotic carbon (C) balance in Vienna.</li> </ul> <p>Main categories of MFA cover bulk materials</p>
Denmark	<p>SFA for individual substances:</p> <ul style="list-style-type: none"> <li>• metals and heavy metals: aluminium (Al), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), tin (Sn)</li> <li>• organic substances: azo colorants, AMPA, brominated flame retardants, CFCs, HCFCs, HFCs, chloroparaffins, chlorophenols, dichlorofemethane, dioxins, orghanotin, fluorecyclobutane, fluoroethane, fluoroethane, fluorohexane, fluoropropane, formaldehyd, methylbromide, nonylphenols and nonylphenoethoxylates, PCB/PTB, phthalates, sulphur-hexafluoride, tetrachloroethylene, trichloroethylene</li> </ul>
Germany	<p>SFA studies on individual substances:</p> <ul style="list-style-type: none"> <li>• endocrine disrupting industrial chemicals: Bisphenol A; Dibutylphthalat, Benzylbutylphthalat; Nonylphenol, Alkylphenoethoxylate</li> <li>• heavy metals: lead (Pb), copper (Cu), cadmium (Cd), aluminium (Al)</li> <li>• nutrients: nitrogen (N), phosphorus (P), potassium (Na),</li> <li>• chlorine (Cl) and PVC</li> </ul> <p>Main categories of MFA cover bulk materials</p>
Netherlands	<p>SFA for individual substances:</p> <ul style="list-style-type: none"> <li>• heavy metals: copper (Cu), zinc (Zn), lead (Pb), chromium (Cr), mercury (Hg), cadmium (Cd), nickel (Ni)</li> <li>• nutrients: nitrogen (N) and phosphorus (P)</li> <li>• chlorinated compounds and plastics (PVC)</li> </ul> <p>NAMEA covers bulk materials</p>
Norway	<p>Studies on:</p> <ul style="list-style-type: none"> <li>• heavy metals: chromium (Cr), arsenic (As), copper (Cu), lead (Pb), nickel (Ni), zinc (Zn),</li> <li>• tin organic substances and</li> <li>• organic compounds: tetra chloroethene, chlorophenols, carbon tetrachloride, trichloroethene, absorbing substances, dioxins, nonylphenol and nonylphenoethoxylates, brominated flame retardants, phthalates and chloroparaffins, Short chained chlorinated paraffins, Brominated flame retardants, biocides and biocidal products, muskxylenes, perfluoroalkylsulfonates (PFAS)</li> <li>• others, e.g. a few chemicals with endocrine effects, hazardous substances in toner powder for laser printers and copying machines, PCB in building materials: grouting, concrete admixture, floor covering and paint/marine coating, chemicals used in development and management of transport works, endocrine disrupters in cleaning and car maintenance products, paints and varnishes</li> </ul>
Sweden	<p>SFA for individual substances for Stockholm:</p> <ul style="list-style-type: none"> <li>• heavy metals (cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), zinc (Zn) and antimony (Sb)),</li> <li>• organic substances (polybrominated diphenyl ether (PBDE), polycyclic aromatic hydrocarbons (PAH), alkylphenoethoxylate (APA), Di(2-ethylhexyl) phthalate (DEHP) and perfluorooctane sulfonate (PFOS) (currently ongoing study for Stockholm 2005-2007)</li> </ul>
Switzerland	<p>SFA for individual substances:</p> <ul style="list-style-type: none"> <li>• heavy metals: cadmium (Cd)</li> <li>• organic compounds: vinylchlorid, halogenated solvents, dioxins and furans, polybrominated flame retardants, chlorinated paraffins</li> <li>• other compounds: nitrogen (N), metallic/non-metallic substances in waste electronics</li> </ul>

Source: See Tables 3.1 to 3.7..



Conducting SFA for certain substances might be hindered by several factors or its scope may prove to be very limited. In case of many substances, output side flows are very unpredictable. Emission sources might be diffuse, e.g. VOC for transportation. Also, final utilisation of the product may vary or the substance outflow may be highly influenced by environmental circumstances that are very unpredictable or stochastic. This is the case with highly reactive chemicals and volatile organic compounds. This can render SFA studies for certain substances very complicated (if not impossible) to carry out.

### *Coverage of priority substances*

The priority list of existing chemicals (<http://ecb.jrc.it/existing-chemicals>), in accordance with the Council Regulation (EEC) 793/93 on the evaluation and control of the risks of existing substances, covers 141 substances of primary concern. The priority list covers the most hazardous and harmful substances which require immediate attention because of their potential effects to man or the environment. A few of these priority substances have already been studied by SFAs in some countries. Reports exist for zinc, nickel, aluminium and chromium, and a CFC (chlorodifluoro-methane) and chlorinated organic compounds, such as chlorophenols, tetrachloroethylene, trichloro-ethylene.

#### **4.1.4 Resource requirements**

In some report cases there has been significant influence on government policy-development. However, analyses of single substance flows are a rather costly and time-consuming effort. According to Femia and Moll (2005), they should only commence when a sufficient level of detail and the limitations of the analysis have been clarified and deemed acceptable.

Heavy resource needs, such as time, cost and sound expertise, are considered a significant bottleneck when speaking about the application of SFA studies. Carrying out a detailed SFA for a single substance or group of substances has been estimated by Femia and Moll (2005) to take approximately one person-year. The exact costs of conducting SFA studies may vary due to differences in wages, complexity of the study, information needs and availabilities etc. Nevertheless, one can use this one person-year per substance figure as a first reference based on the experience up to now.

A standardised methodology would likely shorten this time and reduce costs. It would also provide the opportunity to employ more researchers, experts and professionals to carry out studies on many more substances, such as the framework of a longer-term, EU-wide programme. The economy and scale of carrying out SFAs for similar substances (factored group(s) of substances) in a single research programme should be considered when launching SFA activities.

## **4.2 Alternative to a complete European SFA**

One of the main obstacles to preparing a full SFA is that it is very data demanding. These data are rarely readily available. From the country overviews it seems that it is possible to prepare an SFA for a small and well-regulated country, such as the Netherlands and Denmark, whereas it seems to be more complicated for large countries such as Germany and France.

As mentioned, a Dutch study carried out by Eshkaki *et al.* (2004) tried to upscale an SFA on lead to EU level. This was not possible due to the lack of appropriate data. So, detailed EU-wide SFAs, even for selected substances, are considered to be extremely difficult if not impossible with the present data sources available.

### **4.2.1 Inventory**

As a complete (dynamic) EU-wide SFA for a selected substance is hardly considered to be feasible, the overview of a national-level SFA or more likely an inventory of the flows of the concerned substance being extrapolated for Europe would be a possible way forward. An overview for just one year or a static analysis would not be that difficult either.

This inventory will, in broader terms, describe the flows of a substance, such as export, import and emission (waste), and it will contain rough estimates with a number of assumptions.

A similar approach has been carried out in the United States by the US Geological Survey for a number of heavy metals. These so-called material flows present a concise review on source, processes, supply and historical use pattern for a wide number of heavy metals. Furthermore, it covers a preliminary estimate of flows of the substance for a given year (Liewellyn, T. O., 1994).

A relevant study has been carried out on mercury releases in the Russian Federation, too. This is not a complete SFA but covers much information on mercury in the Russian Federation, such as production, import and export, use of mercury, mobilisation of mercury impurities and turnover of mercury by waste treatment (Russian Federal Service for Environmental Technological and Atomic Supervision — DEPA, 2005).

#### 4.2.2 SFAs in selected indicator countries

Another way forward could be to look at a number of indicator countries, where each indicator country would represent a number of 'similar' countries, for example Denmark could represent Scandinavian countries (or other countries of similar size and economy), Italy could be selected to represent the Mediterranean region, and Hungary the new Member States. The selection of countries would vary depending on the choice of substances, as the use, production and consumption patterns will vary from country to country.

Furthermore it is important to be aware of the distinction between a so-called 'old substance' like lead and a 'modern' one like brominated flame retardant. The use of the old substances might differ substantially from country to country, because it is connected to specific economic activities and to other traditions, whereas the use of modern

substances is more homogeneous due to their international availability.

The information collected from these carefully selected indicator countries could be used to extrapolate it for the whole of Europe or potentially even beyond. Of course, this will never show the perfect picture of the situation of the concerned substance flows, but it will show the best achievable picture for meaningful policy and management planning with the available data and information.

### 4.3 SFA in support of an integrated environmental assessment

When exploring the applicability of the SFA methodology in support of an integrated assessment at European level of the impact of chemical on human health and the environment, only a hypothetical structure for this assessment can be considered. This is due to the fact that there is no formally adapted approach yet. As a provisional structure, the modules which were suggested by the report *Towards a European Chemicals Information System: a survey on reported monitoring activities of chemicals in Europe* (W. Peijnenburg, J. Bogte, H. van Wijnen and A. Wintersen, 2005) are used. These modules could also be logical parts of an integrated assessment on European level when assessing chemicals, see Table 4.3.

**Table 4.3 A provisional structure of modules of an integrated assessment on European level**

1)	A database containing information on (basic) physico-chemical substance properties. This basic module should preferably include experimentally derived substance properties, but QSAR <sup>(2)</sup> derived values including estimates of their uncertainties may for many purposes be equally suited.  A module with geographic information providing an overview of the characteristic properties of all environmental compartments within Europe at various levels of integration: from local to continental scale.
2)	Regularly updated information on emissions (quantities and sources) at various geographical scales.
3)	A database containing (usually laboratory generated) toxicity data for biota residing in soil, water, ground water and air. Similar to the database on physico-chemical substances properties, this database may be supplemented with QSAR-generated estimates taking into account amongst other things the toxic modes of action.
4)	A database containing data on bioassays with field samples in order to get insight into the actually occurring adverse effects due to either specific chemicals or mixtures.
5)	A database on monitoring data of chemicals in the European environment.
6)	A module relating monitoring efforts to legislative frameworks.
7)	A module containing fate models in order to generate exposure levels at various scales of integration, and to supplement and verify the monitoring database.
8)	A risk module containing eco-toxicity models that quantitatively integrate exposure and adverse effects as expressed on the basis of the databases above. This will allow the calculation of the risks to ecosystems associated with the emission/presence of chemicals in the European environment.
9)	A module containing toxicity data for humans.
10)	A risk module containing models that quantitatively integrate exposure and adverse effects on humans as expressed on the basis of the databases above. This will allow the calculation of the risks to humans associated with the emission/presence of chemicals in the European environment.

<sup>(2)</sup> Quantitative Structure-Activity Relationship (QSAR): Software to explain the observed activities or properties of compounds, then predict them for new compounds.

### 4.3.1 General and module specific support

Considering the applicability of SFAs and the characteristics of the modules for integrated assessment at European level, several options on how the first could be used to provide support to the latter can be identified. For instance, SFA studies on substances or group of substances may provide general support to the integrated assessment at European level by:

- serving as a support for systematic data acquisition;
- supporting it as a verification procedure to look for inconsistencies or non-matching data;
- helping in the identification of missing flows for several modules;
- being applied to the analysis of substance flow trends and their causes for planning integrated assessment at European level;
- helping identify the products and processes in which the substance is present;
- helping trace hidden leaks from processes in society to identify further improvements of the integrated assessment at European level;
- being used as a screening tool, identifying issues for further investigation by other tools or modules.

Identifying, tracing and understanding substance flows also provides information that may be linked directly or indirectly to the specific modules.

Having the different SFA concepts and country-level applications overviewed, a general SFA model (see Figure 4.1) will be used to illustrate the most important elements of tracing a substance by the generic SFA method. This figure illustrates an analysis carried out at national level. The numbers in brackets in the figure refer to the eleven potential modules for integrated assessment at European level to indicate the possible junctions with the SFA steps. In other words, these are junctions or links between the proposed modules and the flows studied or information gathered by a general SFA study. This approach enables the exploration and simple visualisation of the SFA applicability to be carried out in relation to the integrated assessment at European level.

The model incorporates the substance flows between the environment and the technosphere. The environment is the overall global eco-system of natural and artificial environments. Thus, it is

the basic life-supporting system, while the human induced social and economic systems constitute the technosphere. This system is based on the resources and sinks of the environment.

A substance which is the subject of the SFA study may enter the technosphere by (or in form of) solid, liquid and gaseous materials. They may enter the economy for further use (throughput) in production or consumption processes. The two main input categories are substances of raw materials domestically extracted from the environment and imports from other economies in the technosphere. Substances may also be produced directly in the technosphere with the use of materials extracted from the environment.

Accumulation refers to the net addition to stocks of substances that 'hibernated' in products (e.g. heavy metals in batteries) or other elements of the technosphere.

Unused stocks are stocks of substance in ores and minerals, etc. Substances kept in unused stocks do not 'flow' through the technosphere but are still important for natural reserves or background levels in the environment for some substances (e.g. heavy metals in ores).

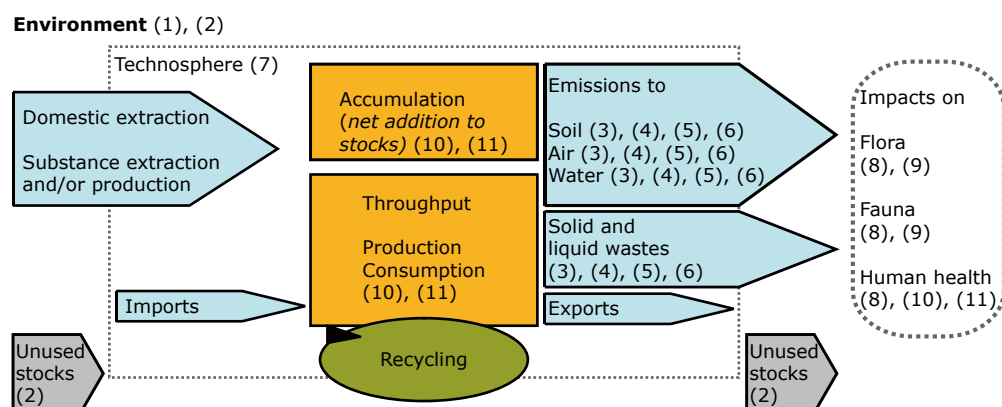
Outputs are defined as all material flows entering the environment, either during or after the production or consumption processes. Outputs include emissions to air, water and soil, and waste. Outputs also include imports to other economies.

Links between the SFA and the EU-IEA may be either direct (e.g. identification of emissions) or indirect (e.g. background information on the substance properties). Following step by step the general SFA model, links are described below.

### 4.3.2 Environment and domestic extraction

Data on substances in the environment and domestic extraction flows are related to the proposed modules of integrated assessment at European level that provide basic and background information on the substance(s) and the natural (geographical) environment they are studied in.



**Figure 4.1 SFA links to integrated environmental assessment modules (referred by numbers)**

**Note:** Size of arrows is non-comparative and does not indicate the scales of flows. Substance flows are measured in mass per time unit (e.g. kg/year). Impact on flora, fauna and human health is not studied by SFAs, but directly related to the emissions and wastes.

### (1) Physico-chemical substance properties

- A database containing information on physico-chemical substance properties is rather important for carrying out the SFA itself, providing basic information on the substance subject to the SFA study.

### (2) Geographic information

- Although the module is not necessarily chemical, it may provide basic geographic information when tracing substances in the environment and assessing diffusion routes of substances.
- This may also provide information on the natural source of substances (i.e. to estimate resources and discover stocks) and predict or consider the transmission of substances in air, water or soil, for example.

### Emissions and wastes

Modules (3), (4), (5) and (6) have a very direct junction to the SFA generated information, as these modules are directly related to the substance outputs (e.g. emissions) to the environment and the impacts caused (e.g. toxicity).

### (3) Information on emissions

- SFA can help identify and predict emissions of a substance or substance group to the environment from different natural and/or artificial sources by identifying their natural stocks, throughput, and net addition to stocks, in the technosphere and as output flows.

- SFA can also be used as a screening tool to identify the need for further measuring or monitoring of a studied substance.
- SFA can help identify emissions and losses to air, soil waste water, solid waste, hazardous waste from manufacturing processes and use of finished goods by use areas.
- SFA can help assist the quantity disposed of into waste treatment systems and emissions to those systems.
- SFA can provide information on reporting on releases of hazardous substance.

### (4) Toxicity data for biota residing in soil, water, ground water and air

### (5) Database on bioassays with field samples

- These modules are directly linked to the impacts of the substances arising from the impacts of emissions and wastes on the environment.

### (6) Monitoring data of chemicals in the European environment

- When conducting measures or planning monitoring systems, SFA results for different substances may facilitate the systematic data acquisition by tracing the substance's route in the environment.
- Substance-flow related information may support the integrated assessment at European level as an error check procedure and look after inconsistencies or non-matching data of the monitoring system.

- SFA may also help experts understand differences in the values measure in different circumstances (such as heat, elevation, etc.) in the environmental compartments;
- SFA can help identify major problem flows to the environment, such as substances that are not regularly measured.

### **Technosphere (including throughput and accumulation)**

In the technosphere, the SFA may provide several relevant inputs for the integrated assessment at European level.

#### **(7) Monitoring efforts for the legislative frameworks**

- SFA modelling offers the possibility to explore the possible shifting of problems, for instance caused by a redirection of the substance flows.
- SFA may also help assess the degree to which material cycles are closed to track the impact of related policy.
- SFA can be used for the identification and the prediction of the effectiveness of potential pollution abatement measures as a basis for priority setting.
- SFA can assist the sound national and international regulation on the use of the substance.
- SFA may help clarify needs for action.
- SFA can help identify most successful measures.
- SFA can help control the effects of already introduced measures.
- SFA can help identify the need for further studies and regulation.
- SFA can help monitor the effects of regulatory actions on consumption, emissions and waste generation.
- SFA can help ensure that regulatory actions directly address the main sources of emissions and wastes of the substance.
- SFA can provide input to economic assessments regarding the cost of substituting the substances, economic consequences of new regulation, and the consequences of environmental taxes and fees.
- SFA can provide background information for regulatory actions to reduce hazardous substances in waste.
- SFA can provide information for European policies on chemicals.

- SFA can provide information for the integrated assessment at European level.

#### **(10) Toxicity data for humans**

#### **(11) Risk module on humans**

- These modules are linked to the output flows impact, but it is important to stress that humans are also exposed to the chemicals while using them in the technology processes, not only after releasing outputs to the environment. Therefore, tracing substances in the technosphere may assist in assessing exposure and risk while the substance is used in products, for example.
- SFA can provide a qualitative description of human exposure through the use and disposal of unfinished products.
- SFA can help explore the fate of substances, orexplore hidden human or eco-toxicity risks.

### **Impacts**

Impacts are highly determined by the emissions, but module (8), (9), (10) and (11) are also related to the assessment of the impacts of chemicals.

#### **(8) Fate models**

- SFA may help in the identification of missing flows and leaks when exploring the fate of substances.

#### **(9) Risk module containing eco-toxicity models**

#### **(10) Toxicity data for humans**

#### **(11) A risk module on humans**

- Eco-toxicity, human risk and toxicity modules are linked to the use of chemicals and exposure to different substances. SFA may help explore hidden human or eco-toxicity risks with the identification of missing flows or leaks of substances.

The above list contains only preliminary assumptions. Whenever the decision is made to develop a future formalised approach to integrated assessment at European level, an in-depth analysis should be carried out to explore the concrete, realistic, reasonably feasible, and most useful SFA applicabilities in support of this development.

## 5 Conclusions

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SFA is used for tracing the flow of a selected chemical (or group of substances) through a defined system (e.g. geographic area or economic sector). SFA is a specific type of material flow analysis tool. It only deals with the analysis of flows of selected chemical substances or compounds such as heavy metals (mercury, lead, etc.), nitrogen, phosphorous, persistent organic substances (PCBs) etc., through society, economy and the environment.

There is no formally standardised methodology accepted for SFA studies. However, different methodologies established by academia are available.

The report gives an outline of the existing experience of SFA studies carried out in Austria, Denmark, Germany, the Netherlands, Norway, Sweden and Switzerland. These countries are considered to be the most advanced in this context.

The studies proved that SFA may provide much very useful information for policy-making at national level, and such studies have been used for different purposes in different fields. Several aspects of the following areas have been identified:

- production, trade and consumption;
- regulation and policy support;
- tracing flows and understanding fate of substances;
- human effects;
- general purposes.

This report concludes that while European-level SFA studies can provide useful information, substantial barriers have to be overcome for the broader applicability of SFA. The most important barriers include non-standardised methodology, high data and resource demands, and the broad variety of substances and high variability in substance properties.

Two options have been proposed as possible first steps towards the broader applicability of SFA: (a) production of an inventory of the flows of a substance for Europe (see Section 4.2.1) and/or (b) examination of a number of indicator countries where the selected countries could represent a number of countries. Both of these options are considered to be feasible.

Furthermore, the applicability of the SFA methodology in support of integrated assessment at European level has been assessed. SFA studies on substances or groups of substances may provide helpful support both for general and specific modules.

## Acronyms used

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CFC	Chlorofluorocarbons
DEPA	Danish Environmental Protection Agency
DMC	Domestic material consumption
DMI	Direct material input
EEA	European Environment Agency
EW-MFA	Economy-wide material flow accounting
GDP	Gross domestic product
GEEA	German environmental economic accounting
LCA	Life cycle assessment
LCI	Life cycle inventory
MFA	Material flow analysis/accounting
NAM	National accounts matrix
NAMEA	National accounting matrix including environmental accounts
NAS	Net additions to stocks
OECD	Organisation for Economic Co-operation and Development
PCB	Poly chlorinated biphenyl
PIOT	Physical input-output table
PVC	Poly vinyl chloride
QSAR	Quantitative structure-activity relationship
SAM	Social accounting matrix
SEEA	System of economic and environmental accounts
SFA	Substance flow analysis
SNA	System of national accounts
TMC	Total material consumption
TMR	Total material requirement
UBA	Umweltbundesamt

# Glossary

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## Material flow analysis (MFA)

The concept of material flow analysis (MFA) refers to a number of methodologies (or MFA tools) which can be used to provide information on industrial metabolism. MFA refers also to accounts in physical units (usually in terms of kilograms; mass is the physical basic unit to characterise materials; kilograms or metric tonnes are the measurement unit for mass) comprising the extraction, production, transformation, consumption, recycling, and disposal of materials, e.g. substances, raw materials, base materials, products, manufactures, wastes, emissions to air or water.

## Substance flow analysis (SFA)

SFA refers to the application of the MFA methodology for individual substances or substance groups.

## Economy-wide material flow accounting (EW-MFA)

Economy-wide material flow accounts (EW-MFA) and derived indicators are used to monitor the overall metabolic performance of national economies. EW-MFA is a physical accounting framework (widely compatible with the monetary system of national accounts) to monitor material inputs, accumulations and outputs of national economies. EW-MFA provides a comprehensive and systematic overview of the physical basis and requirements of all economic activities taking place within a national economy. A number of indicators can be derived from EW-MFA, such as total material requirement (TMR) and direct material consumption (DMC). Those indicators can be used to characterise and monitor the resource use of national economies at an aggregated level. They have been used by several governments to monitor 'decoupling' and to formulate quantitative targets in the context of policies for sustainable resource use and enhanced resource productivity.

The summary indicators derived from EW-MFA provide a physical description of a national economy, complementing the greater detail offered by other common indicators (e.g. energy use, waste generation or air emissions). In economic terms, the summary indicators show the dependency on physical resources and the efficiency with which the resources are used by national economies. In environmental terms, material input indicators can be used as a proxy for environmental pressures associated to resource extraction, the subsequent material transformation, and the final disposal of material residuals back to the environment.

Total material requirement (TMR) aggregates all material inputs required by a national economy on a life-cycle-wide basis. TMR includes not only the direct use of resources, but also indirect flows associated with domestic extraction, and those indirect flows related to the production of imported goods (so-called 'hidden flows'). In economic terms, it is a measure of the physical basis of the economy, or the total primary resource requirements of all production activities of a national economy. In environmental terms, it is a proxy for potential environmental pressures associated with the resource extractions. Since all these material inputs will sooner or later be transformed into material outputs (e.g. emissions, waste) TMR also constitutes a proxy for potential future environmental pressures, on a life-cycle-wide basis, to the domestic as well as foreign environment.

TMR = domestic extraction (fossil fuels, minerals, biomass)  
 + unused domestic extraction  
 + imports  
 + indirect flows associated with imports

**Direct material input (DMI)** measures the input of materials which are directly used in the economy, that is, used domestic extraction and physical imports — it does not include so-called 'hidden flows' like the TMR does. DMI has been used as a substitute for TMR because data on TMR are more difficult and time consuming to compile, and therefore less readily available than DMI data. DMI indicator theoretically may send a wrong signal if a country is decreasing its domestic resource extraction while increasing imports of raw materials, but empirical analyses show that there is a correlation between DMI and TMR.

DMI = domestic extraction (fossil fuels, minerals, biomass)  
+ imports

**Direct Material Consumption (DMC)** accounts for all materials used up by a country and is defined as all materials entering directly the national economy (used domestic extraction plus imports), minus the materials that are exported (DMC = DMI – exports). In economic terms, it is related to the consumption activities of the residents of a national economy. It is also the MFA indicator most closely related to the GDP (Eurostat, 2001a). In environmental terms, DMC is a proxy for potential environmental pressures associated with the disposal of residual materials to the domestic environment.

DMC = DMI – exports

These and further MFA terms are explained in more detail in the methodological guide published by the Statistical Office of the European Communities (Eurostat, 2001).

### **Life cycle inventory (LCI)**

Life cycle inventory (LCI) registers systematically all material and energy flows related to the life cycle of a product (functional unit). The LCI sums up the environmental pressures (inflows and outflows) related to one functional unit, e.g. kg of CO<sub>2</sub> emitted throughout the life cycle of a milk bottle. LCI forms one part of the more comprehensive methodology of Life Cycle Assessment (LCA). LCIs are used for product related policies (e.g. product labelling or IPP) and for the environmental management at company level.

### **PIOT and NAMEA**

Physical input-output tables (PIOT) and national accounting matrices including environmental accounts (NAMEA) are used to monitor the material flows related to economic branches and sectors. PIOTs account for all material transactions within a national economy, i.e. material flows between economic sectors and branches, and also include all material transactions with nature (i.e. raw material inputs and emission outputs). PIOTs are mass balanced at industry level. NAMEAs show selected material flows (e.g. air emissions, waste, material inputs) broken down by economic sectors and integrated with monetary Input-Output Tables. NAMEAs form the basis for environmental Input-Output Analyses (eIOA). eIOAs based on NAMEAs provide a huge variety of insights into the determinants of environmental pressures, useful in the context of environmental policies (e.g. Integrated Product Policy, Climate Policies, Sustainable Resource Management).



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# Annex I Overview on the European chemical industry

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The following section gives a general overview on the European chemical industry in terms of scope, structure, geography, economy and potential risks. Furthermore, the main policy instruments in the field will be presented <sup>(3)</sup>.

## Profile

The chemical industry is heterogeneous, both in terms of size of companies and in terms of products. The product range is very large, going from basic inorganic and organic products, over pharmaceuticals and fertiliser, plastic products, aromatics, glues and paints, cosmetics, etc. (UIC).

### Chemical industry outputs

Economic development has to a considerable extent been driven by progress and innovation achieved by the chemical industry. This process has led to the marketing and use in different applications of ever-increasing numbers and quantities of chemical substances. More than 10 million chemical compounds (natural or man-made) have been identified. Of these, about 100 000 are produced commercially (200 to 300 new chemicals enter the market each year) and are potential subjects of concern.

The output of the chemical industry covers four wide ranges of products: base chemicals, speciality and fine chemicals, pharmaceuticals, and consumer chemicals.

**Base chemicals** covers petrochemicals and derivatives and basic inorganics. They are produced in large volumes, and are sold to both the chemical industry and to other industries. They represent 37.8 % of total EU chemicals sales.

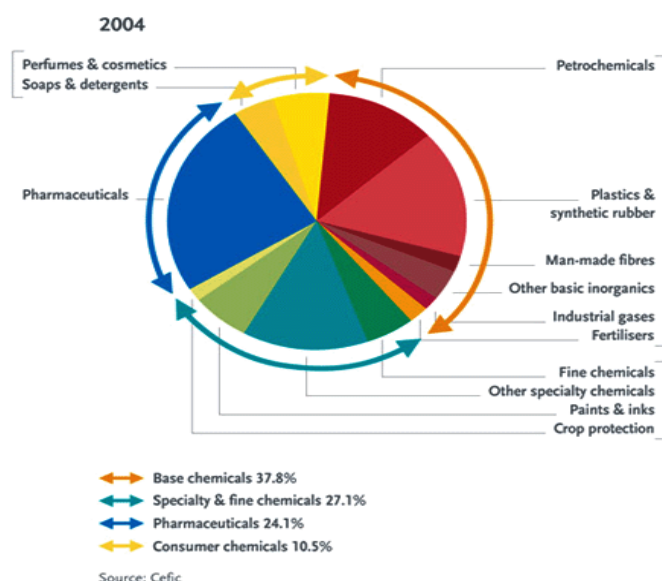
**Specialty and fine chemicals** are produced in smaller volumes than base chemicals. Specialty chemicals cover the auxiliaries for industry, dyes and pigments, oleochemicals, crop protection, and paints and inks. Fine chemicals represent pharmaceutical intermediates, agro-intermediates, and chemical intermediates. They represent 27.1 % of total EU chemicals sales.

**Pharmaceuticals** represent both basic pharmaceutical products and pharmaceutical preparations but not pharmaceutical intermediates. They account for 24.6 % of total EU chemicals sales.

Finally, **consumer chemicals** are sold to final consumers: soaps and detergents, perfumes and cosmetics. They represent 10.5 % of total EU chemicals sales.

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<sup>(3)</sup> Most of the figures on the European chemical industry and some of the comments on them are collected from the website of European Chemical Industry Council (CEFIC). Reproduction and dissemination of the data are authorised provided the source is acknowledged by Cefic ([www.cefic.org](http://www.cefic.org)).

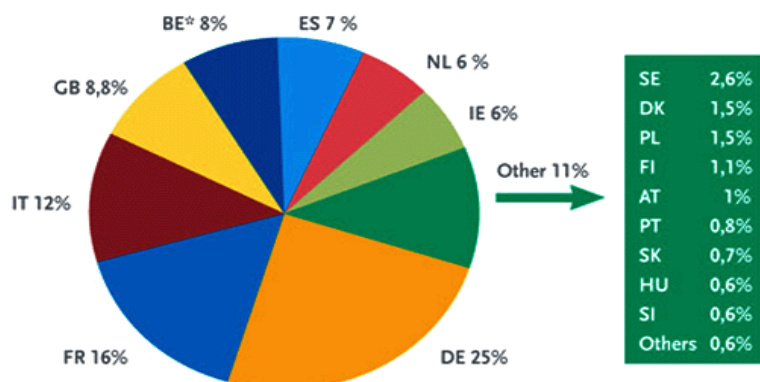
**Figure AI.1 Sectoral breakdown of EU chemical industry sales****Geographical scope**

EU-15 represents more than 95 % of total EU chemicals turnover. Eight countries stand out, often referred to as 'the Big 8': Germany, France, United Kingdom, Italy, Belgium, Spain, the Netherlands and Ireland, accounting together for about 92 % of the total European production. Germany is the largest chemicals producer (with 27 % of total production) in Europe, followed by France, Italy and the United

Kingdom. Together, those four countries produce 62 % of EU chemicals output (EUR 580 billion). Adding Belgium, Spain, the Netherlands and Ireland raises the share to 89%. Poland is the biggest new EU country, representing 1.5 % of total EU-25 chemicals sales, more than Austria, Finland and Portugal and followed by the Czech Republic and Hungary among the new Member States.

**Figure AI.2 Geographical breakdown of EU chemical industry sales**

Sales 2004: € 580 billion  
Percentage shares

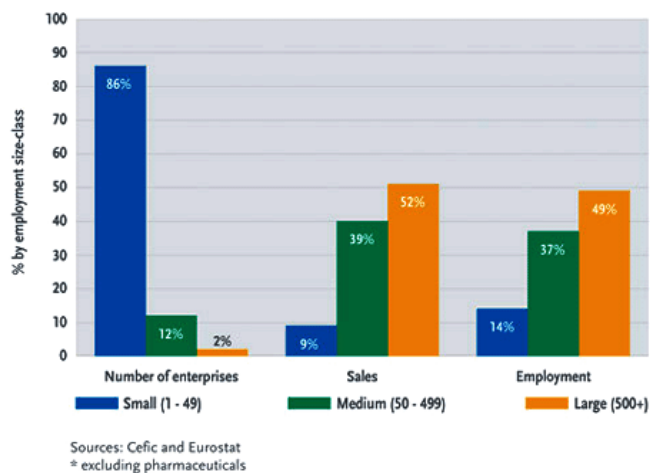


Source: Cefic

Notes: Big 8: Germany, France, Italy, UK, Belgium, Spain, Netherlands and Ireland. This is based on NACE 24. Only France and Denmark exclude man-made fibers.

\* Belgian sales also include NACE 25



**Figure AI.3 Number of enterprises, sales and employment by size-class**

### Structure of the chemical industry

In the EU, some 27 000 (excluding pharmaceuticals) chemical companies employ a total staff of about 1.9 million, or 6 % of the overall workforce in the manufacturing industry. Employment in the EU chemical industry is decreasing but with a lower rate than the total industry. Employment in Japan and the USA are experiencing a steeper decline for both chemicals and industry compared to the EU. Approximately 96 % of the enterprises have fewer than 250 employees and may be considered as small and medium-sized enterprises. These account for 30 % of sales and 37 % of employment. Around 4 % of EU chemical enterprises employ more than 250 employees. These large enterprises employ 63 % of the labour and generate around the 70 % of total chemical sales (Cefic, 2005).

### Economic Scope

In economic terms, the European chemicals industry (EU-25) equalled in 2003 about 34 % of world production, corresponding to EUR 556 billion. On the following places were USA (25 %), Asia (12 %), Japan (11 %) followed by minor shares to China, other Europe, Latin America and other.

Also in terms of trade in chemicals, EU is in the lead. The region accounts for around 65 % of world export and 53 % of world import. It is the only region with a surplus on the balance of trade.

The chemicals industry accounts for almost 2.5 % of the gross European product, almost equal to the agricultural sector. The industry is growing at a faster rate than total industry, so the relative share is increasing as well (EU2004Reach).

Over the period, 1999–2004, chemicals production grew more strongly in the EU than in either the US or Japan. However, the industry in the EU and in the USA grew by a similar rate and faster than in Japan. Chinese growth for both chemicals and total industry is still impressive. Over the past 10 years, the EU chemicals industry grew by 3.1 % per annum, while growth in the US was 2 % and 1.5 % in Japan.

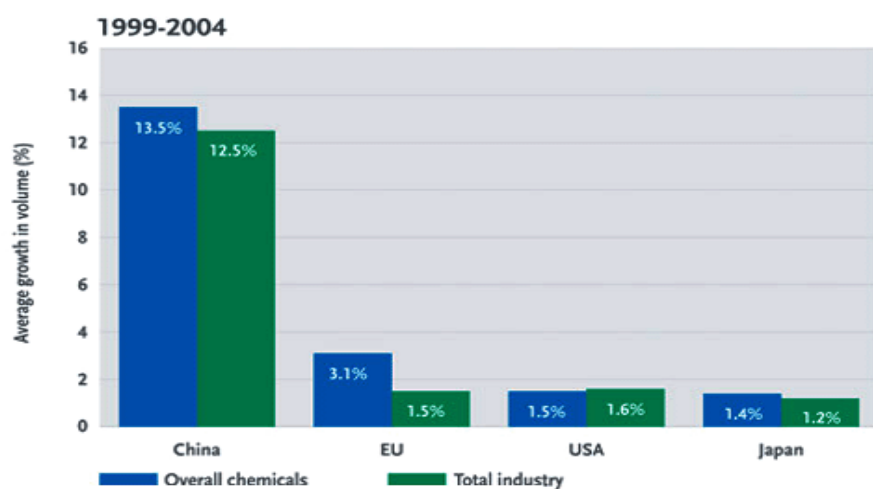


In 2004, the key trading regions were the EU, Asia, and North America. EU-25 was the world's leading exporter and importer of chemicals, accounting for more than half of global trade. However, it should be taken into account that EU is a single market which simplifies intra-EU trade.

#### Energy and material intensity

By 2002, production in the EU-15 chemical industry had risen by 38 % since 1990, while total energy consumption has increased by only 2.5 % and CO<sub>2</sub> emissions have fallen by 8 %.

**Figure AI.4 International growth rate comparison of production**



**Figure AI.5 Regional shares in world trade in chemicals**

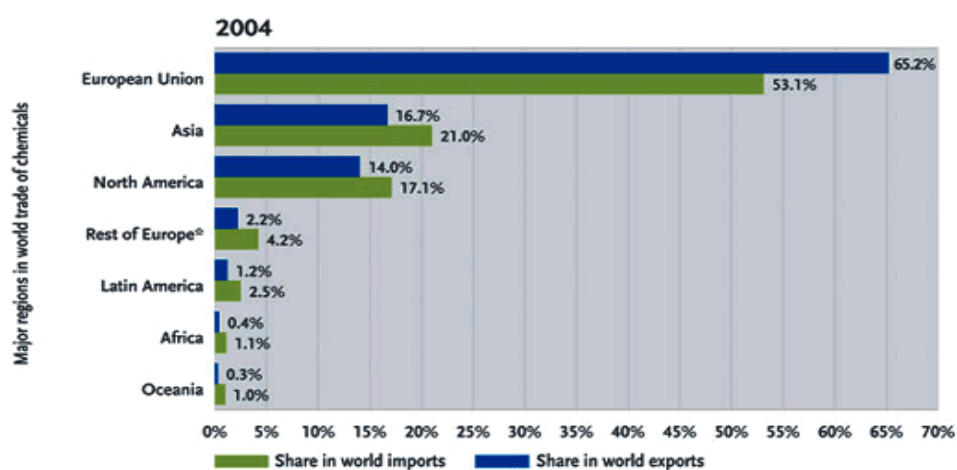
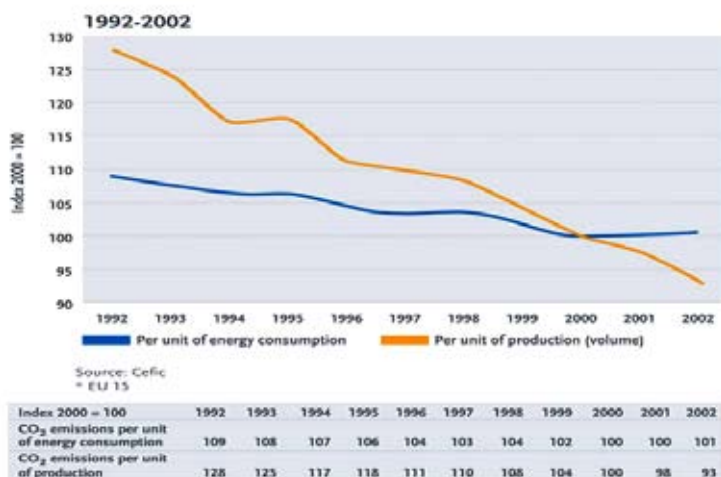
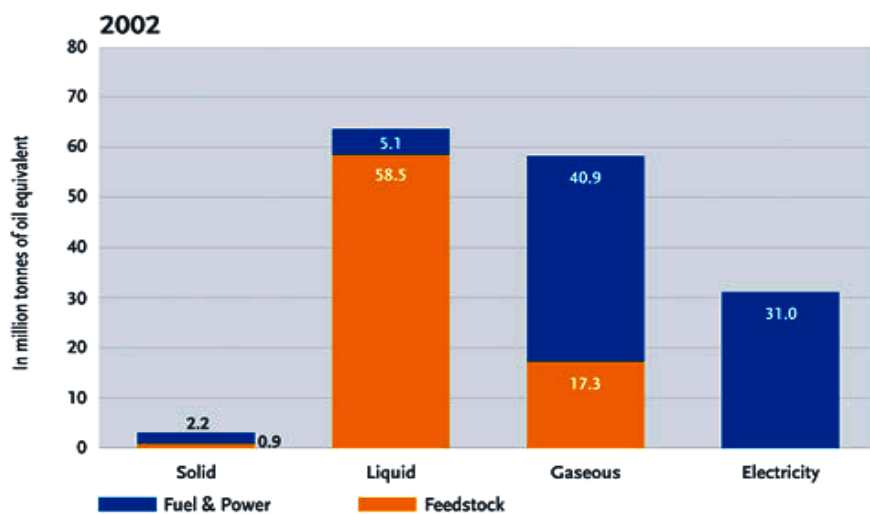
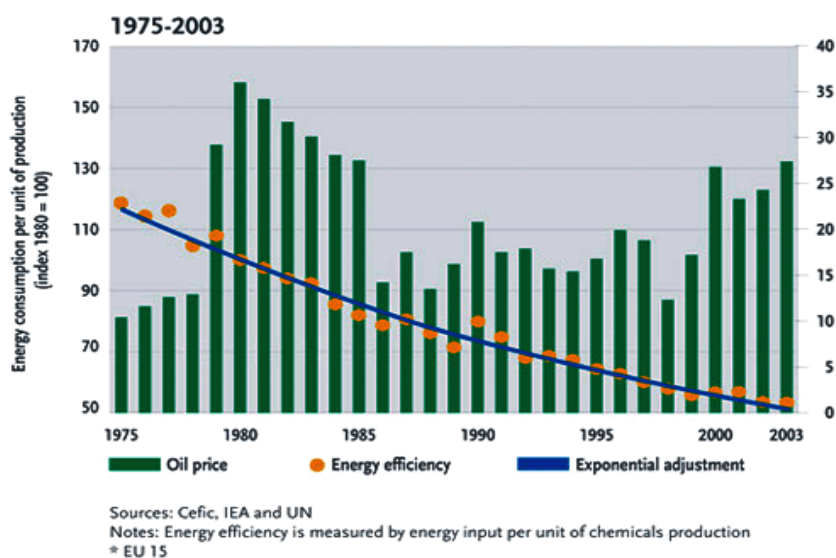


Figure AI.6 Production, fuel and power consumption and CO<sub>2</sub> emissionsFigure AI.7 CO<sub>2</sub> emissions per unit of energy consumption and production

Hence, CO<sub>2</sub> emissions per unit of energy consumption have been dramatically reduced, and CO<sub>2</sub> emissions per unit of production have even decreased almost 44 % since 1990.

The main supplier of raw materials to the EU-15 chemical industry is the mineral oil industry with products like naphtha, gas oil, heavy and gaseous mineral oil fractions and natural gas. It also purchases a broad variety of natural or

processed starting materials, e.g. metals, minerals and agricultural raw materials (sugar, starch, fats, etc.). From the energy sector, it consumes coal, oil products, natural gas and electricity, using them both as raw materials (feedstock) and as fuels. The chemical industry upgrades energy and raw materials into products required by other industrial sectors as well as by final consumers. The cost of these inputs is a prime factor in competitiveness on world markets.

Figure AI.8 CO<sub>2</sub> feedstock for chemical industryFigure AI.9 CO<sub>2</sub> energy consumption per unit of production

The EU-15 chemical industry has made efforts to improve energy efficiency, reducing its fuel and power energy consumption per unit of production. In 2003, energy consumption per unit of production was 55 % lower than in 1975. This continual progress

in energy efficiency has not been related to oil prices. As suggested by the fitted curve, energy efficiency is subject to decreasing returns: the higher the level of energy efficiency attained, the more difficult it becomes to make further improvements.

## Potential risks

In the following section, the main potential risks associated to chemical industry are summarised briefly based on EEA reports and the publication *REACH – What happened and Why? The Only Planet Guide to the Secrets of Chemicals Policy in the EU* by Greens/European Free Alliance in the European Parliament.

### Chemicals released to the environment

Many chemicals are applied directly to the environment or are discharged after use. Adequate toxicological and ecotoxicological data have been produced for only a small fraction of the chemicals, and data on environmental pathways and ecotoxicological effects are even more sparse. The human-generated sources of dangerous chemicals which enter the air are widespread. The smokestacks of factories, power-generating stations, waste incinerators, motor vehicles and smelter discharge emit sulphur dioxide, nitrogen oxides, carbon monoxide, hydrocarbons and other combustion products often contaminated with substances such as heavy metals, dioxins, furans, etc.

In highly industrialised or populated areas, chemicals are often released into water bodies in exceptionally large volumes through industrial discharge pipes and municipal sewage. Apart from large volumes of chemicals entering the environment in such areas, the environmental danger comes from the fact that these releases contain significant amounts of many types of chemicals which are commercially used.

The release of highly toxic chemicals (often as contaminants in high-volume production chemicals) also causes serious problems. Well known examples of these substances are chlorinated hydrocarbons, heavy metals and hydrocarbons. Once a chemical is emitted to the air it is usually deposited with rainwater and snow and eventually ends in runoff into rivers and seas. Another main source of chemicals in the environment is from the agricultural use of pesticides, which contain potentially dangerous chemicals that can leach into groundwater. Some non-degradable (heavy metals) and very slowly degradable substances (PCBs, dioxins) can be transformed into more toxic intermediate compounds (DDE from DDT or methylmercury from mercury). On the other hand, bioaccumulation may take place in the food chain, which can result in concentrations toxic to biota, especially top predators.

Natural transport from one compartment to the next further accelerates the dispersion of a given substance through the ecosystem. This eventually leads to accumulation of a substance and harmful effects in another compartment than that to which it was originally released. Most of the chemical compounds released to the environment are subject to biotic and/or abiotic degradation but some are persistent and therefore accumulate in the environment, leading to long-term exposure of organisms. Depending on the toxicity and persistence of the substance, exposure can lead to disorders, genetic mutation, adverse effects on reproduction, cancer, mortality and adverse effects on the nervous and immune systems. It may also cause effects on ecosystems.

### Risk management in chemical industry: assessment of existing and new substances

The current situation in Europe is characterised by the fact that there are two groups of chemicals. By far the largest group are the 100–106 substances that were registered in the EU before 1981 – also known as existing substances and listed in the European Inventory of Existing Commercial Substances (EINECS). The second group only contains some 3 000 substances registered after 1981 – known as new substances – listed in the European List of Notified Chemical Substances (ELINCS). While all the new substances have undergone a certain degree of testing, hardly any of the existing substances have been evaluated for possible effects on humans or the environment. When EINECS and ELINCS were established, the intention was that also the existing substances would be tested, but this has not happened. Only some 140 of the existing substances have been identified as priority substances and are subject to comprehensive assessments. To date, only 39 assessments have been published and only 22 of them have been implemented into community legislation by 31 March 2006 (for the actual list of actions see [http://ec.europa.eu/environment/chemicals/exist\\_subst/pdf/implementation.pdf](http://ec.europa.eu/environment/chemicals/exist_subst/pdf/implementation.pdf)).

The reasons are debated: the enormous amount of information needed for a single risk assessment, delayed reporting by the industry, lack of resources by Member States, bureaucracy, etc. Some also point out that producers have little interest in speeding up the process as sales are permitted until risk reduction measures are adopted. Such measures can only be taken after a full-fledged risk assessment and an extensive regulatory process.

Current EU regulation is based on ideas developed jointly by authorities in Europe and the USA in the late 1970s almost 30 years ago. One of the main features of the EU model is that it prescribes that the risk assessment should be complete before any regulatory action is considered.

This model (see Figure 10) is considered to have certain advantages. Theoretically it enables a fully scientific approach to assessing the risk associated with a substance. The result of this scientific risk assessment can then be used to decide on any regulatory action. In theory, this should prevent political decisions based on assumptions and ignorance.

But it also has some serious disadvantages. In particular, it prescribes that a complete risk assessment should be made before any regulatory action may be taken. This requires obtaining a reasonably complete set of data, an extensive and extremely resource-demanding process. Until the completion of such an assessment, any regulatory action is blocked.

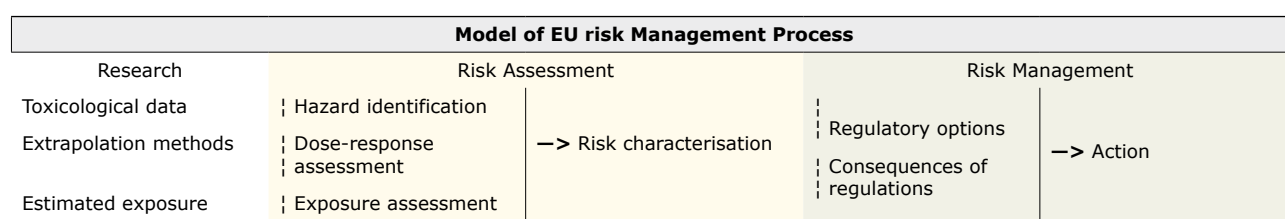
A fundamental problem with this model — and risk assessments in general — is that it disregards that there are always data gaps in the scientific part of an assessment. It is simply impossible to determine all the relevant aspects that need to be covered. Instead, assumptions have to be made all the time. Decisions are taken on incomplete, sometimes even rudimentary, information. Yet, risk assessments are presented as a scientific and fully neutral process.

Such assumptions, also called defaults, are of different character depending on what purpose or use the substance is intended to have on the market and what kind of data are lacking. If the substance in question is a food additive lacking data about toxicity, the data gap will be considered serious. The following assumption will be that the substance should be regulated as being toxic. If, on the other hand, the substance in question is a basic industrial chemical it may be assumed to be non-toxic.

Prior to the introduction of pre-market regulation in 1979, industrial chemicals could be put on the market with very little or no information concerning their potential risks to human health and the environment. The exact number of such 'existing' substances still on the EU market is unknown. 100 106 were registered before the deadline 1981 but not all of them are in production. The current estimates for those actually on the market vary widely from 30 000 to 70 000 (EEA/UNEP, 1998). Given the large number it is considered unfeasible to conduct extensive testing on all of them within a reasonable timeframe. The starting point for setting priorities for information gathering, testing and assessment among this large number of chemicals has generally been production volume, which is considered to reflect potential exposure.

Thus, substances being produced in volumes above 1 000 tonnes per year, also called High Production Volume (HPV) chemicals, are prioritised for assessment. But also the number of HPVs is considered too great for immediate risk assessment.

**Figure AI.10 Simplified Model of EU Risk Management Process**



There are 2 465 HPVs in the EU and only a few of them have a 'full' data set, including long-term eco-toxicity results, degradation behaviour in various environmental compartments and a complete mammalian toxicity profile. Thus another tier of prioritisation is used to identify which of the HPVs should be prioritised. To this end, the EU has identified a minimum package of information — known as a base set — needed to make an initial assessment. The data required to fulfil a base set, but even data for prioritising is scarce:

- 3 % of the HPVs in the EU have a full data set;
- 14 % have data at the level of the base-set (including the above);
- 86 % have less than the base-set level (including the below); and
- 15 % have no data at all.

### **Risk related to accidents**

Technology-related accidents are of major concern as sources of impacts on human health and the environment. This concern arises from three interrelated characteristics: unpredictability of when and exactly how they will occur (and hence perceived lack of control), uncertainty over environmental pathways and impacts, and unforeseen interactions (human and technical) in the source facility. The complex and possibly long-term damage to environmental resources (particularly soils and water) and dependent ecosystems is cause of increasing concern.

The industrial activities which give rise to these risks — primarily production and transport of chemicals — are increasing in intensity. In addition, interactions between human society and the natural environment are showing increasing signs of vulnerability to hazardous events.



## Annex II Related policy instruments

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In the following, the main policy instruments at European and international level are briefly presented. National level policies will not be covered, since it will be a too far reaching exercise.

### Registration, Evaluation and Authorisation of Chemicals (REACH)

REACH, the new EU regulation for chemicals was proposed by the European Commission in December 2003 and adopted by the European Parliament and the Council in December 2006. REACH will enter into force on 1 June 2007

The proposed regulation will replace over 40 existing directives and regulations. At the core of the proposed system is REACH, a single, integrated system for Registration, Evaluation and Authorisation of Chemicals. REACH will require companies that produce and import chemicals to assess the risks arising from their use and to take the necessary measures to manage any risk they identify. This will reverse the burden of proof from public authorities to industry for ensuring the safety of chemicals on the market.

#### Registration

This is the main element of REACH. Chemicals that are manufactured or imported in quantities of more than one tonne per year and per manufacturer/importer will be registered in a central database. Some groups of substances will not have to be registered (such as certain intermediates, polymers and some chemicals managed under other EU legislation). The registration will include information on properties, uses and safe ways of handling the chemicals. The information required will be proportional to production volumes and the risks that a substance poses. The safety information will be passed down the supply chain, so that those that use chemicals in their own production processes — to produce other products — can do so in a safe and responsible way, without jeopardising the health of workers and consumers and risking damage to the environment.

A new European Chemicals Agency (ECHA) — which will be established in Helsinki — will manage the database, receive the registration dossiers, and be responsible for providing non-confidential

information to the public. It is expected that around 80 % of all registered substances will require no further action.

#### Evaluation

There will be two types of evaluation: of dossiers and of substances. Firstly, a dossier evaluation has to be carried out on all animal testing proposals. The main purpose of this compulsory evaluation will be to minimise animal testing. REACH has been designed with the goal of restricting animal testing and costs to industry to the necessary minimum. It requires the sharing of data obtained in tests and encourages the use of alternative sources of information. A dossier evaluation could also be performed to check that the registration was in compliance with the registration requirements.

Secondly, the competent authorities could evaluate any substance where they had justified reasons to suspect that there was a risk to human health or the environment. This represents a quality and compliance check. The programme of substance evaluations will be based on rolling plans prepared by Member States Competent Authorities. The programme will take account of criteria for setting priorities drawn up by the European Chemicals Agency.

For both types of evaluation, the outcome could be a request for further information. The European Chemicals Agency will take the final decision on requests for further information if all Member States agreed. In case of disagreement, the European Commission will make a decision.

#### Authorisation

Substances of very high concern will require authorisations for particular uses. This applies to substances that cause cancer, infertility in men and women, genetic mutations or birth defects and to those which are persistent and accumulate in our bodies and the environment. The Authorisation system will strongly encourage companies to switch to safer alternatives. In fact, all applications for an authorisation need to include an analysis of alternatives and a substitution plan where a suitable alternative exists.

REACH will also enable more rapid total or partial bans where unacceptable risks are detected.

### Seveso II Directive

Council Directive 96/82/EC on the control of major-accident hazards — the Seveso II Directive — is an amendment of the original Seveso Directive from 1982. From 3 February 1999, the obligations of the Directive have become mandatory for industry as well as the public authorities in the Member States.

The aim of the Seveso II Directive is two-fold. Firstly, the Directive aims at the prevention of major-accident hazards involving dangerous substances. Secondly, as accidents do continue to occur, the Directive aims at the limitation of the consequences of such accidents not only for man (safety and health aspects) but also for the environment (environmental aspect). Both aims should be followed with a view to ensuring high levels of protection throughout the EU in a consistent and effective manner.

The scope of the Seveso II Directive is solely the presence of dangerous substances in establishments. It covers both, industrial 'activities' as well as the storage of dangerous chemicals. Under the Directive there are three levels of proportionate controls, where larger quantities mean more controls. A company who holds a quantity of dangerous substances less than the lower threshold levels given in the Directive is not covered by this legislation. Companies who hold a larger quantity of dangerous substance, above the lower threshold contained in the Directive, will be covered by the lower tier requirements. Companies who hold even larger quantities of dangerous substances (upper tier establishments), above the upper threshold contained in the Directive, will be covered by all the requirements contained in the Directive.

Important areas excluded from the scope of the Seveso II Directive include nuclear safety, the transport of dangerous substances and intermediate temporary storage outside establishments and the transport of dangerous substances by pipelines.

The Directive contains general and specific obligations on both operators and Member State authorities. The provisions broadly fall into two main categories related to the two-fold aim of the Directive, that is control measures aimed at the prevention of major accidents and control measures aimed at the limitation of consequences of major accidents.

All operators of establishments coming under the scope of the directive need to send a notification to the competent authority and to establish a major-accident prevention policy. In addition, operators of upper tier establishments need to establish a safety report, a safety management system and an emergency plan.

In order to assist Member States with the interpretation of certain provisions of the Seveso II Directive, the Commission in cooperation with the Member States has elaborated a number of guidance documents which are available from the Major-Accident Hazards Bureau (Seveso website).

### Basel Convention

The Basel Convention on the control of transboundary movements of hazardous waste and their disposal of 22 March 1989 is a convention under the United Nations. As of February 2005 there are 164 parties to the convention.

In the late 1980s, a tightening of environmental regulations in industrialised countries led to a dramatic rise in the cost of hazardous waste disposal. Searching for cheaper ways to get rid of the wastes, 'toxic traders' began shipping hazardous waste to developing countries and to Eastern Europe. When this activity was revealed, international outrage led to the drafting and adoption of the convention.

During its first decade, the convention was principally devoted to setting up a framework for controlling the 'trans-boundary' movements of hazardous wastes. It also developed the criteria for 'environmentally sound management'. A control system, based on prior written notification, was also put into place.

During the next decade (2000–2010), the convention will build on this framework by emphasising full implementation and enforcement of treaty commitments. The other area of focus will be the minimisation of hazardous waste generation. Recognising that the long-term solution to the stockpiling of hazardous wastes is a reduction in the generation of those wastes — both in terms of quantity and hazardousness — Ministers meeting in December of 1999 set out guidelines for the convention's activities during the next decade, including:

- active promotion and use of cleaner technologies and production methods;
- further reduction of the movement of hazardous and other wastes;
- prevention and monitoring of illegal traffic;
- improvement of institutional and technical capabilities — through technology when appropriate — especially for developing countries and countries with economies in transition;
- further development of regional and sub-regional centres for training and technology transfer.

Under the convention, trans-boundary movements of hazardous wastes and other wastes can take place only upon prior written notification by the country of export to the competent authorities of the countries of import and transit (if appropriate). Each shipment of hazardous waste or other waste must be accompanied by a movement document from the point at which a trans-boundary movement begins to the point of disposal. Hazardous waste shipments made without such documents are illegal. In addition, there are outright bans on the export of these wastes to certain countries. Trans-boundary movements can take place, however, if the state of export does not have the capability of managing or disposing of the hazardous waste in an environmentally sound manner.

Each country that is a party to the convention is required to report information on the generation and movement of hazardous wastes. Every year, a questionnaire is sent out to member countries, requesting information on the generation, export and import of hazardous wastes covered by the convention. This information is reviewed and compiled by the secretariat and is presented in an annual report, which includes statistical tables and graphic representations of the data.

In order to assist countries (as well as interested organisations, private companies, industry associations and other stakeholders) to manage or dispose of their wastes in an environmentally sound way, the Secretariat cooperates with national authorities in developing national legislation, setting up inventories of hazardous wastes, strengthening national institutions, assessing the hazardous waste management situation, and preparing hazardous waste management plans and policy tools. It also provides legal and technical advice to countries in order to solve specific problems related to the control and management of hazardous wastes. In the case of an emergency, such as a hazardous waste spill, the secretariat cooperates with parties and

relevant international organisations to provide rapid assistance in the form of expertise and equipment.

### **Pollutant Release and Transfer Register (PRTR)**

A key tool governments are using to provide data to the public about potentially toxic releases to the environment is a Pollutant Release and Transfer Register (PRTR). A PRTR is a database or register of the quantities of potentially harmful chemicals, reported by facilities, which are released to air, water and soil and/or transferred.

In 1996, the OECD Council adopted a recommendation on implementing PRTRs. Since its adoption, OECD has worked together with governments, industry and NGOs to develop practical tools that help reduce efforts by Member countries, provide outreach to non-member countries, and coordinate international activities.

A PRTR database can assist authorities in setting priorities or even eliminate the most potentially damaging releases and track progress towards meeting environmental objectives. A PRTR also provides an incentive for industry to reduce its releases and transfers.

To help member countries implement efficient and effective PRTR systems, OECD produces documents dealing with: the experiences of countries who have developed PRTRs; current and emerging uses of PRTR data; how PRTRs differ; and the identification, selection and adaptation of release estimation techniques that industry uses to calculate PRTR releases and transfers (OECD).

### **European Pollutant Emission Register (EPER)**

The European Pollutant Emission Register was established by a Commission Decision of 17 July 2000. The EPER Decision is based on Article 15(3) of Council Directive 96/61/EC concerning integrated pollution prevention and control.

According to the EPER Decision, Member States have to produce a triennial report on the emissions of industrial facilities (listed in Annex A3 of the decision) into the air and waters. The report covers 50 pollutants which must be included if the threshold values indicated in Annex A1 of the EPER Decision are exceeded.

The first reporting year was 2001; this information had to be reported by June 2003 at the latest. The second reporting year was 2006.

The EPER Decision obliges the European Commission to make this data publicly accessible on the internet, and this is done on a website hosted by the European Environment Agency (EPER).

EPER will be replaced by the European Pollutant Release and Transfer Register (European PRTR) that has been adopted on 18 January 2006 and laid down in Regulation (EC) No 166/2006. The PRTR's first edition is expected to be published in the autumn of 2009 and will include data for the first reporting year 2007.

The European PRTR implements the UNECE PRTR Protocol, which was signed in May 2003 in Kiev.

The European PRTR will be more comprehensive than EPER since it will cover more than 91 substances emitted from industrial installations in 65 different sectors of activity (respectively 50 substances and 56 sectors under EPER), and will further include transfers of waste and waste water from industrial facilities to other locations as well as data on emissions caused by accidents on the site

of the facilities. The European PRTR will also be published annually, a much shorter time period than the triennial reports under EPER. Data on releases from diffuse sources such as road traffic, agriculture, domestic heating, shipping, etc. will be included.

### **Safety Data Sheets Directive (SDS Directive)**

European legislation requires producers of dangerous chemicals to set up an information system in the form of Safety Data Sheets (SDSs) in order to enable industrial and professional users to take the measures necessary to ensure the protection of health, safety and the environment at the workplace. Directive 91/155/EEC sets out the requirements for the information which should be included in a SDS relating to dangerous preparations in implementation of Art. 14 of the DPD and to dangerous substances in implementation of Art. 27 of Directive 67/548/EEC. Directive 2001/58/EC amending for the second time Directive 91/155/EEC extends the obligation to provide SDSs to certain preparations not classified as dangerous. The SDS directive will be repealed and replaced by REACH.

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