

Hanna-Leena Pesonen

## From Material Flows to Cash Flows

An Extension to Traditional Material Flow Modelling

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UNIVERSITY OF JYVÄSKYLÄ

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Hanna-Leena Pesonen

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## ABSTRACT

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Finnish summary

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The balance between economy and ecology is an ideal situation often repeated in political discussion as well as in the strategic planning of a company, but in fact, in most decision making situations we still miss tools which could offer information both about environmental and economic impacts of the possible outcomes. Material flow models have typically not addressed the economic or social aspects of the system. Recently several bodies engaged in the development of these tools have, however, made recommendations about including economic and social variables in the abovementioned models. The purpose of this study has been to discuss the applicability of material flow models in economic decision making and to increase understanding about the possibilities of combining economic data with material flows. The study is exploratory research and the research methods applied are secondary data analysis and case analysis. Both deductive and inductive theory formulation has been used: deductive within secondary data analysis and inductive in connection with the case studies. Material flow models have proved to be a powerful tool for environmental decision making and they also offer a suitable basis for economic evaluation and decision making. The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data offered by material flow models about the system, its logistics and flows, which in most cases is directly useful for economic calculations.

Keywords: material flow models, cash flows, scenarios, uncertainty, environmental management

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## FOREWORD

Three years of work on this project, my dissertation, is just about to reach the end. This also means an end to a phase of life. It has been a good phase, though sometimes not very easy. At the moment I feel very anxious to start the next phase with some new challenges and will be eager to see what is reserved for me in life from now on. Hopefully this work has taught me something and I would be better prepared for new challenges. Before any of that it is anyhow time to finish the last page of this phase and take a little look back.

Looking back makes me very thankful and I am happy to have the opportunity to have this page to thank all of you who have in different ways helped me along this project.

First of all I want to thank my supervisor Professor Tapio Pentto who has kindly lead me all the way through this project. I also want to thank my colleagues as well as my students at the University of Jyväskylä for your support and inspiring conversations.

I also owe a lot to Professor Paul H. Brunner at the Technical University of Vienna. I was lucky to have the possibility to participate in the research project ASTRA under Professor Brunner's supervision in 1996-97. I actually came up with my research theme during the ASTRA project for which I will be eternally thankful. I also want to use this occasion to thank my colleagues and friends in Vienna once again. Because of you all my Austrian year will stay amongst the most precious memories of my life. Vielen Dank!

Professor Ab Stevels, second reviewer of my work, from the Technical University of Delft has offered me a lot of help and support in terms of literature, comments and discussions during the last phase of the project. Your guidance has been most important and I have enjoyed the co-operation we have had. Thank you very much for all of that!

Very warm thanks go to my family and friends. Even though I have certainly neglected you all, giving you all too little time and lead a very selfish life during my research work, you all have been there for me. Now I have the opportunity to thank you all for that. Kiitos teille, kaikki ihanat ihmiset!

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Thankful and looking forward to new challenges,

Hanna-Leena Pesonen  
Jyväskylä 10.5.1999



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## RESEARCH ARTICLES

- Article 1** Pesonen, H-L. 1999. Material flow models as a tool for ecological-economic decision making. *Eco-management and Auditing*. No 1 Vol. 6, 1999.
- Article 2** Pesonen, H-L. 1999. Non-linear data improving the reliability of the results of dynamic material flow analysis. Will be published later in 1999.
- Article 3** Pesonen, H-L. 1998. How to include economic data into LCA research - some empirical findings. *Business Strategy and the Environment Conference Proceedings*. University of Leeds.
- Article 4** Pesonen, H-L. 1999. From material flows to cash flows - case Finnish printing papers 1994-2000. *R'99 Conference Proceedings*. Geneva.
- Article 5** Pesonen, H-L. 1999. Economic considerations in Joined Time Projection -modelling - case Austrian printing papers 1994-2001. University of Jyväskylä. School of Business and Economics. Working paper 196/1999. Jyväskylä.



## 1 INTRODUCTION

Environmental problems are one of the major questions we are facing in today's world. While there may be some disagreement relating to the scale of the problem or the ways in which it should be addressed, there is a general consensus that the environmental problems are extremely serious (Welford & Gouldson, 1993). For more than a decade, environmental policy-makers have been struggling to move from fragmented end-of-pipe and end-of-product-life approaches toward more integrated approaches that reflect the complexity of technology and environmental systems (Allen et al., 1998). The main topics of discussion have changed from preservation issues in the 1970's to pollution control in the 1980's, and finally in the 1990's the most important subjects of conversation have been sustainable growth and global environmental problems (Raatikainen, 1997). The first wave of environmental legislation focused on the end-of-pipe control of emissions such as waste water, dust, SO<sub>2</sub> etc. in order to protect human health and the local environment. Through the introduction of the 'Precautionary Principle' many regulations and guidelines define 'best environmental industrial practices' for setting environmental rules which, in turn, aim at preventing harmful releases and promote sustainable behaviour in the use of natural resources. This regulatory trend toward up-stream environmental solutions tends to shift the basis of decision making from an anticipatory understanding of the environmental effects of pollution to a 'cradle-to-grave' environmental assessment of industrial processes. (Gronow, 1996) What is now needed is a shift away from traditional end-of-pipe solutions towards early recognition of environmental problems.

As the importance of environmental protection and early recognition have gained increasing attention, different tools of environmental management have been developed to assess the environmental impacts of products/companies/industries: environmental auditing, environmental impact assessment, life cycle assessment, risk assessment, cost benefit analysis, input-output analysis etc. Several different quantitative models are used to measure flows of products and/or substances through a defined system and to help in decision making on the basis of these inventories and the studied

environmental impacts. According to the system boundary and level required, different methods of material flow analysis can be used: Life Cycle Assessment (LCA) measures and assesses environmental impacts of a single product or industry along its life cycle; eco-balances concentrate on the environmental impacts of a given company; and substance flow analysis (SFA) traces the path of a selected substance through the system. (Pesonen, 1999c)

However, not only environmental resources, but also financial resources for environmental protection are scarce. Firms and governments should therefore spend their budgets efficiently to obtain the most benefit for the environment. (Schaltegger, 1997) For this reason, several bodies (e.g. SETAC, ConAccount and CHAINET) engaged in the development of material flow models have recently made recommendations about including economic and social variables in the abovementioned models. These models have typically not addressed the economic or social aspects of the system (see e.g. CEN, 1997). Nordic guidelines on life cycle assessment (Nordic Council of Ministers, 1995) also exclude economic and social aspects from the scope of LCA. Its definition of LCA concludes with the remark: "It does not address economic or social effects". Applications of LCA include such areas as product development and improvement, strategic planning, public policy making and marketing (see figure 2 in chapter 3.2.1.). When making decisions in any of the previously mentioned situations, information about the economic consequences of the possible outcomes is, however, also crucial. For example, decisions between different product alternatives and their marketing without detailed economic analysis sounds somewhat unrealistic.

Supporting the integration of environmental and economic analysis EU Concerted Action Program CHAINET Definition Document (1998) argues that: *"European policy has committed itself to the goal of sustainable development. Following this commitment, the European Union has placed its activities within a framework of environmental controls based on the best knowledge available at any particular moment in time. This includes a continuing movement away from an 'end-of-pipe' philosophy of environmental protection (one which, in any case, tended merely to shift problems from one environmental issue to another or from one societal sector to another), towards a new paradigm in which environmental considerations encompass the whole material and energy supply chain and consider the full social and economic structure."*

EU Concerted Action Program ConAccount has also presented some ideas about further development and application of the material flow analysis methodology. ConAccount recommends analyses of the interlinkages between material flows and economic development, and gives a suggestion that a standard framework for analysis should be developed, which should support an assessment of the decoupling/recoupling of economic activities and material throughput. (Bringezu et al., 1998)

As addressed above, whilst the idea of combining economic data with material flows has gained wide support, very little research has been done in this area to date. There is some empirical work done in this field but any guidelines and principles of how this should be done in a uniform way are missing. The first empirical studies include studies of ENDS (1993), Magnell (1993), Tulenheimo (1995) and White et al. (1991). The purpose of this



particular study has been to discuss the applicability of material flow models in economic decision making and to increase understanding about the possibilities of combining economic data with material flows. My sincere hope has been that the results of this study would offer a useful contribution to the on-going discussion and be of help for practitioners of material flow management when implementing economic evaluations combined with material flow analysis.

## **2 RESEARCH METHODOLOGY AND DESIGN OF THE STUDY**

### **2.1 Research problem**

As presented in the previous chapter, the purpose of this study has been to discuss the applicability of material flow models in economic decision making and to increase understanding about the possibilities of combining economic data with material flows. This definition of the purpose actually already includes the main research problem: How can material flow models be applied in economic decision making?

To elaborate the main research problem further, six more detailed research questions were derived. Answering these questions would bring an answer to the main problem as well. The six research questions are:

1. How do the concepts of material flow management relate to those of economic decision making? Could concepts of economic evaluation be defined on the basis of the concepts of material flow analysis?
2. Which are common features and differences in the modelling of ecological and economic flows?
3. Are there differences in the importance of the flows of a system in environmental and economic terms? If yes, are they significant and how should these be identified?
4. What are the advantages and restrictions of combining economic variables into material flow models?
5. In studies with a long time horizon, how can the long term costs be estimated? How can the studied scenarios be formulated in material flow modelling?
6. Which are the reasons for uncertainty in material and cash flows and how should it be dealt with?

## 2.2 Methodology

Burns & Bush (1998) define research design as *"a set of decisions that make up the master plan specifying the methods and procedures for collecting and analysing the needed information"*. Research methodology literature has traditionally separated three basic types of research design: exploratory, descriptive and causal research (see e.g. Burns & Bush, 1998 or Churchill, 1996). This study is typical exploratory research as it is unstructured, informal research undertaken to gain background information about the general nature of the research problem (Burns & Bush, 1998). In exploratory research the major emphasis is on gaining ideas and insights and it is particularly helpful in breaking up broad, vague problem statements into smaller, more precise subproblem statements, ideally in the form of specific hypotheses (Churchill, 1996). Exploratory research is suitable in cases where there is no previous research done and the phenomena to be studied is still unknown. It can be used to increase the researcher's familiarity with a problem, clarify concepts and also to establish research priorities within the studied area. As was discussed in previous chapters, the topic of this study - the applicability of material flow models for economic decision making - is still very poorly known. As mentioned, the purpose of the study is to increase understanding about this topic.

Typical research methods in exploratory research include secondary data analysis, experience surveys, case analysis, focus groups and projective techniques (Burns & Bush, 1998 and Churchill, 1996). Because so much is typically unknown at the beginning of the study, exploratory studies are generally very flexible with regard to the methods. Rather, researchers frequently change the research procedure as the vaguely defined initial problem is transformed into one with more precise meaning, which also turned out to be the case in this study. The research methods applied in this study included secondary data analysis and case analysis, and the research philosophy underlying the study could be defined as phenomenological (about phenomenology see e.g. Boland, 1985; Kvale, 1983 or Järvinen & Järvinen, 1995).

Secondary data analysis can also be defined as a theoretical-conceptual approach (Järvinen & Järvinen, 1995). This describes very well the basic nature of this study: to discuss (and possibly create) the concepts of the research area and to reorder them, thus creating a new theory about the studied theme. According to Niiniluoto (1980) theories are very similar to systems of concepts. Theories collect and combine previous separate research results. Näsi (1980) has separated two levels of conceptual analysis: basic and meta level analysis. This study is typical basic level analysis, which relates the concept formulation process continuously into real life by reflecting the concepts under study to the research area, in this case material flow models, using case studies.

Case analysis is one of the subheadings of the action-oriented approach which also seeks answers by understanding in the same way as the theoretical-conceptual approach. The difference between these two approaches is, that the action-oriented approach investigates the phenomenon within its real-life

context (Yin, 1989) whilst the theoretical-conceptual approach is limited to previous research results and secondary data. The case study method applied in this study was a multiple case study using three material flow models presented briefly in article 3 as the basis of economic calculations. A case study can be descriptive, or it can be used to test or create theory and it can include both quantitative and qualitative information (Järvinen & Järvinen, 1995). The cases in this study were used for all of the abovementioned purposes: to describe the phenomenon, to test the theory developed by the researcher based on the secondary data and to create new theory by combining the new information gained during the case studies with the previously developed theory.

An axiom system, where all the basic arguments of the theory are reduced into a number of basic claims, i.e. axioms, has been seen as an ideal model of theory. These axioms are chosen in a way that they can be used to logically derive all the other claims of the theory. A theory, which has been traced from the axioms using rules of logic is defined as deductive. An inductive theory is instead concluded from empirical generalisations. (about axioms see e.g. Niiniluoto, 1980) Both deductive and inductive theory formulation has been used in this study: deductive within secondary data analysis and inductive in connection with the case studies.

### 2.3 Outline of the study

In the first chapter, **Introduction**, the background and objectives of the study were presented.

Chapter two, **Research methodology and design of the study**, presents the research problem, research questions and the methodology used in the study as well as the outline of the study. Reliability and validity of the study are also discussed in this chapter.

In chapter three, **Material flow models**, the central concept and method of material flow analysis is described and studied. Concepts of static and dynamic material flows are determined and their differences are presented. Suitability of static and dynamic models to various decision making situations is also discussed. At the end of the chapter selected types of material flow models (Life Cycle Assessment, Eco-Balances, MIPS, Environmental Risk Assessment and Joined Time Projection -technique) and their use are presented.

Chapters four, five and six constitute the main body of the study. Chapter four, **Applicability of material flow models in economic decision making**, discusses the basic features of cash flows. This chapter presents the advantages of combining economic variables into material flow models, common features and differences in the modelling of ecological and economic flows, defines concepts of economic modelling based on the concepts of environmental material flow analysis and discusses the importance of how to identify the important flows of a system. A relating concept 'Life Cycle Costing' will also be presented in this chapter.

Chapter five, **Long term costs and scenarios in material flow modelling**, offers first an introduction to the development of scenario thinking in business decision making with a brief historical summary. Then the concept 'scenario' and related concepts such as 'scenario planning', 'multiple scenario approach' and 'worst-case scenario' are discussed. Further, scenario development is discussed in the context of material and cash flows and as a conclusion two basic methods for scenario development in material flow modelling are suggested. The basic methods of how the long term costs can be estimated are discussed in connection with the scenarios.

**Uncertainty in material and cash flows** is discussed in chapter six. Different reasons for uncertainty both within material and cash flows are identified and classified. Also some solutions about how to deal with it are offered.

Chapter seven, **Discussion**, is devoted to discussion about some topics and points of interest which have come up and created thoughts during the study. Also some problematic, even basic philosophic, issues which have occupied my mind during my research work are discussed here.

Finally chapter eight, **Conclusions**, concludes the results of the study.

This study is mainly based on five separate **research articles** written previously by the researcher and published in different publications. Each of these five articles are included as complete in the end of the study. As the study discusses issues presented in detail in these articles, several quotations are made throughout the text to the articles.

## 2.4 Validity and reliability of the study

The validity of a study can be defined as the accuracy of its measurement: it is an assessment of the exactness of the measurement relative to what actually exists (Burns & Bush, 1998; Churchill, 1996 and Holopainen & Pulkkinen, 1996). Validation of the results requires that identical answers must be obtained from a different data source. To ensure the validity of this study, two sources of information have been used: secondary data and case studies. The researcher can then evaluate the results of the study by asking if two methods of collecting the same information agree. Secondary data, the theory formulation and case study experiences have been compared throughout this study to assess the convergent validity of the research.

The collected data is reliable when it does not include any inconsistencies (Grönfors, 1985). It refers to the ability to obtain similar results by measuring an object, trait, or construct with independent but comparable measures (Burns & Bush, 1998). This verification of reliability is difficult in the context of a theoretical-conceptual approach, because there are no explicit measurements taking place; instead, the evaluations and weightings of the data are carried out in the researcher's mind. It is impossible to construct 'an independent but comparable measure' in this case. The research report is actually the only proof available of the reliability of the conceptual study. Whether the calculations and

the data used in case studies are reliable or not, is, however, easier to determine. The possible sources of uncertainty in case studies are presented briefly in the articles 3, 4 and 5 discussing the case studies. Article 2 discusses the concept of uncertainty in depth using examples from the same case studies which are presented in articles 3 and 4.

### 3 MATERIAL FLOW MODELS

I had several doubts during my research process as to how to classify and name the different tools discussed in this chapter now under the title 'Material Flow Models'. I remember the confusion I had in the beginning when studying different techniques which are in principle serving the same purpose: gathering information on the environmental impacts of separately determined systems in order to be able to redirect the system in a more environmentally friendly direction. Heijungs (1997) has also stated that *'despite these possibilities for choosing a substance, a material, a product or energy, all these tools go back to exactly the same type of formalism'*. When I had clarified for myself the differences between the first few models, I ran into a few more with again some slight changes in the determinations. To make some order from this chaos, I even tried to find out if any of them would be superior to others.

At one point I decided to classify these different models under a common name 'material flow models'. The basic definitions and concepts of material flow models given by Baccini & Brunner (1991) seemed to me somehow universal and such that it would be possible to generalise them to other methods. Later I changed my mind and decided to use the term 'chain management tools' instead of 'material flow models', which is a term suggested by CHAINET (1998). The concept 'environmental value chain management' is used to describe the management of a whole product system from an environmental point of view (see e.g. Linnanen, 1995). The metaphor of 'chain' and 'chain management' appealed to me, but working on this concept for some time eventually made me suspicious about it. Even though the metaphor of chain is still stimulating to me, I could not help doubting if someone unfamiliar with the concept would have any idea what the term implies to.

For the time being I have returned to 'material flow models'. In my opinion this term describes the basic idea inherent in all of the presented models extremely well. All of them include a defined system with a system boundary, determination of processes, products and flows and finally the environmental impacts based on the flows. 'Flow' and 'materials' are central

concepts to all of these models. In addition I find the term material flow model quite descriptive: the term itself helps to create a vision of what it is all about.

The whole history of material flow modelling and environmental management originates from materials and energy analysis. Companies started to register the quantitative input and output information of materials and energy, and to analyse the efficiencies of processes. (Tulenheimo & Thun, 1995) According to Johnson (1998) the genesis of Life Cycle Analysis (LCA) dates back to the two energy crises of the 1970s. Given the apparent shortage of oil, which was seen to be of highest political and military significance, and given the burgeoning computational power of computers, the discipline of energy-systems analysis was born. Further Johnson (1998) claims that the energy-system analysis was, however, not an 'environmental' discipline as such. Rather the objective function of energy-systems analysis was to conserve fossil fuels, especially oil, either by maximising efficiency or by substituting renewable fuels. Conceptually, it was a very small step from energy-systems to LCA, which began to include mass flows of non-fuel items as well as emissions from combustion, then emissions from other sources etc.

Another source for material flow models was offered by Input-Output Analysis, which was devised by Leontief (1986) in the 1930's and first implemented in the 1940's for the USA. Leontief's approach is based on input-output tables describing the flow of goods and services between all the individual sectors of national economy over a stated period of time. One of the main uses of Input-Output Analysis is to display all flows of goods and services within an economy, simultaneously illustrating the connection between producers and consumers and the interdependence of industries. An advantage of input-output tables is that economic components, such as income, output and expenditure, are expressed in a consistent framework reconciling the discrepancies between the estimates of these components. (CHAINET, 1998 and Leontief, 1986)

Material flow models were developed to describe systems which take inputs from nature into the anthroposphere in the form of materials or energy, and return outputs as effluents or waste back to nature. Material flow models measure the flows both within the anthroposphere and between the anthroposphere and nature. They can systematically track the physical flows of natural resources through extraction, production, fabrication, use and recycling, and final disposal (Adriaanse et al., 1997). The results of a material flow model can be used to redirect the input and/or output flows to a desired direction. Material flow models offer a tool for early recognition instead of the end-of-pipe solutions used in the past: when the flows within the anthroposphere and between the anthroposphere and nature are known, it is possible to assess the environmental impacts of the system and to plan new solutions based on decreased raw material and energy demand as well as reduced generation of emissions and waste. (Pesonen 1999c)

There are two basic types of material flow models according to the objects of primary interest (CHAINET, 1998):



- Type 1 starts with specific problems that are related to selected substances or materials, e.g. eco-toxic substances, nutrients, carbon, chlorinated substances or energy carriers. This first type of material flow model can also be defined as Substance Flow Analysis (see e.g. Weidema, 1998).
- Type 2 starts with the question of whether the volume and structure of the throughput of selected sectors or regions is sustainable. The selected section can be defined as a product, single company, whole industry, specified geographical region etc.

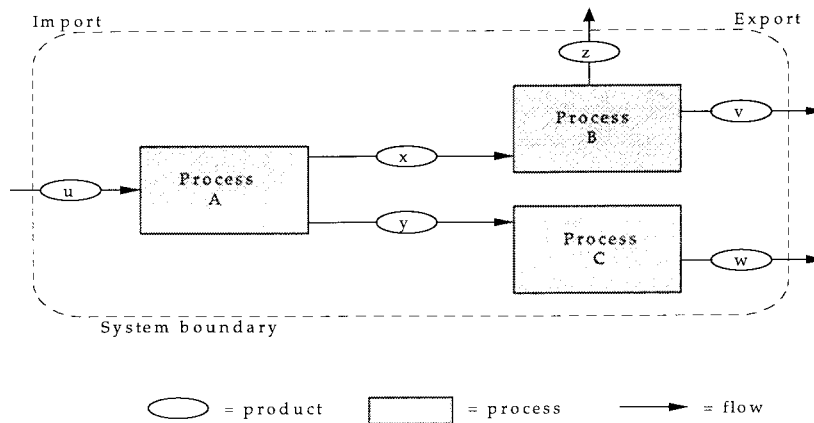


FIGURE 1 Material flow system (see e.g. Baccini & Brunner 1991 or Daxbeck et al. 1994)

Material flow models consist of a system of processes, and the flows of materials between these processes. 'Process' is defined here according to Baccini & Brunner (1991) as meaning transport, transformation and change of value of materials and goods. 'Flows' describe transport of products, materials or energy between the processes. A simple example of a material flow system is given in figure 1. Product *u* is an import product to the system and products *v*, *w* and *z* are export products. Product *x* is an output product from process A and an input product of process B. Process A can be defined as the process of origin of product *x* and process B as the process of destination of product *x*. (Pesonen 1999c)

It is important to distinguish between two levels of material flow analysis: the goods level and the material (or element or substance) level. Baccini & Brunner (1991) define 'goods' as materials or material mixtures with economic value and 'materials' as chemical elements and their compounds. The material level is actually more important for environmental analysis because the materials in goods cause the environmental problems - not the goods themselves. For economic analysis, instead, the goods level is interesting because according to the definition above, the goods have economic value and thus are responsible for cash flows. The goods level serves as a basis for several different types of analysis of which economic estimations are only one:

substance flow analysis, energy analysis, water balances and economic analysis.

According to Baccini & Brunner (1991) material flow analysis include following phases:

1. A systems analysis comprising a list of educts (goods) and products.
2. The measurement of the mass fluxes of all educts and products per unit of time for several time periods (mass per time or per mass unit of product; for gases volume is measured instead of mass).
3. The determination of the concentrations of the selected elements in the educts and products for several time periods (mass/mass, or mass/volume).
4. The calculation of the elemental mass fluxes from the fluxes of goods and the measurement of the concentrations of the elements.
5. The appropriate presentation of the results.

There are slight differences in the contents of each separate technique of material flow models (e.g. whether they are balanced on the level of goods or elements), but the basic principles correspond to these listed by Baccini & Brunner. The main features of selected techniques will be discussed in chapter 3.2.

The static and dynamic approaches of material flow modelling are discussed in the next chapter (3.1.) and in the following chapter (3.2.) a brief introduction to five selected material flow techniques is given. The selection of the techniques presented here was made on the basis of how widely used they are. A dozen more various techniques with minor differences could have been discussed, but I have tried to restrict the number of techniques presented to the most relevant ones for the moment. Four static models (LCA, Eco-balances, MIPS and Environmental Risk Assessment) are presented and the Joined Time Projection -technique is included as an example of a dynamic model.

### **3.1 Static vs. dynamic material flow models**

Static material flow models calculate the input and output of the defined system for a specific time period, typically one year. They analyse the environmental impacts of the studied system at a given moment in a static situation using historical average data, and are applicable to environmental planning when identifying the areas of improvement. However, they fail to assess the development of the system over time. The basic idea of material flow models is to give quantified data to help redirect the flows in a more sustainable direction. Static models can identify the problem areas but cannot be used to assess different policy options and their impacts on the determined problems. Static models can well be used to improve and compare different product or process variations in order to develop them to be more environmentally friendly. They can also be of help as an inventory to assess the

environmental impacts of a company's entire production at a certain time (Gronow 1996).

Dynamic material flow models are a more powerful tool for material flow management than static models because they include the aspect of time into the system, and can thus predict the changes of the system within a given period of time in the future. They are suitable for long term analysis and planning. Even in the short term, in systems where the product mix and/or product contents evolve rapidly (due to technological development, rapid changes in markets like in consumption or supply of raw material, capacity changes etc.), a dynamic material flow model is more suitable alternative than static one (Gronow 1996). Static material flow models can be used to calculate effluents, energy and materials used and produced in a system in a static situation; dynamic models offer the possibility to simulate the effects of changes in environmental policy, technology, consumption patterns etc. over a given period of time in the future. An instrument for forecasting the future effects of different policy options is also needed in environmental planning. Dynamic models offer a powerful tool for this purpose, whilst the traditional static models are not able to meet these needs. With dynamic material flow models it is possible to assess different future scenarios and their impacts in the future.

Gronow (1996) has compared the applicability of static and dynamic material flow models. He claims that dynamic material flow models should be preferred in environmental policy planning on a national or industry level. Static models, instead, are applicable in a national context only when the scope of the inventory is related to a single product, service or process and in stable situations when historical data is reliable. Static models should be used in national environmental planning only in very limited cases. If the interest of the policy maker is on the future development of material flows or on the effects of a particular action, a dynamic model is to be preferred.

## **3.2 Different types of material flow models**

### **3.2.1 Life Cycle Assessment**

Product orientation is central to Life Cycle Assessment (LCA). It is a technique developed to support product oriented environmental policies. What is studied in LCA is actually not the product itself, but the whole system of production, use and disposal processes needed to provide the product (Weidema, 1997). LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences. (CEN, 1997)

LCA is the only technique discussed here for which widely approved guidelines have been determined. The International Organisation of Standardisation (ISO) started working on the standards on environmental

management (the ISO 14000-series) in 1993, and the first final ISO text on life cycle assessment (the ISO 14040-series) was ready for approval as an international standard in 1997 (Weidema, 1997).

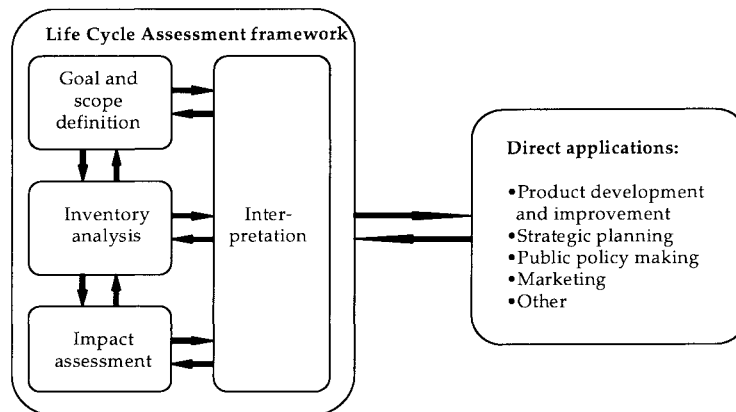


FIGURE 2 Phases and application areas of an LCA (CEN, 1997)

According to the ISO 14040 standard concerning environmental management, life cycle assessment and their principles and framework, LCA is defined as a technique for assessing the environmental impacts associated with a product (see also figure 2), by

- compiling an inventory of relevant inputs and outputs of a product system,
- evaluating the potential environmental impacts associated with those inputs and outputs,
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. (CEN, 1997)

The possible application areas of LCA are manifold. Figure 2 includes the possible internal application areas for LCA. A typical use for LCA can be found in the eco-labelling schemes (Tulenheimo & Thun, 1995). In addition to these, LCA provides important information to external audiences such as shareholders (to analyse the potential environmental impacts of their investment), consumers (to assess the environmental impact of a product), environmental pressure groups (to be used, for example, in green consumer guides), as well as other interested parties such as the company's immediate neighbours, environmental authorities etc. (Fava et al., 1994, Ulhøi, 1995 & Vigon et al., 1994).

As the use of LCA results in marketing (for eco-labelling purposes) has been emphasised in literature and also in the ISO 14040 standard, I would like to offer some insight to this discussion from the marketing point of view. Traditional marketing literature includes four basic parameters which are used for implementing the marketing plans: product, price, distribution and marketing communication (advertising, personal selling, PR etc.). The first

parameter, product, and its environmental performance form the basis of all environmental communication but in addition to this all the other parameters listed above can also be used in environmental marketing.

Marketing works basically on two different kinds of target markets: consumer market and organisational market including business customers, public and other organisations. The needs of these two types of markets can be very different. Both target markets also need different marketing tools and channels of communication. The organisational buyers are usually experts on the area and also the amount and level of information they require about the product is high. Personal communication with technically specific information, demonstrations etc. is the communication method which is usually used with customers of the organisational market. Consumers, instead, are not environmental or technical experts which means that the detailed, scientific information about products and their environmental performance has to be translated into a language which is easy to understand and does not require any special knowledge about the issue. The most typical communication channels in consumer markets are different types of mass media.

Different media also have special requirements concerning the message. In electronic media (TV, radio) it is impossible to give very detailed information about the product, which in turn is possible in print media, where people have the possibility to take time reading the message, possibly seek for more information and even save the message for closer study. Marketing is a communication tool that not only sells more products and services, but also educates the target audience. It can be a very powerful means e.g. in changing or guiding the consumption patterns.

Eco-labels are one method to communicate green claims to consumers. When the eco-labelling schemes are widely accepted and recognised by consumers they can be a very effective tool of communication because they offer an easy-to-read indication about the environmental performance of a product. In eco-labelling LCA can be used for three different purposes: to identify the stages of the life cycle in which the most significant environmental burdens take place, so that the labelling criteria can be developed to improve the environmental attributes of these stages; to identify the most significant types of environmental burdens in those stages and over the life cycle of the product, so that labelling criteria can be developed to address those burdens; and for certification and award of eco-label for product applicants (Allen et al., 1998). About the applicability of LCA to the first two stages Neitzel (1997) has certain doubts while he has stated that LCA results cannot be transformed by themselves into labelling criteria, but they have to be discussed by practitioners and competent bodies as other findings from science. The possible use of LCA in eco-labelling and as a tool for communication will be discussed next.

The International Chamber of Commerce (ICC) has published the International Code of Environmental Advertising (about the Code see ICC, 1996) as the basis for promoting high standards of ethics in advertising. The purpose of the Code is to help business to make responsible use of environmental advertising. The Code is based on the idea of self-regulation and it contains rules with 10 articles. The Code offers some guidelines to the use of

LCA within advertising. In article 4 about scientific research, special attention is paid to the use of environmental claims in advertising. The importance of 'serious scientific work' behind the environmental claims is stressed. Another important point in this article concerns the language and the terms used in advertising: *'Environmental jargon or scientific terminology is acceptable provided it is relevant and used in a way that can be readily understood by consumers.'* Article 8 gives guidelines to the use of environmental signs or symbols. They should only be used in advertising when the source of the signs or symbols is clearly indicated, and there is no confusion over the meaning. Such signs and symbols should also not falsely suggest official approval.

Stevens et al. (1999) have also made some critical remarks about the possibilities of using LCA as a tool for communication to the stakeholders. They point out that even in the most environmentally conscious countries environment as such is only an appealing factor to a minority of the potential customers (25 % or less). The majority of the customers, instead, is attracted by a combination of an environmental benefit and another benefit (like money, fun/ease/comfort or other positive emotion). Thus the art of combining these elements in marketing becomes a crucial issue. Stevens et al. (1999) claim that environmental standalones like eco-labels should be replaced by a segmented approach in which combinations are communicated (e.g. in case of lower energy: "It is good for the environment and good for your wallet"). They argue that *'general public is calling for simplification rather than for sophistication and wants to get addressed in terms of a world they live in themselves'*. I strongly agree with this statement.

Reliability of the data and results is a theme which has created a lot of discussion. It is by far the most significant limitation in the use of LCA. However, the same applies to other material flow model techniques and thus will not be discussed further in this study. Another important limitation of LCA relates to its static nature. LCA reflects a specific moment in time and can never provide a final answer to a particular company or to society as a whole. Also Blanco (1999) has criticised LCA because of its static nature. He claims that the conclusions of LCAs are based on existing industry practice and are historic perceptions. No knowledge of newer processes and technologies is fed into the models and they are only rarely used to assist in evaluating and developing new technologies. As long as this limitation is known, it can be handled. New process data can provide a basis for a vision or scenario of how the process is likely to develop (Jönson, 1996).

Brezet (1997) has pointed out another important limitation of LCA. He claims that by improving our present products (the area in which LCA can be useful) we will not reach significant improvements in sustainability. To gain large improvements we need to move to more innovative solutions on a higher level. According to Brezet (1997), to improve eco-efficiency by a factor 20, which is often quoted as a sustainable level, an impact reduction of 95 % is needed and this is not possible by just improving our present products.

### 3.2.2 Eco-Balances

The Eco-Balance is a structured method for reporting the physical inflows and outflows of resources, raw materials, energy, products, and wastes occurring within a particular organisation during a specified period of time (White & Wagner, 1996). The first extensive projects to measure environmental impacts on a whole firm basis were initiated in the late 1980's in Germany. The method has similarities to the 'mass and energy balance' approach used in the USA. In an Eco-Balance project data is collected and reported in a number of physical units. It can assist a company in identifying opportunities for pollution prevention and cost savings, prioritising these and measuring the efforts made for pollution prevention.

An Eco-Balance is constructed from three major components: the organisation balance, the process balance and the product balance (White & Wagner, 1996). Even though Eco-Balance has many conceptual variants, common to all are the two components they include: data inventory and impact assessment (Böning, 1995). The phases of an Eco-Balance are presented in figure 3 as described by Böning (1995) (see also Schmidt, 1995). Impact assessment has here been further divided into two phases including data characterisation and classification, which corresponds very well to the phases of impact analysis within LCA recommended in the ISO 14040 standard (CEN, 1997).

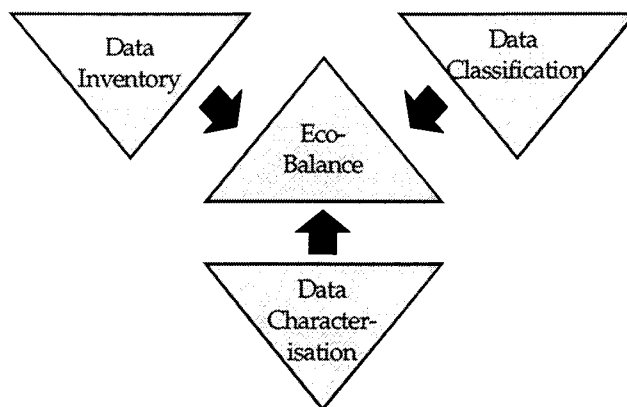


FIGURE 3 Phases of an Eco-Balance (Böning, 1995)

According to White & Wagner (1995) an Eco-Balance offers numerous benefits. The results of an Eco-Balance allow a company to identify environmental weak points; they serve as a valuable method of fostering cross-departmental communication and providing a purpose for environmental dialogue within the company; and they can serve as a basis for certification. Kurki (1998) adds to this list also the applicability of Eco-Balances as an important element of environmental reporting for companies.

Finkbeiner et al. (1998) have compared the interfaces between LCA and Eco-Balances. While LCA has a 'cradle-to-grave' approach Eco-Balance could

be called a 'gate-to-gate' analysis because instead of covering the life cycle of a product it consists of all processes which take place at a company or at a particular production site of a company. Other important differences in these approaches concern reference units, allocation as well as data and parameters used in the studies. Whereas LCA has a functional unit which is the basis for calculations and comparison, for Eco-Balances the reference unit is typically a certain period of time (e.g. one year). Therefore, the unit and the order of magnitude of LCA and Eco-Balance results are different and cannot be compared with each other. Allocation problem, i.e. partitioning the input or output flows of a unit process to the product system under study (definition of ISO 14040), is one of the major methodological problems within LCA. In Eco-Balances this problem does not occur, because multi-input and multi-output processes are considered as a coherent unit (see also Udo de Haes & Snoo., 1996 & 1997). The differences in data and parameters in the two types of approaches is understandable because their focus is different: in LCA the whole life cycle of a product and in Eco-Balances an organisation.

### 3.2.3 MIPS

The Material Impact Per Service unit -method (MIPS) was developed by Schmidt-Bleek (see e.g. 1993) in the beginning of the 1990's at the Wuppertal Institute for Climate, Environment and Energy. It is used to quantify the life-cycle-wide requirement of primary materials for products and services. Material inputs can be calculated for regions as well. Inputs of raw materials, both virgin and recycled, and energy are measured in physical units and aggregated to five main categories: abiotic raw materials, biotic raw materials, soil removal, water and air (CHAINET, 1998 and Schmidt-Bleek & Tischner, 1996). The most important drawback of MIPS is the question of how to make an assessment of different (toxic and non-toxic) substances in the material flows, while all the substances have the same weight (Gronow, 1996). Use of weighting factors for the different categories of mass flows are proposed, based on a non-technical, subjective approach and relying on expert opinions (Tulenheimo & Thun, 1995).

For regions the material productivity can be calculated by dividing the total material input of the region by a value for the affluency, usually GNP. The resource productivity of goods can be defined as the inverse of MIPS. This implicates the total amount of units of services in relation to the total material inputs, measured in 1/kg. The resource productivity as defined in MIPS has also been called the 'ecological rucksack' of products, services or processes (Schmidt-Bleek & Tischner, 1996).

MIPS is applicable for estimation and comparison and is often followed by more elaborate analyses. Due to this, MIPS has been compared to the screening steps of LCA by some authors (e.g. CHAINET, 1998 and Tulenheimo & Thun, 1995).



### 3.2.4 Environmental Risk Assessment

Environmental risk assessment can be used to analyse already operating plants and processes as well as processes in the planning stage. It has a preventative effect against the negative consequences of continuous emissions, accidents and accumulated releases. (Tulenheimo & Thun, 1995) Environmental risk assessments use critical path analyses which have very similar components to material flow models. A full risk assessment is normally based on a process involving three steps (CHAINET, 1998):

- A hazard identification, by which a relationship is studied between different levels of exposure and the incidence and severity of effects, normally including toxicological as well as ecotoxicological effects evaluation,
- An effects assessment and
- An exposure assessment, including descriptions of the nature and size of exposed targets, as well as magnitude and duration of exposure.

### 3.2.5 Joined Time Projection -model

The JTP-model is presented here as an example of a dynamic material flow model. Another reason for including it here is because it is the method used in the two dynamic case studies in articles 3, 4 and 5. The JTP-model is designed for analysing complete material systems and forecasting the effects of different policy options in the future. It takes into consideration several dynamic changes in the future and thus makes it possible to assess different policy options (see also Gronow & Pento 1995). The structure of the JTP-model is described in figure 4.

Annual material flows are determined on the basis of variables drawn from the collected data. They in turn are used to calculate different factors, such as consumption of raw materials or energy, emissions, waste generated or changes in imports or exports. The model can be made dynamic by drawing the annual estimates together, which makes it possible to forecast future changes in any of the variables over a given period of time.

The main advantage of the JTP-model is that it allows the researcher to make detailed, quantified estimates and scenarios for the future. Several variables and their changes over time can be evaluated in chosen scenarios simultaneously. The JTP-model also offers the possibility to analyse dynamic changes of material flows in a multivariable case.

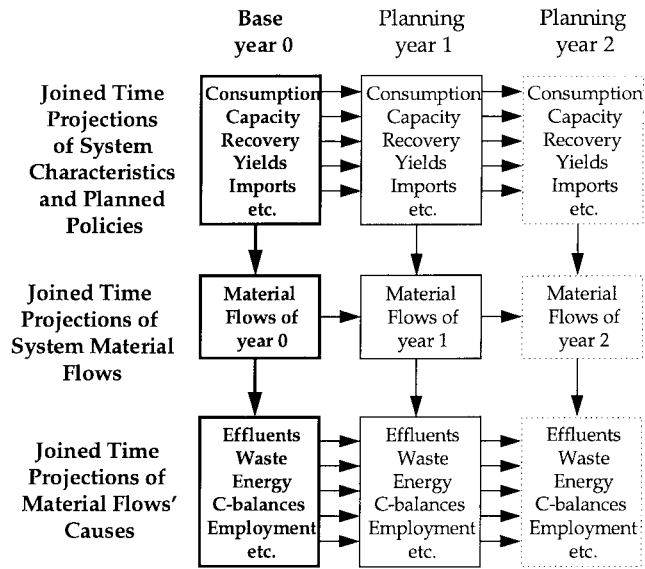


FIGURE 4 Structure of the Jointed Time Projection -model (Gronow & Pento 1995)

## 4 APPLICABILITY OF MATERIAL FLOW MODELS IN ECONOMIC DECISION MAKING

The balance between economy and ecology is an ideal situation often repeated in political discussion as well as in the strategic planning of a company. In reality, however, the technically or scientifically best solutions supporting the idea of sustainable development are often rejected by economists because these solutions are extremely expensive in economic terms. In fact, in most decision making situations we still miss decision aids which could offer information about both the environmental and economic impacts of the possible outcomes. Environmental issues are anyhow also business issues, and the importance of the cost aspect in environmental protection is definitely increasing in the future as more developed and expensive technology will be needed. That is why these two decision factors should not be seen or approached separately. New approaches to combine environment and economics are needed. Material flow models have proved to be a powerful tool for environmental decision making and their possible applicability in economic decision making will be discussed in this chapter. (Pesonen 1999c)

The approach I have chosen is to include economic parameters into material flow modelling, i.e. the material flow model serves as a basis for economic calculations. This means that the system boundary is given and does not need to be separately considered for economic assessment. The system boundary (whether it is a product system, an organisation or a geographical area) also defines which costs/revenues are to be included in economic analysis.

In environmental economics a distinction is usually made between internal (or private or direct) and external (or social or indirect) costs (see e.g. Allen et al., 1998, Frischknecht, 1998 or Otterström et al., 1998). Private costs are the costs included in any conventional cost analysis. Externalities are the unintentional side effects of production and consumption of goods that affect third parties (Veefkind, 1998) and which give estimates of the economic implications of environmental damage (Allen et al., 1998). There are different

valuation methods about how to give an economic value to environmental goods (i.e. the externalities): air, water, ground, emissions, waste, species etc. A distinction can be made between use values and non-use values of externalities. Other definitions in the area include e.g. option values, existence values and bequest values. (Otterström et al., 1998) Like Allen et al. (1998) state, there is grave doubt in the scientific community about the ability to meaningfully assign monetary values to the range of environmental impacts or to the far more limited range of effects considered in human health risk assessment. Most such monetisations, such as 'cost per life saved', lose credibility through a failure to consider other significant aspects of toxicity and through naive assumptions regarding the scale properties (Allen et al., 1998).

In my approach I do not intend to value the environment but, instead, I try to assess the economic impacts connected to the defined material flow system. Therefore in my approach there are no social costs or externalities in the sense of how they are defined above. The processes which are included in the studied system determine the studied costs and revenues - depending on the system boundary this includes the so called social costs or not.

In my approach the environmental and economic impacts are expressed separately: in my opinion it is more transparent for the decision maker to see the absolute figures as the results of both environmental and economic analysis. Many approaches have had the attempt to end up with one single figure expressed in monetary units (e.g. Frischknecht, 1998) or as a some kind of point on a defined scale (e.g. different valuation methods in LCA: the Swiss Ecopoints, the Swiss Critical Volumes, the Swedish EPS method, about valuation methods see e.g. Jönson, 1996) which would include environmental, economic, social etc. impacts of the studied system. These approaches always include several stages of valuation (how to make different emissions to air comparable; how to compare air emissions to water emissions and waste; how to value these in monetary terms etc.) where one impact is weighted against another. If it is difficult enough to make the judgement how to value the environmental impacts with each other, it is even more difficult to value these in monetary terms. Allen et al. (1998) have also paid attention to the problematic nature of valuation in LCA. According to them, the problem of comparing impacts become commensurably great when different categories of impact are compared and no successful objective scheme has yet been devised, even for limited problems such as comparing carcinogenic and non-cancer toxic effects. They state that in the practice of LCA, critical importance has been placed on making any incorporated value judgements, as well as scientific and technical assumptions, transparent. Anyone presented with a life-cycle study should be able to clearly identify any and all value judgements that it contains.

Because of the transparency I prefer keep environmental and economic impacts separate. Like I claimed above, this in my opinion is more transparent to the decision maker and in conclusion, the decision maker will have to face the problem of valuation himself. In article 4, where two scenarios of Finnish printing paper industry were compared, an example of this is given. The adapted scenario proved to be a lot better from the environmental point of view: 50 % more waste was generated and 2,5 times more greenhouse gases

were emitted in the basic scenario compared to the adapted one. The decision maker would in this case face the problem of valuation: are 20 % higher costs too much for the abovementioned savings in environmental impacts?

Decision problems including environmental and economic (and social etc.) variables are multiobjective. In some of the approaches briefly discussed above, the approach itself has inherent the multiobjective valuation method. A number of separate techniques and tools have been developed to provide assistance in multiobjective decision making situations; like the one presented above about the case of Finnish printing paper industry. E.g. Hokkanen (1997) has studied and discussed the use of these different methods in detail. One solution to this problem could be offered by Linear Programming (LP). Azapagic & Clift (1998) have encouraged the use of LP in order to quantify a compromise between environmental and economic performance in LCAs by using multiobjective optimisation.

Strebel (1992) has claimed that material flow analysis are not per se instruments for environmental decision making offering straightforward answers, but rather they serve as a basis for decision making offering information about different options. I share the opinion of Strebel and for this reason have tried to speak for transparency in the context of decision making above.

#### 4.1 Economic concepts and their applicability in connection with material flow models

Figure 5 presents the transactions between company and environment (Müller 1993). The impact of companies on the environment typically includes such flows as wastes and emissions. The environment, in turn, is the source of raw materials and energy to the economy.

Direction of transaction	To economy	To environment
From economy	Products and services	Emissions and wastes
From environment	Raw materials and energy	Ecology

FIGURE 5 Transactions between economy and environment (Müller 1993)

Industrial metabolism is a concept introduced by Ayres & Simonis (see e.g. Ayres & Simonis, 1994) to illustrate the connections between environment and economy. They define industrial metabolism as *'the set of physico-chemical transformations that convert raw materials (biomass, fuels, minerals, metals) into manufactured products and structures (i.e. goods) and wastes'*. In economics these processes, in the aggregate, are called production. A further transformation of economic goods into services (and wastes) is in economic terms consumption. Industrial metabolism includes all the materials and energy transformations that enable the economic system to function, i.e. to produce and consume. (Ayres & Simonis, 1994)

The concepts of environmental material flow analysis can be modified for economic models with some slight changes. In economic terms process of origin would be the seller of the product  $x$  and process of destination the buyer of the same product (see figure 1 in chapter 3). Cash flow (price) of the product  $x$  means revenue for the seller and costs for the buyer. (Pesonen 1999c) Costs of a process are the expenses incurred in producing goods or services and revenues is the amount earned by selling goods or services during a defined period (Begg et al., 1991).

The basic data needed for economic calculations of one single process are quantity ( $q$ ) and price ( $p$ ) of the product. Total costs for one process are:

$$TC_{\text{process } x} = q_{\text{process } x} \times p_{\text{process } x}$$

Correspondingly, the total costs of a built up system in a material flow model can be calculated. When the costs of each process are known, adding these together will give us the total costs of a system (for instance total manufacturing costs of a product):

$$TC_{\text{system}} = TC_{\text{process } 1} + TC_{\text{process } 2} + \dots + TC_{\text{process } x}$$

(where  $x$  = number of processes).

Average costs of a system can also be calculated by dividing the sum of the costs of each process by the amount of import material to the system:

$$AC_{\text{system}} = \sum \text{process } 1 \dots x / q_{\text{import}}$$

Material flow models do offer quantitative data about the studied system, i.e. the other half of the required data for economic calculations. In the case studies presented in articles 3, 4 and 5 it was testified that the quantitative data from the material flow models concerning the amounts of materials in each process were directly useful for cost calculation. Cost data for the calculations naturally has to be collected separately. The case studies presented were all in the area of waste management, and the cost data was obtained from various sources: interviewing different actors in the area (waste management plant directors, equipment producers and other experts), literature and previous research. All the scenarios in these studies included every phase of waste management, from waste collection to final storage. Total costs of each process (e.g. waste incineration) include investment and operating costs as well as possible revenues from the sold energy.

In each of the abovementioned studies the functional unit (i.e. the quantified performance of a product system for use as a reference unit in a life cycle assessment study, definition by CEN, 1997) was determined as a ton of waste. Also the results of cost calculation were thus presented in relation to this determined functional unit as ATS/t or FIM/t. In this way it was possible to compare the results of chosen scenarios. In addition to this, total costs of the studied systems were also calculated. Empirical results of the case studies are presented in articles 3, 4 and 5 and will not be discussed here.

In the end of this chapter I want to discuss the use of one concept of economics in the connection of material flow models: the concept of efficiency. As Schaltegger (1997) has stated, economic rational management is characterised by being efficient, as the purpose of economic behaviour is to manage scarcity in the best possible manner. Efficiency measures the relation between input and output. The higher the output for a given input, or the smaller the input for a given output, the more efficient is an activity (or product, company, nation etc.). The units in which the output and input are measured can be varied. The corresponding concept to economic efficiency for environmental management 'eco-efficiency' was first introduced by Schaltegger and Sturm (1990). It measures how much environmental protection has been achieved with scarce financial resources and it is defined by the ratio between value added and environmental impact added, i.e. by the ratio between an economic and an ecological performance number. In most cases the ecological benefits can hardly be measured in monetary units and thus for environmental impact added the quantitative physical units are used. (Schaltegger, 1997) Stevels (1998a) has discussed the possible use of eco-efficiency within take-back systems and given the following definition of it:

$$\text{Eco-efficiency (kg/ECU)} = \frac{\text{Environmental gain (kg/kg)}}{\text{Costs (ECU/kg)}}$$

According to Stevels (1998a) the precise definition of environmental gain (i.e. environmental impact added according to Schaltegger) depends on the general goal set for the measurement. For take-back systems he has identified four possible goals and in consequence also four environmental gain definitions. If the maximising of the volume of materials not ending up at landfills is the goal, environmental gain should be defined as the relation of the volume of materials not ending up at landfills to the total volume of materials. Same analogy applies for other three goals: maximising the amount of materials being recycled; minimising the amount of certain environmentally relevant substances ending up at landfills; and maximising the amount of certain environmentally relevant substances brought under control.

## 4.2 Similarities and differences of material and cash flows

The basic considerations concerning the similarities and differences of material and cash flows are discussed in detail in article 1 by focusing on six separate issues: types of cash flows or stock, direction of the flows, growing entropy of the flows, input vs. output of a process, process as a black box and impacts of material and cash flows. They are also briefly presented in this chapter because they form the basic philosophical foundations for the use of economic terms combined with material flow models. Details can be found in article 1.

The concept of throughput was introduced into economics by Boulding (1966), and more fully elaborated and integrated into economic theory by

Georgescu-Roegen (e.g. 1971), who called it the 'metabolic flow' and emphasised the manifold consequences of its entropic nature (Daly, 1989). The laws of thermodynamics have ever since been applied to economic theory by several scientists (see e.g. Burness et al., 1980; Daly, 1989; Faber et al., 1987; Georgescu-Roegen, 1971; Perrings, 1987 and Ullhøi, 1995). Ullhøi (1995) has even included what he calls 'Economics and thermodynamics' among new disciplines appearing around environmental issues. Kneese et al. (1970) have paid respect to the concept by emphasising the importance of 'material balances', thus recognising the constraint on the economic process of the first law of thermodynamics, but neglecting that of the second law (Daly, 1989). Until now the second law of thermodynamics has gained much less attention than the first one. I have, however, found both of them useful in explaining the relationship between economy and environment. The first law of thermodynamics will be discussed in chapter 4.2.4. and the second in chapter 4.2.3. It is a conscious decision to present them in this reverse order in this context, as in my opinion this order is more suitable and logical when presenting the features of cash flows.

#### 4.2.1 Types of cash flows or stock

The environmental protection requires financial means for basically three different purposes: environmental investments, operating costs and funds used for research and development (Otterström et al., 1998). All of the abovementioned costs can be connected to material flows as well. Kytzia (1997) has separated three different types of cash flows or stocks especially in connection with material flows:

- *Cash flows connected with material or energy flows:* Such cash flows, which are directly connected with a material or energy flow, are included in the material management system. As this type of flow is unique in the sense that they occur in a certain moment of time and have no consequences in the future, there are usually no major allocation problems connected to them. The material as well as cash flows are typically easy to follow and determine. In economic terms, in accounting, the cash flows connected with material or energy flows are referred to as costs or revenues (see definitions of costs and revenues in chapter 4.1).
- *Cash stocks connected with material stock:* Material accumulated in a given process form a material stock (definition according to Baccini & Brunner, 1991), e.g. real estate, machinery, raw material stocks or landfill. The value of such a stock has to be estimated in economic terms. Material stocks are usually accumulated in a relatively short period of time (the building phase) but their environmental impacts occur during a longer period of time in the future. For this reason it can be very difficult to estimate the impacts of the stock in coming years (or decades or even centuries as is the case with landfills). In economics



there are established methods of economic cost and investment accounting which are used to allocate the investment costs for various products and periods. In accounting cash stocks are presented in balance sheet in assets.

- *Immaterial cash flows*: Immaterial cash flows occur in case of services. What was said above about the cash flows connected with material or energy flows applies here as well. The only difference is in the direction of the flow. This detail is discussed in article 1 and briefly presented in the next chapter.

In the case studies, examples of each of the three types of cash flows were to be found. Energy sold from incineration plants is an example of the first type of flow, where cash flow is connected with energy flow. Examples of the cash flows connected with material stock would be processes like an incineration plant, biological waste treatment plant or landfill which require high investments for the building site, buildings and equipment. These form a material stock with a considerable economic value which was transformed into yearly costs for cost calculation. Transport and collection are services which provide examples of the third type of cash flow. The determination of the costs of these services was relatively straightforward, and followed the same principles as in the case of cash flows connected with material or energy flows.

#### 4.2.2 Direction of the flows

Cash flows are consequences of market transactions. The buyer pays the seller for a determined product (whether it is a physical product e.g. raw materials or machinery or an immaterial service e.g. financing, waste handling) which is purchased to satisfy his/her special needs. In most cases the goods have positive economic value and in the market transaction the cash flow takes the opposite direction than the material flow. This is the usual case with physical products. When a good has a negative economic value (e.g. waste) the material flow is in the same direction as the cash flow. Actually in this case the buyer pays for the service of 'getting rid of the waste'; not for any physical product.

Consumption is an interesting process when studying the direction of the cash flows, because it is during consumption when the economic value of a product changes from positive to negative. As was discussed above in chapter 4.1 in connection with industrial metabolism, in consumption a transformation of economic goods (with positive economic value) into services and wastes (with negative economic value) takes place (Ayres & Simonis, 1994).

#### 4.2.3 Growing entropy of the flows

The second law of thermodynamics relates to the concept of entropy (the state of disorderliness or diffusion of energy). According to this law entropy never decreases in the system. This means that the substances and materials are

refined, mixed and distributed during the material flow so that in the end one single substance is almost impossible to trace and separate. When a substance or a material is being imported to the system it is more or less one consistent flow. As it flows through the system it is spread over the whole system to various processes, possibly recycled etc.; finally in the export products of the system different import materials together compose very complex compounds.

This is also true for cash flows. The payment for a product is further divided to subcontractors, raw material suppliers, financiers etc. Even though the directions of the material and cash flows are opposite the second law of thermodynamics applies in both cases.

#### 4.2.4 Input vs. output of a process

The first law of thermodynamics, the law of conservation of mass and energy, (i.e. the principle that the amount of material and energy remains constant at any flow or process in a system; energy is something which cannot be created or destroyed, though its form can be changed) claims that the input and output of a process must be equal. For the material as well as energy flows this is true.

For cash flows, however, this does not apply. In each process some value is added to the product. Riahi-Belkaoui & Fekrat (1994) define the concept of value added as *"a measure of the total return generated in a firm through the utilisation of its productive capacity, i.e. labour and capital in the broad classical sense"*. Because of the value added within a process the input of cash flow has to be larger than the output. Output refers to the expenses of bought-in materials and services, and input to the sales revenue. Input - output gives the value added within one process. In reality, cash input does not always exceed output in the short run, but if the company is to stay alive, in the long run this has to be the case.

The process of consumption forms a special case where value reduction takes place instead of value adding. As was discussed in previous chapter, the change of signs of economic value of products happens during consumption.

#### 4.2.5 Process as a black box

In the definitions of material flow models, processes are considered to be black boxes (see e.g. Baccini & Brunner, 1991). What is happening inside the process is not considered important; instead attention is paid to the input and output of a process.

For material flows this practice is suitable because input and output are equal. But in the case of cash flows the process has to be taken into account. As discussed above, a process is an active part of the system which adds value to the product during its production. Value is added (or in case of consumption reduced) within the process and so it cannot be seen as a black box when studying cash flows.

#### 4.2.6 Impacts of material and cash flows: emissions and costs

The outputs of each process in material flows are products (which were the actual goals of production and have some economic value), by-products (unintended products of production which also have some economic value) and/or emissions (unintended products with no or negative economic value). Emissions (to air, water or ground) are studied when trying to assess the impacts of the material flows of a system. In addition to the output-related impacts discussed above (i.e. emissions), input-related impacts form the other group of interest for environmental analysis. Input related impacts refer to consumption of energy resources and depletion of other natural resources (Weidema, 1997). Daly's (1989) statement also proves the fact that flows cause environmental impacts: "*It is the gross flow that provokes environmental impact*". The processes themselves do not cause any environmental impact but the material flows do.

The impacts of cash flows are expressed as costs or revenues. Costs (and revenues) are, in turn, caused by the processes; not the cash flows. Processes add value to the product (and to the system) and cause costs. Weidema (1991) has defined 'flow-independent impacts', which include human and social welfare. Economic impacts can be seen as a part of this group as well.

### 4.3 Important processes and flows

The systems of material flow models are usually so complex that it would not be possible or reasonable to build it up using every single detail. It is therefore important to identify the central processes and flows of the system. This is a common goal for material and cash flow analysis.

Brunner et al. (1996) gives a guideline as to how to limit the number of material flows: such flows which make less than 1 % of the largest flow in the system should not be included in the study. For some research settings it is nonetheless essential to also include these very small flows. Certain substances can for example cause severe impacts in very small concentrations. It is also possible that a studied element (e.g. zinc) is only to be found in these smallest flows. The absence of these small flows would in this case make the whole study impossible. Fava et al. (1994) have also stated that even if it might be tempting to omit some minor flows, it is unwise to neglect any operation until it can be established quantitatively that its contribution to overall system performance is negligible.

An important material flow could be thus defined as one which either is quantitatively large and/or has environmentally significant concentration of the studied trace element(s). Correspondingly, an important process for cost analysis could be defined as a process which has a quantitatively large material flow input and/or has high average costs (costs/unit). If the flow is very small in amount even the highest average costs do not make it important in economic terms.

Important flows in material terms are not always important economically and vice versa. Figure 6 presents the possible connections of these two flows. Examples of each type of flows presented in figure 6 are given in article 1.

When the economic calculations are based on the material flow models, special attention should be paid to the economically important but environmentally unimportant flows, marked as number 3 in figure 6. There are usually flows in each system which have been excluded from the material flow model because of their relative unimportance in environmental terms. Some of them are probably unimportant also in economic terms (these are marked as number 4 in figure 6) and their absence would not cause any problem in economic terms either but there might well be flows missing which are extremely important in economic terms. The material flow model and the system should therefore be critically studied and the possibly missing important processes in economic terms should be added into the model before applying it to economic calculation. If this is not done, it can lead to major errors in the results.

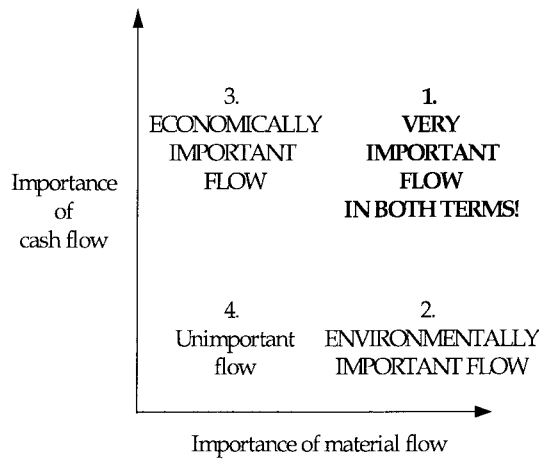


FIGURE 6 Connections of material and cash flows

#### 4.4 Advantages and restrictions of combining economic data with material flows

The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data produced about the system, its logistics and flows, which in most cases is directly useful for economic calculations.

An important argument supporting the linking of economic variables to environmental information is the communicative value of monetary terms.

Costs and revenues are concepts of the language used by management responsible for decision making. Speaking in terms of cash, savings and investments translates the environmental information into a more understandable form for the business decision maker (Bundesumweltministerium, 1997).

As discussed in previous chapters material flows offer quantitative data (which in most cases is directly useful for economic calculation) about the studied system. Cost data for the processes has to be collected and determined separately. The ordinary accounting of a company, however, does not necessarily split out the production costs on the individual products or processes. It might be difficult or even impossible to determine precisely specific costs of a certain product needed for the economic evaluation. Activity-based costing (i.e. the ABC system developed by Cooper & Kaplan, 1988) where all costs are allocated back to the products and processes whence they arose, would offer a solution here (see e.g. Weidema, 1997). According to ABC, costs which were traditionally classified as general costs are allocated to products or product groups based on individual product's consumption or demand for each activity. ABC system makes it easier to identify product-related processes from the total business of the company (Tulenheimo, 1995). ABC systems simply recognise that businesses must understand the factors that drive each major activity, the cost of activities and how they relate to products. It pays attention to the differences in relative input consumption, and traces the appropriate amount of input to each product. It attempts to model the consumption of resources throughout the organisation (Drury, 1992)

Generally, there exists no consensus (definitions, guidelines, standards etc.) about how the cash flows connected to environmental protection should be measured which causes such methodological problems as were discussed above (Otterström et al., 1998, Tilastokeskus, 1997, Azzone et al., 1994).

The most relevant danger when using material flow models in economic evaluation relates to the identification of important and unimportant flows. As was discussed in the previous chapter, it is possible that some important flows in economic terms are missing from the material flow model because they have been determined as unimportant on an environmental basis. If they are not included for economic calculations the results of the economic evaluation might have major errors. Therefore it is extremely important to study the system critically before applying it to economic calculation and add the probably missing processes into the model.

## 4.5 Life Cycle Costing

Life Cycle Costing (LCC) is a tool developed to be used in connection with Life Cycle Assessment (LCA). LCC is the economic assessment of all money flows which are caused by the existence of a specific product (Fabricky & Mize, 1991). As well as within LCA, also LCC has a cradle-to-grave approach: it assesses the total costs arising during the whole life cycle of a product, i.e. planning,

investments, use, maintenance and disposal costs, extending the time horizon of cost calculation in accordance with the concept of sustainable development. LCC offers a complete picture about the costs which are related to the product during its life cycle regardless of who is responsible for the costs in different phases. The full life cycle costs include the cost of material, product, process, or service, which explicitly includes the costs of environmental, health, and safety issues (Cohan, 1996).

Other environmental accounting tools found in the literature for the same type of cost accounting as LCC include 'Full cost accounting', 'Total cost accounting', 'Full-cost pricing' and 'Total cost assessment' (Tulenheimo, 1995).

Even though LCC is a technique especially developed for analysing the costs of product I have chosen to introduce it here, because in my opinion the underlying philosophy and the framework of this technique could be more widely generalised for economic evaluation in the context of material flow management. Also Cohan (1996) has noted that the concept of life cycle costing may be extended beyond products or materials to more complex components, systems, and processes by clearly defining each of the elements of a system, each of the steps in a process, and each stage in the life cycle of materials used in the system or process, and then identifying each of the cost elements within the defined scope of the system or process.

The first LCC evaluations were made in the 1960s, but the technique has not been utilised on a large scale. LCC methodology was developed in the US Defence Ministry where the method was primarily applied for public purchases. Later it was used for the same purpose in other areas of government. Also industry has used LCC in the USA: especially during planning of projects such as power plants, oil rigs, railways and other large systems alike. (Brown & Yanuck, 1985) Later the use of LCC has been introduced in the planning of single products. Despite its minor applications, the use of LCC could, however, be useful in many cases. When applied properly, it could mean remarkable savings e.g. in connection with the material choices of products (Lokka & Hänninen, 1994).

LCC allows potential applications in the following areas: (Cohan, 1996, Kohopää, 1989 and Lyytikäinen, 1987)

- evaluation of new product alternatives and materials management
- long term planning and budgeting: maintenance planning of machinery and replacement of existing machinery
- process design and management
- waste management

The calculation of life cycle cost involves the inventory of all relevant costs, estimation of unknown costs and conversion of money flows which occur at several points in time (Veefkind, 1998). LCC does not require any new, revolutionary method of cost accounting. Instead, it uses the traditional methods of cost accounting in a broader environment. While traditional economic investment calculations pay attention to such variables as investment costs, interest rate, depreciation method and period, LCC analysis also includes

the costs from use, maintenance and disposal. (about LCC see e.g. Brown & Yanuck, 1985; Kohopää, 1989; Lamberg, 1983; Lokka & Hänninen, 1994 and Fabrycky & Blanchard, 1991)

The cost elements which are considered in life cycle costing include the cost of acquisition (including direct purchase cost, handling or transportation costs, record keeping etc.), cost of use (including the direct costs of use, associated labour and other material costs, training and management costs, occupational liabilities, costs of waste minimisation efforts etc.), cost of disposal (including treatment costs, actual disposal costs, costs of record keeping and management etc.) and postdisposal costs (including long term record keeping, potential legal liabilities etc.). Cohan (1996) divides the costs in life cycle costing into four categories according to their dimension:

- *Direct costs* that will be incurred by a firm with certainty. They are the costs included in any conventional cost analysis.
- *Indirect costs* that will be incurred with certainty, but which usually are not attributed to or directly associated with the given chemical or material. These costs are typically not included in cost analyses. They are incurred by the firm and show up on someone's budget but typically not on the budget of those evaluating the decision.
- *Uncertain costs* are potential costs which are uncertain in magnitude and/or timing. These may include e.g. legal liabilities.
- *Social costs* (i.e. *external costs, environmental externalities*) which include environmental releases or impacts that are not reflected in the price of a product or otherwise borne by the firm using a product.

The largest problem in LCC relates to the difficulties in the determination of future costs (Lokka & Hänninen, 1994). Other restrictions in the use of this method include uncertainties in other critical variables of calculation (interest rate, depreciation period, technology changes etc.) and the large amount of work required for the analysis (Kohopää, 1989).

The approach I have chosen to include economic parameters into material flow modelling (presented in the beginning of chapter 4) has similarities with life cycle costing, but there are certain significant differences as well. First, I do not limit my approach to product systems but instead, it is applicable to all material flow systems independent of its system boundary setting. Second, I do not make a distinction between private (or internal) costs and social (or external) costs. The system boundary of the material flow system defines which costs are included in the system and which are not. Therefore there are no social costs or externalities in the sense of how they are defined e.g. by Cohan above. The processes which are included in the studied system determine the studied costs - depending on the system boundary this includes the so called social costs or not.

## 5 LONG TERM COSTS AND SCENARIOS IN MATERIAL FLOW MODELLING

*"The future is no longer stable; it has become a moving target"* claims Pierre Wack, an economist, who has developed the system of scenario planning for Shell with Edward Newland and has ever since participated in scenario development with management teams around the world and lectured about the theme at the Harvard Business School (Wack, 1985a). Wack's statement summarises extremely well the uncertainty of the world where the companies today live in and also serves as an explanation for increasing demand for scenario planning.

Stationarity of the trends was characteristic to the 1950's and 1960's but in the 1970's it was broken to dynamic crises. Past experiences to which decision makers used to commit themselves included: long term predictability of the future, long term stationarity of prices and costs, low risks of options, and foremost an economic growth which was faster than exponential with only manageable fluctuations in it. A fundamental change, however, occurred in the 1970's. Instead of the expansive growth that had continued since World War II, a turbulent phase of non-growth, a completely new situation with competition under conditions of structural over-capacity and new competitors from the newly industrialised countries, was suddenly reality. One major change after another emerged adding to the overall turbulence of the world situation in an unprecedented fashion. As a result, previous ways of decision making which had worked well in the past started to lose ground. Many companies experienced unpleasant surprises in their strategic decision making. Some companies, instead, managed well in doing business under these new conditions. The turbulence of our time has first and foremost affected conditions and expectations for business decisions and made previous business experience almost obsolete as a standard for a success in the decision making. (see e.g. Malaska, 1983 and 1984)

Unpredictability and uncertainty have thus become factors which have to be dealt with in each and every decision making situation within today's



business. The only certainty seems to be that future will hold surprises. Scenario development is a tool for systematic observation of the environment of a company, to be better prepared for alternative emerging future circumstances, and also to actively construct one's own future. Only when the future options are well known, it is possible to play an active role in the development of the future!

Changes in the environment always include both threats and opportunities. To make use of the opportunities the company must adapt itself and its strategic behaviour accordingly. Companies able to foresee changes in their working environment are expected to adopt different type of strategic decisions from the ones made by companies not involved in active observation of future options.

## 5.1 Concept definitions of 'Scenarios'

The best known scenario studies are probably the reports of the Club of Rome which have had a great contribution to the use of scenarios in future research. Their reports served as an example for other organisations in their future planning. Several definitions of scenarios can be found in literature:

- Gausemeier et al. (1995): *"a description of a complex future situation occurrence that can not be predicted for sure as well as the presentation of the development that could lead from the present to the future."*
- Hansmann (1983): *"description of the development of the object of the analysis in alternative framework conditions"*
- Meristö (1991): *"a holistic script about the future, which defines working environment of a company based on different assumptions and describes the paths from present to the future" and as "possible, but not necessarily probable views of the future"*
- Vartia (1994): *"Scenarios are used to describe that part of the organisations' environment for which projections are difficult or even impossible. Scenarios give the possibility to prepare for alternative and uncertain future options without knowing anything about the probability of the possible outcomes. This makes the scenarios different from forecasts. Effective scenarios are distinct, logical and they are different enough from each other so that they are able to describe the central changing factors of the future and place questions on existing assumptions."*

These definitions include three basic elements of scenarios: the definition of alternative future circumstances, the path from the present to the future and the inclusion of uncertainty about the future.

Changes in the surrounding environment can according to Hunt & Johnson (1995) include changing circumstances, such as changes in technology, environmental damage becoming tangible, and improved understanding of

environmental science. According to Wack (1985b) scenarios can effectively organise a variety of seemingly unrelated economic, technological, competitive, political, and social information and translate it into a framework for judgement.

SETAC working group Scenario development (Pesonen (ed.), 1998) has suggested the following definition of scenario in LCA studies: "*Scenarios in LCA studies are descriptions of possible future situations relevant for specific LCA application, based on specific assumptions about the future, and (when relevant) also including the presentation of the development from the present to the future.*" According to the definition scenario includes a short description of the scenario and the specific assumptions (in detail) underlying this scenario. The description serves as a short introduction to the scenario. The assumptions then specify the scenario in detail. These assumptions are also used as the basis for the modelling of each scenario.

The use of scenarios is a research field closely connected with forecasting. Scenarios are used to describe that part of the organisations' environment for which forecasting is difficult or even impossible. Scenarios give the possibility to prepare for alternative and uncertain future options without knowing anything about the probability of the possible outcomes. This makes the scenarios different from forecasts. Effective scenarios are distinct, logical and they are different enough from each other so that they are able to describe the central changing factors of the future and place questions on existing assumptions. (Vartia, 1994)

Scenarios can effectively organise a variety of seemingly unrelated economic, technological, competitive, political, and social information and translate it into a framework for judgement (Wack, 1985b). Changes in environmental concern are according to Hunt & Johnson (1995) driven by changing circumstances, such as

- changes in technology,
- environmental damage becoming tangible, and
- improved understanding of environmental science.

According to Wack (1985b) scenarios serve two main purposes. The first is protective: anticipating and understanding risk. The second is entrepreneurial: discovering strategic options of which you were previously unaware. The latter purpose is in the long run more important of these two.

Wack (1985a) makes a distinction between two different types of scenarios: first-generation scenarios and real decision scenarios. So called first-generation scenarios are exploratory and present the raw uncertainties but they fail in offering a basis on which decision makers could exercise their judgement. The goal of these scenarios is not action but understanding. They give insight into the system, to identify the predetermined elements, and to perceive connections among various forces and events driving the system. The decision scenarios present a different philosophy, having to do with management perceptions and judgement. Decision scenarios deal with two

worlds: the world of facts and the world of perceptions. They explore for facts but they aim at perceptions inside the heads of decision makers (Wack, 1985b).

### 5.1.1 Number of scenarios

Every material flow model contains at least one (base) scenario. Typically material flow studies include at least two scenarios: the base scenario "everything continues as usual" and (an) alternative scenario(s) with some changes to the first one.

Wack (1985b) has given a suggestion about the appropriate number of scenarios in a study. He claims that there should never be more than four scenarios because otherwise the decision making will become unmanageable for most decision makers. He suggests the ideal number of scenarios to be one plus two; that is, first the surprise-free view (showing explicitly why and where it is fragile) and then two other different ways of seeing the world that focus on the critical uncertainties. Also the suggestions of other authors (see e.g. Meristö, 1991 and Hokkanen, 1997) about the number of scenarios in a study agree with the principles presented by Wack.

### 5.1.2 Time horizon of scenarios

For what time period should a scenario be conducted? How far should a study look? There are no universal answers to these questions. The time span of scenarios has to be determined separately in each case and will be determined at least partly by business considerations such as the lifetime of existing plants and the lead time for developing new products or services. Hunt & Johnson (1995) suggest that environmental scenario development should, as far as possible, cover a time-scale commensurate with that used for business development strategy. According to Meristö (1991) the time horizon of a scenario is typically longer than that of usual strategic planning. In her study about scenario planning in European companies, the time horizon of the scenarios was for most companies between 6-15 years while their usual strategic planning includes a time span of only 3-5 years. Factors causing dangers of trying to look too far ahead include rapid, unforeseeable changes in technology, increasing understanding of environmental sciences which may change our common truths about environmental impacts, revolutionary changes in legislation or policy, or changes in the markets such as consumption patterns, supply of raw material etc.

Weidema (1993) has presented a typology of LCA application areas where he distinguishes between three categories based on time horizon: operational, tactical and strategic level. The operational level is characterised by being non-comparative and by the results being used directly on the product itself, the typical example being product declaration. The tactical level includes typically improvements being evaluated by comparison between products. The results are used to influence the surroundings of the product: producers, suppliers,

employees and customers. Typical example would be eco-labelling criteria. The strategic level, instead, includes improvements evaluated in relation to an environmental target and the results of which are used to place the product in a larger context.

### 5.1.3 Practice of scenario development process

In 1980's Malaska (1983 & 1984) has conducted a study about the practice of scenarios in the business planning in Europe and Linneman & Klein (1982) similar one in the USA. Both of these studies have chosen to use the term 'Multiple Scenario Approach' when referring to the scenario development process. According to Malaska's study, there is no one single way of developing scenarios in a company but, instead, many different methods are used. He claims that in accordance with the uncertainty and unpredictability of the future it is understandable that flexibility and creativity are needed in the scenario development as well. More than a logical structure or a new kind of planning procedure, he suggests that scenario development is an approach, a joint working procedure basically aiming to cultivate and utilise the advanced intuitive knowledge of decision makers and combine it with objective information (Malaska, 1983).

Meristö (1991) has studied the methods of using scenarios in practice in strategic planning and has developed an approach called action scenario approach. The main features of action scenario approach are as follows:

1. Those who are responsible for the strategic decisions are also responsible for action scenario approach and the whole process to formulate and illustrate the scenarios. This ensures the commitment needed in decision making and in action.
2. Action scenario approach describes not only the alternatives of the future but also includes the strategy formulation based on those alternatives. This creates the flexibility to the strategies.
3. Action scenario approach combines futures studies to strategic planning as an integrated part and it is dependent of the planning process used in the company. This guarantees that no double system of planning is used and scenario approach will broaden the view of traditional strategic planning.

The breadth of the scenario should range from issues which have not attracted external concern as yet, but which the organisation has reason to believe will attract attention in the future, to those that have already given rise to legislation soon to come into force (Hunt & Johnson, 1995).

Worst-case scenario is one of the concepts related to the scenario development. It is a possibility by some combination of events and/or human error the probability of which seems, however, remote (Welford, 1994). Welford refers to the chemical accident in Bhopal as an example of a worst-case scenario that turned out to become reality.

## 5.2 Two basic methods of scenario development in material flow modelling

On the basis of the different definitions of scenarios discussed in chapter 5.1 I suggest to distinguish between two basic approaches of scenarios in the context of material flow modelling: What if -scenarios and Cornerstone scenarios.

What if -scenario is the more widely used one of the two approaches in LCA research. It is used to compare two or more alternatives in a well known situation where researcher is familiar with the decision problem and can set defined hypothesis on the basis of existing data. These are often studies where some specific changes within the present system are tested and their implications to environmental impacts are studied. The results of a study using What if -scenarios are typically quantitative comparison of the selected alternatives: e.g. alternative A is better than alternative B by x %. This type of research could also be defined as one offering operational information in case of short term decision making situations. According to CHAINET (1998) operational information describes small changes of small scale systems with a short time horizon. Product development serves as an example of this type of information needed because it is mainly relevant in a short-term setting.

Cornerstone scenario approach, instead, does not necessarily give quantified results comparing any pre-set alternatives. It offers the researcher guidelines in the field of study and typically serves as a base for further research. In cornerstone approach researcher chooses couple of alternatives which can be very different from each other in order to get an overall view of the studied field - these alternatives then serve as 'cornerstones' of the studied field. The results of Cornerstone scenario approach can point out a potential direction of future development or at least give some information about alternative path/s of development in the studied area which is/are certainly not possible. Cornerstone scenario approach offers a tool for long term planning and the nature of this type of study and the information gained from it is more strategic than in What if -scenario approach. Strategic information refers to large and possibly qualitative changes of large scale systems with long time horizons (CHAINET, 1998). Cornerstone scenarios can offer new ways of seeing the world, which allows the decision makers to break out of a one-eyed view. Cornerstone scenarios can thus serve as means to re-perceive reality.

Results of a study using Cornerstone scenario approach often serve as a basis for further, more specific research where the scenarios can be defined according to What if -scenarios. Wack (1985b) has also paid attention to the importance of starting with scenarios at more general level (in his definitions first-generation scenarios) and then work further towards more specific ones (decision scenarios). He claims that one cannot start with a narrow focus because key things (or dimensions) will thus be missed: *"You must wide-angle first to capture the big picture and then zoom in on the details"*.

Several similarities between the features of the two basic research approaches, quantitative and qualitative research, mentioned in research methodology literature (see e.g. Burns & Bush, 1998) and the two defined basic

methods of scenario development can be stated. I have found the comparison very useful in this context. Table 1 summarises the features of What if -scenarios and Cornerstone scenarios defined on the basis of differences between quantitative and qualitative research.

TABLE 1 Features of the basic scenario approaches

WHAT IF -SCENARIOS	CORNERSTONE SCENARIOS
<ul style="list-style-type: none"> <li>• Field of research is well known; researcher is familiar with the object of the research</li> <li>• Research object is simple</li> <li>• Well defined research plan, standardised research</li> <li>• Purpose of the research is to test previously set hypothesis</li> <li>• Comparison of existing systems (process alternatives, product modifications etc.)</li> <li>• Operational information</li> </ul>	<ul style="list-style-type: none"> <li>• Field of research is new, unknown to the researcher</li> <li>• Research object is complex</li> <li>• Open research plan, scenarios are developed in the course of the study</li> <li>• Purpose of the research is to increase understanding about the studied object</li> <li>• Design and development (of new products, technologies etc.)</li> <li>• Strategic information</li> <li>• Often serve as a base for further, more specific research with What if-scenarios</li> </ul>

Wack (1985b) claims that scenarios are most effective when they are combined with strategic vision and option planning. These two factors correspond very well to the features of Cornerstone and What if -scenarios suggested here.

According to the ISO 14040 standard possible internal application areas of LCA studies (CEN, 1997) include: product development and improvement, strategic planning, public policy making, marketing and other. Strategic planning and public policy planning clearly require research using Cornerstone scenarios approach. All the other applications mentioned here require more operational information and would thus include research methods applying What if -scenarios.

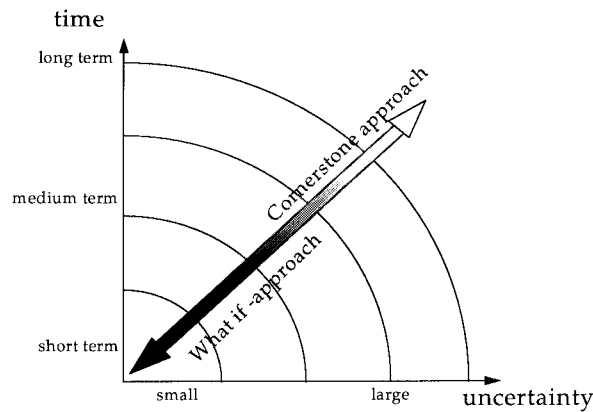


FIGURE 7 Two basic approaches to scenario development in material flow studies

Figure 7 summarises the use of Cornerstone and What if -approaches corresponding to the two dimensions of material flow studies, time and uncertainty included in the system. When the research problem is specific and it covers short to medium term time horizon, What if - approach is typically used. When the time horizon grows and the problem area becomes more uncertain, Cornerstone approach is more suitable. What if- and Cornerstone approaches describe the two ends of the continuum from very strictly defined scenarios to complex research settings in the Cornerstone approach.

Stevens (1997) has presented different levels in environmental improvement of products (see also table 2):

- Level 1: Incremental improvement, which will result in improvements in the order of 5-10 %
- Level 2: Complete redesign of existing concepts, which will result in improvements of up to 30-50 %
- Level 3: Alternative fulfilment of functionality, which may result in improvements of up to 50-75 %
- Level 4: Change of functionality, which may result in more than 75 % (factor 4) improvements

The levels of improvement suggested are a combination of technical, social and institutional innovation. The higher levels of design require changes in society and require the engagement of multiple stakeholders. The time horizon of different levels is also included in the table. The optimisation of existing systems concerns decisions with a short-term horizon, while the change of product systems and improvements to existing technologies concern decisions over a medium-term horizon. Fundamental changes of several technologies or concepts pertain to long term decisions. (see also CHAINET, 1998)

TABLE 2 Levels of improvement (Stevens, 1997)

Level of improvement	Goal	Example	Time horizon	Change of consumer lifestyle	Infra-structure change
1	Incremental improvements	Current better TV	0-2 years	-	-
2	Redesign of existing concepts	"Green TV"	0-5 years	+	-
3	Alternative fulfilment of functionality	LCD TV	0-10 years	+++	+++
4	Sustainability	?	0-30 years	++++	++++

The different levels of improvements also require different levels of information. Level 1 typically requires operational information and research in

this case would use What if -scenarios. At level 4, instead, strategic information is required which makes Cornerstone scenario approach suitable for this case.

The scenarios of the case studies in article 3 studying the dynamic changes in Austrian and Finnish paper industry are typical What if -scenarios. Both have basic scenarios and one adapted scenario, which differs from the basic one in only few variables. Both of these studies have clearly two options of possible future policies which are then compared in the results. The scenarios in the Austrian waste management study, instead, could be defined as Cornerstone scenarios because the intention in the study was to identify extreme, not practical or possible future scenarios in order to gain new insights for the possible ways of development of the Austrian waste management. With the help of the lessons learnt during this study the last scenario 5 was developed as an attempt to build up an optimal scenario about the system.

### 5.3 Implications of different scenarios to cost accounting

In the case of What if -scenarios the economic calculations are usually relatively easy to carry out using the traditional methods of cost accounting (including cost estimation and investment accounting).

Cost estimation is the prediction of future costs based on product information, cost information, experience and assumptions. Veefkind (1998) has divided the cost estimation techniques to three main categories: qualitative, global quantitative and detailed quantitative cost estimation techniques. Qualitative cost estimation techniques provide insight in the predicted cost by comparison, without predicting the absolute value of the cost. Global cost estimation techniques use cost related data on existing products or processes in order to predict the costs in the future. Detailed cost estimation techniques, instead, apply data about manufacturing processes to enable cost estimations of a future product or process.

Cost accounting becomes problematic when the time horizon (and thus also uncertainty) of the studied scenarios grow, i.e. when moving towards Cornerstone scenarios. There are no specific guidelines for cost accounting in very long term cases and basically the same cost accounting methods as for shorter term cost accounting apply also here. The assessment of future costs/revenues becomes more difficult when the time horizon grows: how should the costs of future investments or operations be estimated if the exact technologies of the future are still unknown? Future costs can not be measured in absolute terms and thus estimates e.g. based on expert assessments can be used if no calculations are available.

The effort given for collection and estimation of each cost element has to be in proportion to its overall importance in cost calculations (Uusi-Rauva, 1989). Rational cost accounting starts from the most significant (I have used earlier in chapter 4.3 the term 'important' instead of significant) costs. Important costs (process which has a quantitatively large material flow input and/or has high average costs/unit; see definition more closely in chapter 4.3)



need to be more exactly assessed whilst for less important costs a rougher estimate can be sufficient.

An important distinction between long and short term cost accounting is in the definition of fixed and variable costs. In short term, there is a clear difference between fixed and variable costs. Fixed costs are the costs that do not vary with output level and variable costs the costs that do change with output level (Begg et al., 1991). In long run, all the costs become variable because also the short term fixed elements (e.g. the capital investments) can (and must) be adjusted. In short term calculations investment costs of existing plants and machinery are given and do not require any special assessments. In long term, instead, different investment options have to be compared and the costs of each option have to be estimated. Investment accounting methods are used for this purpose.

The determination of the used interest rate and the operating period for investment calculations can have significant impact on the results. If there is any uncertainty about the significance of these choices, it would be recommendable to run a sensitivity analysis using different interest rates and operating periods (see more about sensitivity and sensitivity tests in the next chapter 6.1).

One central problem within long term scenarios is the discounting of future costs/benefits. Discounting becomes an extremely important issue when the time horizon of the cost assessment is very long. In the case of landfills, for example, the time horizon for the estimation of both environmental and economic impacts can be hundreds of years. Despite of the on-going discussion about the 'right' discount rate, there are no straight-forward guidelines about how to determine the used discount rate for economic calculations. The problem is of very ethical nature. In principle, the higher the used discount rate is, the lower is the present value of future costs/benefits. Often a discount rate of 1-3 % is used, but very different, even negative, rates have been applied in some studies. If according to the principles of sustainable development the needs of the future generations are taken into account, the discount rate has to be low. According to Otterström et al. (1998), one fair way to determine the discount rate would be to use the average increase of the global GNP as a basis. This would lead to a discount rate of about 1 %. An uniform discount rate should, however, be used for each compared scenario when discounting the future costs/benefits. (Otterström et al., 1998)

The longer the time perspective of the study, the more uncertain the results of an economic comparison are. It is anyhow important to include all the future elements into the calculations - also the very uncertain ones - because excluding them would probably lead to even more uncertain results. It is extremely important that the decision maker basing his/her decision on a calculation is also familiar with the uncertainties included in the cost comparison. Uncertainties within results (i.e. output data) are discussed in depth in the next chapter (6.3).

## 6 UNCERTAINTY IN MATERIAL AND CASH FLOWS

The reliability of the results has created a lot of discussion in material flow modelling. It certainly is an important topic that should be given thought to when assessing the results of studies based on this method. Ayres (1994) has noted: "...uncertainty is a fact of life in all matters pertaining to the physical world. All physical measurements are uncertain to some degree." Uncertainty exists where there are several possible outcomes, but there is little previous statistical evidence to enable the possible outcomes to be predicted (Drury, 1992).

Weidema (1997) has described the dual, complex relationship of data coverage and uncertainty in the context of Life Cycle Assessment: "*The ambition of LCA is to include all environmental problems in all stages of the product life cycle. At the same time, this is the Achilles' heel of LCA, especially because the uncertainties of the results become very large compared to the more narrow analyses. The more data and assumptions, the larger the uncertainties.*" In material flow models uncertainty can be associated with input data or output data or it can occur as sensitivity within the system. A lot has been written about sensitivity tests within the area of material flow modelling, but uncertainty in input and/or output data has gained much less attention. These three basic sources of uncertainty will be discussed in the next chapters (6.1, 6.2 and 6.3).

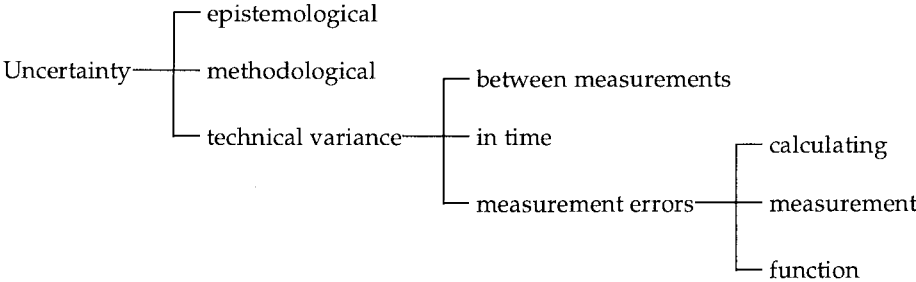


FIGURE 8 Different types of data uncertainty (Nordic Council of Ministers 1995)

Different types of data uncertainty contributing to the overall uncertainty in relation to LCA have been specified in the Nordic Guidelines on Life-Cycle Assessment (Nordic Council of Ministers 1995). These are presented in figure 8.

## 6.1 Sensitivity

Steen (1997) describes sensitivity as a derivative  $\delta y/\delta x$ , where  $y$  represents the result and  $x$  any input parameter. The parameter  $y$  varies with  $x$  according to the derivative. Typically, a sensitivity analysis is conducted by evaluating the range of uncertainty in the input data and recalculating the model's output to see the effect (Vigon et al., 1994). Values of such input parameters for which the results are very sensitive should be defined very carefully because errors in them cause great errors in the results. E.g. if the system seems to be very sensitive to the used interest rate, sensitivity analysis on different levels of interest rate should be run and special attention should be paid to the selection of the applied rate. Whenever there are uncertainties about the data quality it is possible to evaluate the reliability of the results using sensitivity tests. In such tests it is possible to see how dependent the results are on the used data (see e.g. Jönson 1996 or Wenzel et al. 1997).

The results of a sensitivity analysis should provide clear justification for a decision, even if there are uncertainties in the input data. The sensitivity analysis should demonstrate whether or not these uncertainties really matter to the decision. In addition, the analysis should provide documentation to explain why the decision is appropriate, as well as indicating how the decision might change if some of the key assumptions or elements should change in the future. (Cohan, 1996)

According to Weidema (1997) sensitivity analysis should also be used during the study to determine the system boundaries, i.e. the parts of the product systems which shall be included and the parts which may be excluded from further analysis on the grounds of insignificance. This kind of sensitivity analysis should be carried out for mass and energy flows (as well as economic variables when they are included in the study) and in comparative studies also for all important environmental parameters or data categories.

Sensitivity analysis has, however, also a number of serious limitations. In particular, the method requires that changes in each key variable is isolated. Usually decision makers are more interested in the combination of the effects of changes in two or more key variables. In addition, the method gives no indication of the probability of key variables or a combination of these variables occurring. (Drury, 1992)

## 6.2 Uncertainty in input data

Uncertainty in input data refers to the uncertainty associated with the determination of a parameter value in the system.

In material flow modelling, as well as in economic calculations connected to it, there are three basic sources for input data:

1. Site specific data
2. Average data (of an industry, country etc.)
3. Marginal data

All of these data sources have different features concerning the uncertainty of the data and therefore each of these three groups will be discussed separately in the next three chapters.

### 6.2.1 Site specific data

Site specific data is the most adequate and natural choice when the scope of the study is limited to a certain site. In some applications, the locations of the various processes in the system are to a wide extent fixed and known, e.g. for LCAs used in marketing of a specific product. In such applications there is a need and a possibility to include site specific data, because the decision will affect the specific product/process (Wenzel, 1998). If exact data through measurements or other data collection methods is available, site specific data can be regarded as data which does not include major uncertainties. The possible sources of uncertainty should, however, be eliminated also in the case of site specific data. One typical problem with site specific data is that often only a limited number of parameters are measured at the specific site which then leads to data gaps (Lindfors et al., 1995). In order to find information about all relevant parameters it is therefore often necessary to use literature data to complement these gaps. Weidema (1997) has given guidelines about things that should be given thought to when assessing the quality of site specific data:

- Reference unit
- What the data includes (the definition of the processes, whether the data includes only normal operating conditions or also shut-down/start-up conditions and reasonably foreseeable emergency situations)
- Geographical location of the site
- The applied technology
- Data relevant for the allocation if the site produces more than one product
- The period of data collection and how it has been collected

Lindfors et al. (1995) have also noted that, in case of LCA, if the studied product is produced at only one site, it is data from this site that is relevant for the study. They continue, that if the product can be produced at several sites, it is the weighted average of these sites that is relevant data in this case. This brings us to next type of data: average data.

### 6.2.2 Average data

As was discussed above, Lindfors et al. (1995) claim that the ideal data in LCA is a weighted average of site specific data from all relevant sites. The input values of material flow studies are most typically average values from the past, which can lead to major misinterpretations, especially when the studied system is part of very dynamic environment where rapid development and movements are common.

Linear data, based on historical average data, is usually used for calculations in material flow modelling. Linear data refers to a situation where the input parameter value is considered to be constant over time. In reality, however, technology develops continuously, causing changes in the input parameter values over time. As Weidema (1997) has claimed "*Technology develops with time and often becomes more environmentally benign. The choice of technology is therefore of great importance for the results of the life cycle assessment.*" He suggests distinguishing between several technologies:

- *Worst technology* (the technology which will give the largest environmental improvement if it was taken out of use)
- *Average technology* (the technology which is easiest to obtain information on from statistics and handbooks)
- *Modern technology* (the technology installed today by most enterprises when new investments are made - also known as BATNEEC, Best Available Technology Not Entailing Excessive Costs)
- *Marginal technology* (the technology which is taken into use or taken out of use if the produced amounts are increased or reduced, respectively)
- *Best available technology* (the technology which is relevant to use as a basis for comparison if the investigation has a slightly longer time horizon or is directed towards particularly environmentally conscious enterprises or consumers)
- *Best technically possible technology* (the technology which is not yet installed anywhere, but for which adequate information is available to calculate the potential environmental impacts)

The use of linear data could be defined as one type of technical variance in time contributing to errors in results in figure 8. Environmental policy, consumption patterns or other changes in the market can also be responsible for non-proportionally developing, non-linear input parameters. Temporal correlation represents the correlation between the time period relevant for the study and the age of obtained data. Weidema (1997) argues that as technology

develops very fast in some sectors of industry, 10 years' difference between the year of study and the year of data might cause the emissions and the production efficiency to be totally changed. In some cases the changes in parameter values can be extremely rapid and quantitatively significant, and thus the use of past average data may lead to significant misinterpretations. Especially in the case of dynamic material flow modelling the use of linear data can cause major errors in the results.

Use of linear data adds an extra error into the model. The ISO 14040 standard concerning environmental management, life cycle assessment and their principles and framework sets specific requirements for the quality of input data needed for the study. According to the standard *"Data quality requirements shall be defined to enable the goals and scope of the LCA study to be met. The data quality requirements should address: time-related coverage; geographical coverage; technology coverage; precision, completeness and representativeness of the data; consistency and reproducibility of the methods used throughout the LCA; sources of the data and their representativeness and uncertainty of the information."* (CEN 1997) In these requirements the importance of time-related and technology coverage of data is stressed, which in principle promotes the use of non-linear data within LCA research.

Linear input data is, however, still mostly used for calculations in material flow modelling. The presented examples in article 2, however, clearly show that the use of linear data can be a major source of error in the results and can thus have a strong influence on the reliability of dynamic material flow modelling. In the cases in article 2 the differences between the amounts of the studied emissions (COD<sub>cr</sub>, Tot P, SO<sub>2</sub> and NO<sub>x</sub>) in the linear and non-linear scenarios were about 50 % depending on the studied compound, and the error in waste management costs in the linear scenario compared to the non-linear scenario was 21 %. These findings strongly suggest that in dynamic material flow modelling the use of non-linear data - whenever it is available - should be promoted.

There can be several factors responsible for non-linear, non-proportional development of input parameters. In article 2 the non-linear development in the amount of emissions per ton paper produced is an example of technology change with extremely strong implications for the input parameter values. Two different reasons for non-linear behaviour of average costs were presented in the same article in the case of economic assessment: rising average collection costs, which are assumed to increase when the collection rate of paper rises as an example of a change caused by development in the scale of operations, and rising average landfill costs as an example of a change due to environmental policy.

### 6.2.3 Marginal data

Economists traditionally define various concepts using marginal thinking. Marginals represent the increase in output (whether output is e.g. costs, revenue or products) obtained by adding 1 unit of the variable factor, holding

constant the input of all other factors. Marginal concepts in economics include marginal costs and revenues, marginal product, marginal utility, marginal propensity to consume etc. A typical real life example of the use of marginals is the marginal rate of tax which refers to rising rate of tax with an increase in incomes. The most common marginal concepts in economics are (about marginals in economics see e.g. Begg et al., 1991, Drury, 1992, Pekkarinen & Sutela, 1986 or Varian, 1987):

- *Marginal cost* is the increase in total cost when output is increased by 1 unit.
- *Marginal revenue* is the increase in total revenue when output is increased by 1 unit.
- The *marginal product* of a variable factor is the increase in output obtained by adding 1 unit of the variable factor.
- *Marginal utility* is the increase in the total perceived utility of consumer when consumption is increased by 1 unit.

As an example of the use of marginal concepts I will discuss briefly the applications of marginal costs and revenues - the two most commonly used marginal concepts within economics. Economists use marginal costs and revenues as a tool to optimise the output level of a company. In summary, a profit-maximising firm should expand output so long as marginal revenue exceeds marginal cost but should stop expanding as soon as marginal cost exceeds marginal revenue. This rule guides the firm to the best positive level of output.

The use of marginal costs and revenues is, however, not enough for economic calculations. There are three basic costs (total, marginal and average) which are all important and essential for cost calculations. To determine whether the optimal level of output brings profit for the company and whether it should produce at all information about average costs is needed. This is illustrated in figure 9. The company chooses its output level at the point A where marginal revenue (MR) equals to marginal cost (MC). Then it has to check whether it is making losses at the output level Q. If price is equal to or more than average cost (AC), average cost corresponding to output level Q, the firm is not making losses and stays in business. If, instead, price is less than average cost, the firm's output decision should be zero and it should close down.

Average costs are also needed to calculate the total costs of production. In figure 9 the total costs are  $Q \times P$  which can also be illustrated by the area limited by the axes and the dashed lines.

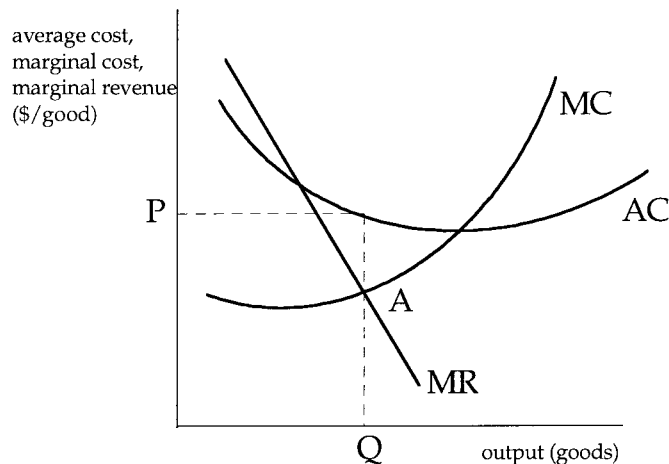


FIGURE 9 The company's output decision and total costs of production

Marginal technology in LCA is defined as the technology actually affected by a small change in demand (Weidema et al., 1998). The definition of marginal technology as such is fully in line with the concept of marginals from economics. This definition, however, includes an inherent assumption that the capacity of the existing processes and technologies under study is 100 % loaded in the present situation and in case of any changes in the demand - even small ones! - new capacity and investments would be needed or some of the existing production sites would immediately be closed down. This assumption does not correspond to the real world. All production sites, processes, technologies etc. are not running with fully loaded capacity. Actually, I would claim that most production sites use something less than the full 100 % of their capacities. This means that small changes (to which is referred in the definition of marginal technologies) do not usually have any effect on the choices of technologies or investments but, instead, they are covered within the limits of present capacity.

Frischknecht (1998) has identified two different meanings of the term marginal in LCA: marginal technology or technology mixes (change in production capacity) and marginal requirements and emissions (change in capacity load). This division corresponds to what I have discussed above about the assumptions about capacity load. However, Frischknecht claims that marginal technology should be applied in LCAs and does not discuss the consequences of its use in his second case (change in capacity load). It is possible and even probable that the rate of capacity load has implications to emissions, costs etc. Unfortunately, exact information about the changes in any output due to changes in capacity load is rarely available about processes. Thus the best and most reliable available data in most cases is actually average data.

There seems to be slight uncertainty about the correct applications of the use of data from marginal technology, which in LCA is referred to as marginal



data. Data collected from marginal technology should only be used when evaluating the small scale changes in the studied systems (as in economics in the case of increase/decrease of 1 unit in output) and if it is correct to assume that there is no unused present capacity. Marginal data should never be used when calculating the total impacts of the system, e.g. total emissions (cf. total costs in economics). Also Frischknecht (1998) has stated that the results from marginal analyses should not be used to explain the environmental impacts of all activities. Average data is needed for this purpose and therefore marginal data cannot eliminate the need for average data. Marginal and average data serve for different purposes and marginal data cannot be used instead of average data but as an addition to it in very specified cases and in comparative LCAs only. This should always be stressed when the concept marginal data is used within LCA. Otherwise it will lead to incorrect use of marginal data in such applications where average data would be the correct choice. The incorrect use of marginal data, in turn, can cause significant errors in the results of a study because the marginal and average data values often are quite far from each other (e.g. the gap between preferred and least-preferred technology from the average).

Wenzel (1998) claims that data for the various processes of the modelled system should always represent the marginal technology, because the marginal technology is per definition the one that is changed due to the decision in question. Frischknecht (1998) shares Wenzel's opinion by stating that any change in demand, either short or long term, should be compensated for by marginal technologies which, however, may be different depending on the time horizon. Based on what was discussed above, it is not so straightforward to claim that marginal data would *always* be the right choice. Instead, as a conclusion, the choice between marginal and average data depends on the scope of the actual study. When the purpose of the study is to evaluate future options it is relevant to use marginal data to cover the changes from the present status. When, instead, minor changes within the existing system are studied, it is more relevant to use the average data. (see also Lindfors et al., 1995)

### 6.3 Uncertainty in output data

The results of a material flow model can hardly ever be made 100 % reliable, which refers to the uncertainty in output data. The results present forecasts of the future in often very complex situations based on past data. Even the best forecasts based on one single result value can usually be interpreted as expected values of the variables presenting the future (Vartia 1994). Decisions have to be made in a situation usually including remarkable uncertainty and based on not always so reliable forecasts. Because of this it is particularly important that the decision maker is fully aware of the uncertainty of the system and forecasts.

In material flow studies the use of intervals in the results (and data) instead of single point forecasts could offer a more reliable and truthful picture

about the results of the studied system. An interval offers the decision maker a range of possible outcomes and presents better the level of uncertainty than a single point forecast. In material flow modelling the use of intervals in data as well as in the results could therefore be considered. Azapagic & Clift (1997) have also encouraged the use of ranges of values instead of 'magic numbers'. They suggest to present the results of a study indicating the minimum and maximum values as well as the 5th percentile (value in the data set for which 5 % of the values are below it) and the 95th percentile (value in the data set for which 5 % of the values are above it).

Azapagic & Clift (1998) base their method on Monte Carlo method, which is an approach developed for risk assessment purposes to build summary indicators accounting for uncertainty in a quantitative fashion. The Monte Carlo method re-calculates the final results a large number of times, with each calculation making use of a value for each uncertain parameter which is drawn at random from the specified input distribution. After repeating this process several hundreds of times, the distribution of the final results can be plotted, providing a reasonably stable approximation for the shape of the output variable's distribution which would have to be obtained from an infinite number of such trials.

Steen (1997) has also pointed out how important it is to clearly state the uncertainty associated with the results. He has chosen another approach to the same problem. According to him there are two main reasons as to why using uncertainty and sensitivity analysis can improve the credibility of material flow analysis: it may show that the contribution of the uncertain input data to the outcome of the result is small or negligible or it may express the result as a probability, thereby stating the degree of uncertainty. The first point refers to sensitivity and the latter to uncertainty in output data. Steen has chosen to recommend the use of probabilities in presenting the uncertainty in results. The result of a statistical uncertainty analysis will be a confidence interval for the results of the study (Weidema 1997).

Whether intervals or probabilities are a more suitable way of presenting the uncertainty in a single study is a detail to be considered in each case separately. Both do meet the basic purpose of stating to the decision maker how reliable the results are and how remarkable is the uncertainty associated with them. Huijbregts (1998) has noted that in practice it would be very difficult to underpin the uncertainty ranges for the huge number of input parameters involved in a study. Therefore focusing on the key parameter uncertainties will increase the feasibility of the uncertainty analysis and will decrease the validity of the uncertainty analysis only in a limited extent.

## 7 DISCUSSION

I will here discuss two topics which have occupied my mind throughout my research work: first the importance of presenting economic data with material flows and second some comparison about the relationship of environment and economics between the approach I have chosen and environmental accounting.

First, some thoughts will be discussed about the importance of connecting economic data with material flows. Weidema (1997) uses the term 'feasibility assessment' to describe a study which assesses environmental improvement options taking into account also social, technological and/or economic aspects of different options. A feasibility assessment may be made separately or as an integrated part of an environmental assessment. Integrated assessments are also known as technology assessments and according to Weidema they have several advantages. It may be more cost-effective than separate studies (especially in the data collection phase), give a more coherent communication to the management of the results of the assessment and wider aspect to the studied situation. Weidema claims, however, that social, technical or economical objections can be used to prematurely limit the scope of the study and this is an argument to keep the feasibility assessment separate, which would allow the environmental concerns to be communicated in their own right.

I agree with Weidema about the danger which he refers to about premature social, technical or economic limitation of the study at the expense of the environment. But I am anyhow supporting the inclusion of economic (and social) information alongside environmental information. Economic estimates are needed for decision making as well. If there is no integration with the environmental assessment, it will have to be done separately sooner or later. I would be extremely anxious to meet a manager in a decision making situation facing several alternatives who would NOT ask how much they cost! In my opinion it is important that we have the means to offer information on the studied topic from different aspects. Only then we can make well-grounded decisions. The moral dilemma, how the decision makers set priorities between environmental, economic and other information and if environmental considerations are overruled by economic arguments, cannot be solved by not

offering one or the other kind of information. I rather prefer conscious, argued decisions based on all available information - whether environmental, economic or some other aspects then become decisive for the final outcome, at least it is a conscious choice.

The second problematic theme which has given me a hard time throughout my research project was how to define my approach to link environment and economics towards environmental accounting.

The latest phases of the development of accounting include the corporate environmental accounting or green accounting. The first efforts to develop environmental accounting were made in the period of corporate social accounting, of which environmental accounting was considered as a part. While the second wave of environmentalism began in the 1980s, environmental accounting developed as its own discipline in the field of accounting (Niskala, 1993a). Tulenheimo (1995) has defined environmental accounting as follows: "*it is applied both on macroeconomic and microeconomic level. On the macroeconomic level, the work is done to integrate the national accounts with the environmental accounts. On the microeconomic level, both the company internal and external accounting systems are developed to include the environmental matters*".

While the approach to the relationship between environment and economics in environmental accounting begins with the existing corporate accounting systems and has attempted to integrate environmental impacts of the corporate activities into it (see e.g. Niskala, 1993a), I have chosen the opposite direction. My approach is to take a material flow model and integrate economic data into it. Whether these two approaches lead to different kinds of results in real decision making situations, is still unclear to me. But they do have different starting points and certainly order priorities differently. I personally chose to start with the environment and environmental impacts, thus implicitly placing them first; only after environment comes economy. Environmental accountants have, however, also pointed out that environmental accounting alone is not enough, because it is 'only' accounting the environmental impacts and costs. But they do offer a basis for systematic recognising of environmental impacts, which again is needed to control and minimise them (Niskala, 1993b). Niskala (1993b) further argues that one of the central purposes of environmental accounting is to include natural resources as important variables in economic decision making which certainly is an important goal and gives valuable information for the decision maker as well. The famous chicken-and-egg question about and which comes first is thus still left unresolved. The differences in the relationship between environment and economics in the two approaches are obvious. Each instrument tackles only a piece of the larger problem, as is also the case with various material flow techniques. None of them alone can offer a solution to all decision making situations. Correspondingly we probably need both approaches for economic evaluation as well: environmental accounting offering information about the environmental impacts of companies on continual basis and material flows as a tool to assess the environmental impacts of different options in products, industries, nations, and why not even the whole world economy, on a more strategic and long term level.

## 8 CONCLUSIONS

The six research questions defined in the beginning of the study are first discussed separately, and the final conclusion answering the main research problem is then shaped based on these answers.

### **1. How do the concepts of material flow management relate to ones in economic decision making? Could concepts of economic evaluation be defined on the basis of the concepts of material flow analysis?**

The connections of material and cash flows were discussed in depth in chapter 4.1. It was found that the concepts of material flow analysis can be modified for economic models with a few slight changes. The analogy between material and economic flows was clear also when the important and unimportant flows were described in chapter 4.3. and the concepts from material flows were adopted to economic flows.

### **2. Which are the common features and differences in the modelling of ecological and economic flows?**

Common features and differences of the material and economic flows presented in detail in chapter 4.2. were summed up in six statements:

- *Types of cash flows or stock:* Three types of cash flows were separated in connection to material flows (cash flows connected with material or energy flow, cash stocks connected with material stock and immaterial cash flows). In economic accounting cash flows connected with material or energy flow as well as immaterial cash flows are expressed as costs and revenues. For cash stocks connected with material stocks (i.e. investments) established methods of economic cost and investment accounting are used to allocate the investment costs for various

products and periods. In accounting cash stocks are presented in balance sheet as assets.

- *Direction of the flows*: Usually cash flow takes the opposite direction than material flow. There is an exception to this basic rule when a good has negative economic value (e.g. waste). In this case the material and cash flows are to the same direction. In consumption a transformation of economic goods into services and wastes takes place and the economic value of a product changes from positive to negative.
- *Growing entropy of the flows*: Entropy grows in both material and economic flows, but in opposite directions.
- *Input vs. output of a process*: The law of conservation, which states that material input and output are equal for a process, was proved to not be true for economic flows because of value added within economic processes (and value reduced in consumption).
- *Process as a black box*: While process can be considered a black box in material flow modelling, this cannot be applied for economic flows, because input and output of the processes are not equal.
- *Impacts of material and cash flows*: Impacts of material flows are expressed as use of material resources or emission and those of cash flows as costs or revenues.

### **3. Are there differences in the importance of the flows of a system in environmental and economic terms? If yes, are they significant and how should these be identified?**

Quantitatively important material flows (discussed in chapter 4.3.) are not always important in economic terms and vice versa. Some examples of this were also given. Important material flow was defined as one which either is quantitatively large and/or has a high concentration of the studied trace element(s), and an important process for cost analysis as a process which has a quantitatively large material flow input and/or has high average costs (costs/unit). Special attention should be paid to the economically important but environmentally unimportant flows when the economic calculations are based on the material flow models because there may be flows missing from the model which are extremely important in economic terms.

### **4. What are the advantages and restrictions of combining economic variables into material flow models?**

The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data offered by material flow models about the system (i.e. the other half of the required data for economic calculations), its logistics and flows, which in most cases is directly useful for economic calculations.

Cost data for the processes has to be collected and determined separately. The ordinary accounting of a company, however, does not necessarily split

production costs between individual products or processes. It might be difficult or even impossible to determine precisely specific costs of a certain product needed for the economic evaluation.

To make the results of different scenarios of a study comparable, it is extremely important that the basic assumptions (functional unit, system boundary, used interest rate and expected lifetime in investment calculations etc.) concerning each process are equal.

The most relevant danger when using material flow models in economic evaluation relates to the identification of important and unimportant flows. As was discussed in the previous chapter, it is possible that some important flows in economic terms are missing from the material flow model because they have been determined as unimportant on an environmental basis. If they are not included for economic calculations the results of the economic evaluation might have major errors. Therefore it is extremely important to study the system critically before applying it to economic calculations and to add the probably missing processes into the model.

### **5. In studies with a long time horizon, how can the long term costs be estimated? How can the studied scenarios be formulated in material flow modelling?**

The different definitions of scenarios discussed in chapter 5.1 included three common basic elements: the definition of alternative future circumstances, the path from the present to the future, and the inclusion of uncertainty in the concept. Uncertainty is no occasional, temporary phenomenon from a reasonable predictability but, instead, it has become a basic structural feature of the business environment. Scenarios acknowledge uncertainty and aim at structuring and understanding it - but not by merely criss-crossing variables and producing dozens or hundreds of outcomes. Instead, they create a few alternative and internally consistent pathways into the future (Wack, 1985b). Scenarios must help decision makers develop their own feel for the nature of the system, the forces at work within it, the uncertainties that underlie the alternative scenarios, and the concepts useful for interpreting key data (Wack, 1985b).

On the basis of scenario definitions two basic approaches for scenario development in material flow modelling were suggested in chapter 5.2: What if -scenarios and Cornerstone scenarios. What if -scenario is used to gain operational information with a short time horizon and to compare two or more alternatives in a well known situation where researcher is familiar with the decision problem and can set defined hypothesis on the basis of existing data. Cornerstone scenario approach offers strategic information for long term planning, new ways of seeing the world, and also guidelines in the field of study. Results of a study using Cornerstone scenario approach often serve as a basis for further, more specific research where the scenarios can be defined according to What if -scenarios.

In the case of What if -scenarios the economic calculations are usually relatively easy to carry out using the traditional methods of cost accounting

(including cost estimation and investment accounting). Cost accounting becomes problematic when the time horizon and uncertainty of the studied scenarios grow, i.e. when moving towards Cornerstone scenarios. There are no specific guidelines for cost accounting in very long term cases and basically the same cost accounting methods as for shorter term cost accounting apply also here. Future costs can not be measured in absolute terms and thus estimates e.g. based on expert assessments can be used if no calculations are available.

An important distinction between long and short term cost accounting is in the definition of fixed and variable costs. In long run, all the costs become variable because also the short term fixed elements (e.g. the capital investments) can (and must) be adjusted.

#### **6. Which are the reasons for uncertainty in material and cash flows and how should it be dealt with?**

Three different types of uncertainty can be distinguished in material and cash flows: sensitivity, uncertainty in input data and uncertainty in output data. Each of them require different procedures in order to improve the total reliability of the study.

Values of such input parameters for which the results are very sensitive should be defined very carefully because errors in them cause great errors in the results. E.g. if the system seems to be very sensitive to the used interest rate, sensitivity analysis on different levels of interest rate should be run and special attention should be paid to the selection of the applied rate.

Input data can be site specific, average or marginal. Site specific data is the most adequate and natural choice when the scope of the study is limited to a certain site. If exact data through measurements or other data collection methods is available, site specific data can be regarded as data which does not include major uncertainties.

The input values are typically average values from the past, which can lead to major misinterpretations, especially when the studied system is part of very dynamic environment where rapid development and movements are common. Use of linear data adds an extra error into the model. Especially in the case of dynamic material flow models the use of non-linear data, whenever it is available, should be promoted.

Marginal data should only be used when evaluating the small scale changes in the studied systems and if it is correct to assume that there is no unused present capacity. Marginal data should never be used when calculating the total impacts of the system. Marginal and average data serve for different purposes and marginal data cannot be used instead of average data but as an addition to it in very specified cases and in comparative LCAs only. The incorrect use of marginal data can cause significant errors in the results of a study because the marginal and average data values often are quite far from each other. The choice between marginal and average data depends on the scope of the actual study. When the purpose of the study is to evaluate future options it is relevant to use marginal data to cover the changes from the present



status. When, instead, minor changes within the existing system are studied, it is more relevant to use the average data.

It is particularly important that the decision maker is fully aware of the uncertainty of the system and forecasts. The degree of specificity of the results needed is highly dependent upon the scope of the study (Fava et al., 1994). In material flow studies the use of intervals in the results (and data) instead of single point forecasts could offer a more reliable and truthful picture about the results of the studied system. An interval offers the decision maker a range of possible outcomes and presents better the level of uncertainty than a single point forecast. In material flow modelling the use of intervals in data as well as in the results could therefore be considered. Another way is to use the probabilities in presenting the uncertainty in results. Whether intervals or probabilities are a more suitable way of presenting the uncertainty in a single study is a detail to be considered in each case separately. Both do meet the basic purpose of stating to the decision maker how reliable the results are and how remarkable is the uncertainty associated with them.

Answers given to the previous research questions also offer a solution to the main research problem: **How can material flow models be applied in economic decision making?**

In material flow analysis a distinction between two levels of analysis can be made: goods and materials level. The goods level can serve as a basis for several different types of analysis. The approach I suggest here, is to include economic parameters into material flow modelling, i.e. economic assessment would be a sub-system of the goods level and it would be a parallel analysis to substance flow analysis, energy analysis and water balances. For economic analysis the goods level is interesting because the goods have economic value and thus are responsible for cash flows. For environmental analysis, instead, the material level is more important because the materials in goods cause the environmental problems.

The system boundary is defined within the overall goal and scope definition of the study and for economic analysis it does not need to be separately considered. The system boundary also defines which costs/revenues are to be included in economic analysis. Therefore there are no social costs or externalities in the sense of how they are usually defined.

The results of this kind of analysis present results from each sub-system (environmental impacts, economic analysis etc.) separately as absolute figures. It is argued that this is more transparent for the decision maker. No inherent valuation integrating the results of different sub-systems is made and instead, the decision maker will have to face the problem of valuation himself. A number of separate techniques and tools have been developed to provide assistance in multiobjective decision making situations

The suggested approach does not require any new, revolutionary method of cost accounting. Instead, it uses the traditional methods of cost accounting in a broader environment. The effort given for collection and estimation of each cost element has to be in proportion to its overall importance in cost

calculations. Rational cost accounting should therefore start from the most significant costs.

Material flow models have proved to be a powerful tool for environmental decision making and it is argued in this thesis that they also offer a suitable basis for economic evaluation and decision making. The balance between economy and ecology is an ideal situation often repeated in political discussion as well as in the strategic planning of a company. In fact, in most decision making situations we still miss decision aids which could offer information both about environmental and economic impacts of the possible outcomes.

Environmental issues are also business issues and the importance of the cost aspect in environmental protection is definitely increasing in the future, as more developed and expensive technology will be needed. That is why these two decision factors should not be seen or approached separately. Profitability is a basic requirement for any business - and this applies also to environmental management issues. Decisions about environmental protection have to be based on information about what is ecologically justified, technologically possible and economically reasonable (Otterström et al., 1998). This means that we need reliable and effective methods for the assessment of environmental and economic impacts of future decisions for those who are responsible for strategic decision making both in public sector as well as within companies. New approaches to combine environment and economics are needed and material flow analysis complemented with economic assessment as an inherent sub-system are applicable for this purpose.

As Ulhøi (1995) has stated: *"It will no longer be technology which limits the quantity of raw materials available to society - the new limits will be set by nature's own carrying capacity. We have to realise that, ecologically and morally, we can no longer allow ourselves the luxury of thinking about economics and ecology in isolation. We cannot carry on talking about such social problems as energy, environmental, or social problems in isolation - they are all interconnected, and must therefore be seen in a broader perspective."*

## YHTEENVETO (Finnish Summary)

### Materiaalivirroista rahavirtoihin - laajennus perinteisiin materiaalivirtamalleihin

Talouden ja ympäristön tasapaino on ideaalinen tavoite, joka toistuvasti tulee esille niin poliittisessa keskustelussa kuin yritysten strategisessa suunnittelusakin. Meiltä kuitenkin puuttuu vielä pääosin sellaiset päätöksentekoa avustavat työkalut, jotka antaisivat tietoa vaihtoehtojen ympäristöllisistä ja taloudellisista vaikutuksista.

Tuotteiden, yritysten ja teollisuudenalojen ympäristövaikutusten arviointia varten on kehitetty lukuisia erilaisia malleja. Näissä määritellään valitun systeemin prosessit sekä näiden läpi virtaavat tuotteet tai materiaalit ja saatavan tiedon avulla voidaan arvioida syntyvien päästöjen ja jätteiden määrää sekä ohjata virtoja haluttuun suuntaan. Tarkasteltavaksi valitun systeemin rajan sekä analyysin kohteen mukaan näillä malleilla on erilaisia nimityksiä: elinkaarianalyysi (Life Cycle Analysis, LCA) määrittää yhden tuotteen tai teollisuudenalan ympäristövaikutuksia sen koko elinkaaren ajalta, ekotaseet keskittyvät yhden yrityksen ympäristövaikutusten arviointiin ja materiaalivirta-analyysit seuraavat valitun aineen reittejä systeemin läpi. Muita samaan ryhmään kuuluvia metodeja ovat esim. kustannus-hyöty-analyysi, riskianalyysit sekä ns. input-output analyysit. Yhteisesti voidaan puhua materiaalivirtamalleista. Käytetyt materiaalivirtamallit ovat keskittyneet ympäristövaikutusten arviointiin eivätkä ole ottaneet huomioon taloudellisia tai sosiaalisia näkökohtia. Viime aikoina useat tahot, jotka ovat olleet aktiivisesti kehittämässä näitä työkaluja, ovat suositelleet, että myös taloudelliset ja sosiaaliset näkökohdat tulisi kytkeä mukaan materiaalivirtamalleihin.

Tämän tutkimuksen tarkoituksena on ollut tarkastella materiaalivirtamallien soveltuvuutta taloudellisen päätöksenteon välineenä sekä tutkia, mitä mahdollisuuksia on yhdistää taloudellista tietoa materiaalivirtoihin. Tutkimus on kartoittavaa tutkimusta. Tutkimusmetodeina on käytetty sekundääritiedon analysointia sekä case-tutkimusta. Teorianmuodostuksessa löytyy piirteitä sekä deduktiivisesta että induktiivisesta päättelystä: deduktiivista päättelyä on hyödynnetty sekundääritiedon analyysin yhteydessä ja induktiivista case-tutkimuksissa.

Taloudellisen tiedon liittäminen materiaalivirtamalleihin on tutkimuksen mukaan mahdollista ja suositeltavaa. Kustannukset ja tuotot ovat sitä kieltä, mitä yritysjohto käyttää ja taloudellisen tiedon liittäminen ympäristövaikutuksien rinnalle tekee tuloksista ymmärrettävämpiä päätöksentekijöille. Materiaalivirtamalleihin koottu määrällinen tieto raaka-aineista, energiasta, tuotteista, päästöistä, jätteistä jne. on myös suoraan käyttökelpoista taloudellisiin laskelmiin.

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**MATERIAL FLOW MODELS AS A TOOL  
FOR ECOLOGICAL-ECONOMIC DECISION MAKING**

Hanna-Leena Pesonen  
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## **ABSTRACT**

In this paper the applicability of material flow models in economic decision making is discussed. It is further argued that material flow models give a good basis for economic evaluation and decision making. Several arguments supporting this statement are presented and the connections of material and cash flows are discussed in depth. Also, possible restrictions when using material flow models in economic decision making are taken into account. Quantitatively important material flows are not always important in economic terms and vice versa. Some examples of this are given and the connection between material and cash flows is further discussed. The principles of how to identify an economically important flow are presented. Also some ideas about the possibilities of how to deal with uncertainty concerning economic flows are discussed.

## 1 INTRODUCTION

Decision making in environmental management has traditionally concentrated merely on environmental analysis. Many types of quantitative models have been developed to assess the environmental impacts of products/companies/industries. These so-called material flow models are used to measure flows of products or substances through a defined system and to help in decision making on the basis of these inventories and the studied environmental impacts. According to the system boundary and level of the analysis different methods of material flow analysis can be used: Life Cycle Assessment (LCA) measures and assesses environmental impacts of a single product or an industry along its life cycle, eco-balances concentrate on the environmental impacts of a given company and substance flow analysis (SFA) traces the path of a substance through the system.

Recently several bodies (e.g. SETAC, ConAccount and CHAINET) engaged in the development of material flow models have made recommendations about including economic and social variables in these models. E.g. EU Concerted Action Program CHAINET Definition Document (1998) argues that *"European policy has committed itself to the goal of sustainable development. Following this commitment, the European Union has placed its activities within a framework of environmental controls based on the best knowledge available at any particular moment in time. This includes a continuing movement away from an 'end-of-pipe' philosophy of environmental protection (one which, in any case, tended merely to shift problems from one environmental issue to another or from one societal sector to another), towards a new paradigm in which environmental considerations encompass the whole material and energy supply chain and consider the full social and economic structure."*

The EU Concerted Action Program ConAccount has also presented some ideas about further development and application of the material flow analysis methodology. ConAccount recommends analyses of the interlinkages between material flows and economic development and gives a suggestion that a standard framework for analysis should be developed, which should support an assessment of decoupling/recoupling of economic activities and material throughput. (Bringezu et al., 1998)

Houldin (1996) has presented a model including five phases by which accountants can contribute to environmental management. These phases are:

1. Modifying existing accounting systems (as in energy costing)
2. Eliminating conflicting elements of the accounting systems (as in investment appraisal)
3. Planning for financial implications of the environmental agenda (as in capital expenditure projections)
4. Introducing environmental performance to external reporting (as in annual reports)
5. Developing new accounting and information systems (as in eco-balance-sheets)

The approach of combining material and economic flows used in this article is an attempt to introduce a new accounting and information system thus representing the fifth phase of Houldin's model.

## 2 MATERIAL FLOW MODELS AS A BASE FOR ECONOMIC CALCULATIONS

Material flow models are used to describe systems, which take inputs from nature into the anthroposphere in the form of materials or energy, and return outputs as effluents or waste back to nature. Material flow models measure the flows within the anthroposphere and between the anthroposphere and nature. The results of a material flow model can be used to redirect the flows in order to change the inputs and/or outputs to a desired direction. Material flow models offer a tool for early recognition instead of the end-of-pipe solutions used in the past: when the flows within the anthroposphere and between the anthroposphere and nature are known, it is possible to assess the environmental impacts of the system and to plan new solutions based on decreased raw material and energy demand as well as reduced amount of emissions and waste generated.

Material flow models consist of a system of processes and flows of materials between these processes. Process is defined here according to Baccini & Brunner (1991) meaning transport, transformation and change of value of materials and goods. Flows describe transport of products, materials or energy between the processes. A simple example of a material flow system is given in figure 1. Product *u* is an import product to the system and products *v*, *w* and *z* are export products. Product *x* is an output product from process A and an input product of process B. Process A can be defined as the process of origin of product *x* and process B as the process of destination of product *x*.

The above mentioned concepts of environmental material flow analysis can be modified for economic models with some slight changes. In economic terms process A would be the seller of the product *x* and process B the buyer of the same product. Cash flow (price) of the product *x* means revenue for the seller (process A) and costs for the buyer (process B).



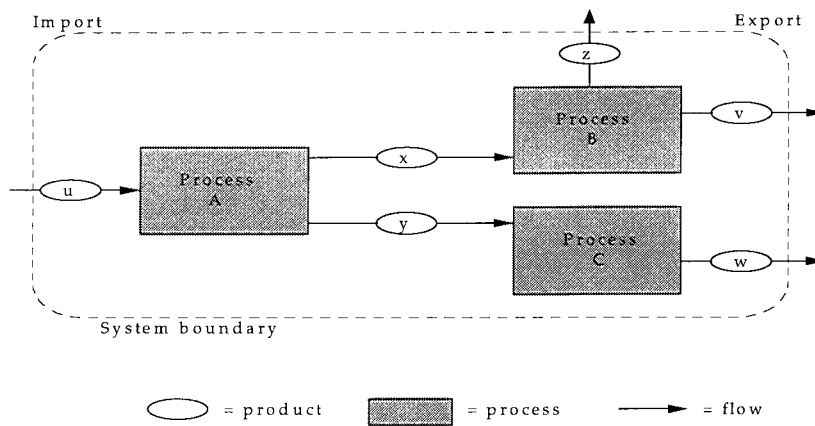


FIGURE 1 Material flow system (see e.g. Baccini & Brunner, 1991 or Daxbeck et al., 1994)

An important argument which supports including economic variables with environmental information is the communicative value of monetary terms. Costs and revenues are concepts of the language used by management responsible for decision making. Speaking of cash, savings and investments translates the environmental information into a more understandable form for the business decision maker (Bundesumweltministerium, 1997).

The discussion of common features and differences in the modelling of ecological and economic flows are further discussed by focusing on six separate issues:

1. Types of cash flows or stock
2. Direction of the flows
3. Growing entropy of the flows
4. Input vs. output of a process
5. Process as a black box
6. Impacts of material and cash flows: emissions and costs

## 2.1 Types of cash flows or stock

Kytzia (1997) has separated three different types of cash flows or stocks in connection with material flows:

1. *Cash flows connected with material or energy flows*: Such cash flows, which are directly connected with a material or energy flow, are included in the material management system.
2. *Cash stocks connected with material stock*: Material accumulated in a given process form a material stock (definition according to Baccini & Brunner, 1991), e.g. real estate, machinery, raw material stocks or

landfill. The value of such a stock has to be estimated in economic terms. The methods of economic cost and investment accounting are used for this purpose.

3. *Immaterial cash flows*: Immaterial cash flows occur in the case of services. This will be discussed more in the next chapter (2.2 Direction of the flows).

## 2.2 Direction of the flows

Cash flows are consequences of market transactions. The buyer pays the seller for a determined product (whether it is a physical product e.g. raw materials or machinery or an immaterial service e.g. financing, waste handling). In the case of a physical product cash flow takes the opposite direction than the material flow in this market transaction. At the same time the ownership of the product is transferred from the seller to the buyer. Other possible flows between processes and their directions are also presented in figure 2, but are not discussed in detail here.

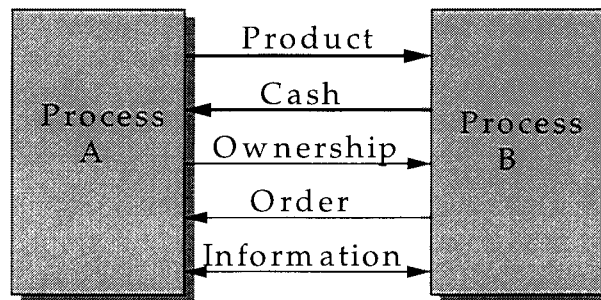


FIGURE 2 Material and cash flows through a process and a system (in the case of transaction of a physical product)

Services usually do not include any material flow (e.g. in the case of financing or insurance) but there are services where some material activities are included. An example of this could be waste management. Waste management company is offering the service of "getting rid of the waste" to the buyer. This service includes material flow of waste from the buyer to the seller. In the case of services the possible material flow is in the same direction as the cash flow (as in the previous example of waste management involving waste and payment).

As material flow models concentrate on flows of physical products, the material and cash flows through one single process have, in most cases, opposite directions.

### 2.3 Growing entropy of the flows

The first two laws of thermodynamics are often used to explain the basic nature of material flow models. According to the second law of thermodynamics entropy increases in the system. This means that the substances and materials are refined, mixed and distributed during the material flow so that in the end one single substance is almost impossible to trace and separate. When a substance or a material is being imported to the system it is more or less one consistent flow. Along the flow through the system it is spread over the whole system to various processes, possibly recycled etc.; finally in the export products of the system different import materials together compose very complex compounds.

This is also true for cash flows. The payment for a product is further divided to subcontractors, raw material suppliers, financiers etc. Even though the directions of the material and cash flows are opposite the second law of thermodynamics applies in both cases.

### 2.4 Input vs. output of a process

The first law of thermodynamics (i.e. the principle that the amount of material and energy remains constant at any flow or process in a system) claims that the input and output of a process must be equal. For the material as well as energy flows this is true. For cash flows, however, this does not apply. In each process some value is added to the product. Riahi-Belkaoui & Fekrat (1994) define the concept of value added as "a measure of the total return generated in a firm through the utilisation of its productive capacity, i.e. labour and capital in the broad classical sense". Because of the value added within a process the input of cash flow has to be larger than the output. Output refers to expenses of bought-in materials and services, and input to the sales revenue. Input - output gives the value added within one process. In reality, cash input does not always exceed output in the short run, but if the company is to stay alive, in the long run this has to be the case.

What is discussed above concerning the input vs. output of a single process also applies to the whole system. Import and export of the system must be equal for material flows. Correspondingly, as a consequence of the value added in the processes, the economic export flow of the system exceeds the import flow.

## **2.5 Process as a black box**

In the definitions of material flow models processes are considered to be black boxes. What is happening inside the process is not considered important; instead attention is paid to the output of a process. For material flows this practice is suitable because input and output are equal. If the transfer coefficients are known, outputs can be determined and it is not necessary to study the process into detail.

In the case of cash flows the process has to be taken into account. As discussed above, a process is an active part of the system which adds value to the product during its production. Value is added within the process and so it cannot be seen as a black box when studying cash flows. Instead, it has to be well known.

## **2.6 Impacts of material and cash flows: emissions and costs**

The outputs of each process in material flows are products (which were the actual goals of production and have some economic value), by-products (unintended products of production which also have some economic value) and/or emissions (uncontrollable or unintended products with no or negative economic value). Emissions (to air, water or ground) are studied when trying to assess the impacts of the material flows of a system. The processes themselves do not cause any environmental impact but the material flows do.

The impacts of cash flows are expressed as costs. Costs in turn are caused by the processes; not the cash flows. Processes add value to the product (and to the system) and cause costs.

### 3 MATERIAL FLOW MODELS OFFERING QUANTITATIVE DATA FOR ECONOMIC ANALYSIS

The basic data needed for economic calculations of one single process are quantity (q) and price (p) of the product. Total costs for one process are:

$$TC_{\text{process } x} = q_{\text{process } x} \times p_{\text{process } x}$$

Correspondingly, the total costs of a built up system in a material flow model can be calculated. When the costs of each process are known, adding these together will give us the total costs of a system (for instance total manufacturing costs of a product):

$$TC_{\text{system}} = TC_{\text{process } 1} + TC_{\text{process } 2} + \dots + TC_{\text{process } x}$$

(where x = number of processes).

Average costs of a system can also be calculated by dividing the sum of the costs of each process by the amount of import material to the system:

$$AC_{\text{system}} = \Sigma \text{process } 1 \dots x / q_{\text{import}}$$

As discussed above material flows offer quantitative data (which in most cases is directly useful for economic calculation) about the studied system. Cost data for the processes has to be collected and determined separately.

## 4 IMPORTANT PROCESSES AND FLOWS

It is a common goal for material and cash flow analysis to identify the important flows of a system. The systems of material flow models are usually so complex that it would not be possible or reasonable to build it up using every single detail. It is therefore important to identify the central processes and flows.

Brunner et al. (1996) gives a guideline as to how to limit the number of material flows: such flows which make less than 1 % of the largest flow in the system should not be included in the study. For some research settings it is anyhow essential to also include these very small flows. Certain substances can for example cause severe impacts in very small concentrations. It is also possible that a studied element (e.g. zinc) is only to be found in these smallest flows. The absence of these small flows would in this case make the whole study impossible.

Important material flow could be defined as one which either is quantitatively large and/or has high concentration of the studied trace element(s). Correspondingly, an important process for cost analysis could be defined as a process which has a quantitatively large material flow input and/or has high average costs (costs/unit). If the flow is very small in amount even the highest average costs do not make it important in economic terms.

Important flows in material terms are not always important economically and vice versa. Figure 3 presents the possible connections of these two flows.

Some examples of different connections of material and cash flows in waste management:

- Waste incineration and landfilling are clearly such processes which have importance to both material flows and cash flows (case 1 in figure 3). First of all they are processes which typically have quantitatively large input flows in waste management. Both have several output flows which have extremely important environmental impacts causing emissions to air, water and ground. The concentrations of these flows no doubt make them central for material flow analysis. Also the average costs (waste management costs/ton waste) are relatively high

in both cases which means that they must be considered in cost calculations as well.

- The filter ashes from waste incineration and their final storage is an example of a case which is extremely important in environmental terms but has no special significance for economic considerations (case 2 in figure 3). The amounts of the filter ashes from waste incineration are very small (only about 0,2 % of the input material). Thus it can be described as a quantitatively unimportant flow. Even though the average costs of the final storage are very high (e.g. in Germany around 1.000 DEM/ton), it has no significant impact on the system's costs because the flow itself is so very small. However, because of the very high concentrations of heavy metals in the filter ashes it has most important environmental impacts and it is absolutely necessary to include it in the material flow analysis.
- Collection of household waste is a good example of an important process economically but not environmentally (case 3 in figure 3). Even though the flow is relatively large it does not cause significant emissions and is thus not very interesting for environmental assessment. While this process, however, has relatively high average costs it would be a mistake not to include it in economic calculations.
- Unimportant in both the environmental and economic sense (case 4 in figure 3) would be a flow of biowaste composting in private gardens. It is a relatively small flow quantitatively, it does not cause significant environmental impacts and the average costs are also relatively unimportant. E.g. in a study of the waste management system at the national level, it would not mean any significant difference in the results in either environmental or economic terms whether this flow is included in the system or not.

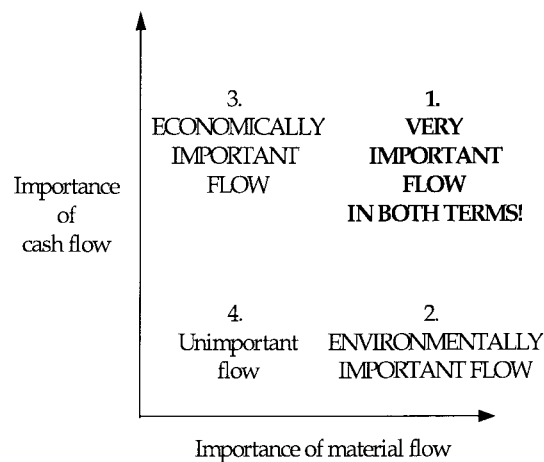


FIGURE 3 Connections of material and cash flows

## 5 DEALING WITH UNCERTAINTY CONCERNING ECONOMIC FLOWS

Reliability of the results has created a lot of discussion in material flow modelling. It is an important topic that should be given thought to when assessing the results of studies based on this method. That is why some aspects of uncertainty concerning the economic data and results in material flow modelling are also discussed here.

Steen (1997) has separated three issues concerning the reliability of material flow models: sensitivity, uncertainty in input data and uncertainty in output data. He describes sensitivity as a derivative  $\delta y / \delta x$ , where  $y$  presents the result and  $x$  any input parameter. The parameter  $y$  changes with  $x$  according to the derivative. Values of such input parameters for which the results are very sensitive should be defined very carefully because errors in them cause great errors in the results. E.g. if the system seems to be very sensitive to the used interest rate, sensitivity analysis on different levels of interest rate should be run and special attention should be paid to the selection of the applied interest rate. Whenever there are uncertainties about the data quality it is possible to evaluate the reliability of the results using sensitivity tests. In such tests it is possible to see how dependent the results are on the used data (see e.g. Jönson, 1996 or Wenzel et al., 1997).

Uncertainty of input data refers to the uncertainty associated with the determination of a parameter value in the system. The input values are typically average values from the past. Use of linear data also adds an extra error into the model. Especially in the case of dynamic material flow models the use of non-linear data, whenever it is available, should be promoted (see e.g. Pesonen et al., 1998).

The results of a material flow model can hardly ever be made 100 % reliable. They present forecasts of the future in often very complex situations based on past data. Even the best forecasts based on one single result value can usually be interpreted as expected values of the variables presenting the future (Vartia, 1994). Economic decisions have to be made in a situation usually including remarkable uncertainty and based on not always so reliable forecasts.



Because of this it is particularly important that the decision maker is fully aware of the uncertainty of the system and forecasts. In material flow studies the use of intervals in the results (and data) instead of single point forecasts could offer a more reliable and truthful picture about the results of the studied system. An interval offers the decision maker a range of possible outcomes and presents better the level of uncertainty than a single point forecast. In the case of economic flow modelling special attention should therefore be paid to the use of intervals in data as well as in the results.

## 6 CONCLUSIONS

The balance between economy and ecology is an ideal situation often repeated in the political discussion as well as in the strategic planning of a company. In reality, however, the technically or scientifically best solutions supporting the idea of sustainable development are often rejected by economists because these solutions are extremely expensive in economic terms. In fact, in most decision making situations we still miss decision aids which could offer information both about environmental and economic impacts of the possible outcomes.

Environmental issues are anyhow also business issues and the importance of the cost aspect in environmental protection is definitely increasing in the future as more developed and expensive technology will be needed. That is why these two decision factors should not be seen or approached separately. New approaches to combine environment and economics are needed. Material flow models have proved to be a powerful tool for environmental decision making and this paper argues that they also offer a suitable basis for economic evaluation. The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data offered by material flow models about the system, its logistics and flows, which in most cases is directly useful for economic calculations.

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**NON-LINEAR DATA IMPROVING  
THE RELIABILITY OF THE RESULTS  
OF DYNAMIC MATERIAL FLOW ANALYSIS**

Hanna-Leena Pesonen  
Will be published later in 1999



## **ABSTRACT**

The reliability of the results has created a lot of discussion in material flow modelling. This article concentrates on selected issues concerning uncertainty of input data, which refers to the uncertainty associated with the determination of a parameter value in the system. One important, but not yet widely discussed, aspect affecting the reliability of material flow models is the use of linear or non-linear data in input data. The input values of material flow models are typically average values from the past, which can lead to major misinterpretations in the results. Two examples are presented, where both linear and non-linear input data is used and their impacts on the results are compared. These findings strongly suggest, that in dynamic material flow modelling the use of non-linear data - whenever it is available - should be promoted.

## 1 INTRODUCTION

While the importance of environmental protection has gained increasing attention, different tools of environmental management have been developed to assess the environmental impacts of products/companies/industries: environmental auditing, environmental impact assessment, life cycle assessment, risk assessment, cost benefit analysis, input-output analysis etc. Several quantitative models are used to measure flows of products or substances through a defined system and to help in decision making on the basis of these inventories and the studied environmental impacts. According to the system boundary and level of the analysis, different methods of material flow analysis can be used: Life Cycle Assessment (LCA) measures and assesses environmental impacts of a single product or an industry along its life cycle, eco-balances concentrate on the environmental impacts of a given company and substance flow analysis (SFA) traces the path of a selected substance through the system.

The reliability of the results has created a lot of discussion in material flow modelling. It certainly is an important topic that should be given thought to when assessing the results of studies based on this method. Ayres (1994) has noted: *"...uncertainty is a fact of life in all matters pertaining to the physical world. All physical measurements are uncertain to some degree."* Weidema (1997) has described the dual, complex relationship of data coverage and uncertainty in the context of Life Cycle Assessment: *"The ambition of LCA is to include all environmental problems in all stages of the product life cycle. At the same time, this is the Achilles' heel of LCA, especially because the uncertainties of the results become very large compared to the more narrow analyses. The more data and assumptions, the larger the uncertainties."* In material flow models uncertainty can be associated with input data or output data or it can occur as sensitivity within the system. A lot has been written about sensitivity tests within the area of material flow modelling, but uncertainty in input and/or output data has gained much less attention. This article discusses issues concerning uncertainty in input data, which refers to the uncertainty associated with the determination of a parameter value in the system.



## 2 MATERIAL FLOW MODELS

Material flow models are used to describe systems which take inputs from nature into the anthroposphere in the form of materials or energy, and return outputs as effluents or waste back to nature. Material flow models measure the flows both within the anthroposphere and between the anthroposphere and nature. The results of a material flow model can be used to redirect the input and/or output flows to a desired direction. Material flow models offer a tool for early recognition instead of the end-of-pipe solutions used in the past: when the flows within the anthroposphere and between the anthroposphere and nature are known, it is possible to assess the environmental impacts of the system and to plan new solutions based on decreased raw material and energy demand as well as reduced generation of emissions and waste. (Pesonen 1998a)

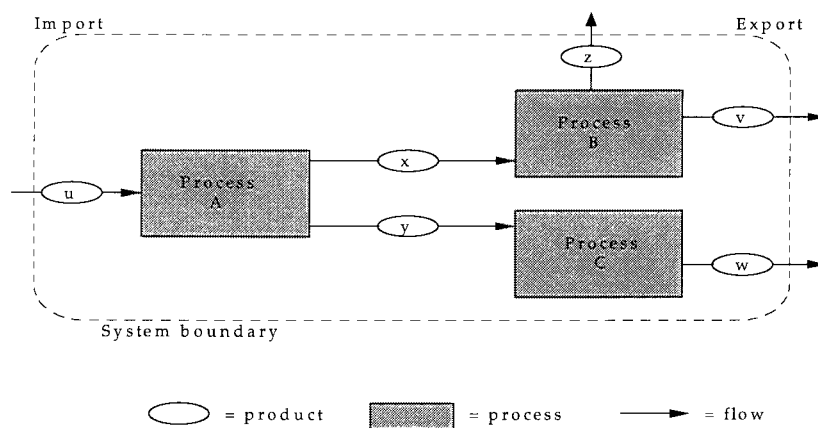


FIGURE 1 Material flow system (see e.g. Baccini & Brunner 1991 or Daxbeck et al. 1994)

Material flow models consist of a system of processes, and the flows of materials between these processes. 'Process' is defined here according to Baccini & Brunner (1991) as meaning transport, transformation and change of

value of materials and goods. 'Flows' describe transport of products, materials or energy between the processes. A simple example of a material flow system is given in figure 1. Product *u* is an import product to the system and products *v*, *w* and *z* are export products. Product *x* is an output product from process A and an input product of process B. Process A can be defined as the process of origin of product *x* and process B as the process of destination of product *x*. (Pesonen 1998a)

## 2.1 Static vs. dynamic material flow models

Static material flow models calculate the input and output of the defined system for some specific time period, typically one year. They analyse the environmental impacts of the studied system at a given moment in a static situation using historical average data and are applicable to environmental planning when identifying the areas of improvement. They, however, fail to assess the development of the system over time. The basic idea of material flow models is to collect quantified data to help redirect the flows in a more sustainable direction. Static models can identify the problem areas but cannot be used to assess different policy options and their impacts on the determined problems. Static models can well be used to improve and compare different product or process variations in order to develop them to be more environmentally friendly. They can also be of help as an inventory to assess the environmental impacts of a company's entire production at a certain time (Gronow 1996).

Dynamic material flow models are a more powerful tool for material flow management than static models because they include the aspect of time into the system, and can thus predict the changes of the system within a given period of time in the future. They are suitable for long term analysis and planning. Even in the short term, in systems where product mix or product contents evolve rapidly (due to technology development, rapid changes in markets e.g. in consumption or supply of raw materials, capacity changes etc.), a dynamic material flow model is more suitable alternative than static one (Gronow 1996). Static material flow models can be used to calculate effluents, energy and materials used and produced in a system in a static situation; dynamic models offer the possibility to simulate the effects of changes in environmental policy, technology, consumption patterns etc. over a given period of time in the future. An instrument for forecasting the future effects of different policy options is also needed in environmental planning. Dynamic models offer a powerful tool for this purpose, whilst the traditional static models are not able to meet these needs. With dynamic material flow models it is possible to assess different future scenarios and their impacts in the future.

Gronow (1996) has compared the applicability of static and dynamic material flow models. He claims that dynamic material flow models should be preferred in environmental policy planning on a national or industry level. Static models, instead, are applicable in a national context only when the scope

of the inventory is related to a single product, service or process and in stable situations when historical data is reliable. Static models should be used in national environmental planning only in very limited cases. If the interest of the policy maker is on the future development of material flows or on the effects of a particular action, a dynamic model is to be preferred.

## 2.2 Material flow models offering quantitative data for economic analysis

The balance between economy and ecology is an ideal situation often repeated in political discussion as well as in the strategic planning of a company. In reality, however, the technically or scientifically best solutions supporting the idea of sustainable development are often rejected by economists because these solutions are extremely expensive in economic terms. In fact, in most decision making situations we still miss decision aids which could offer information about both the environmental and economic impacts of the possible outcomes. Environmental issues are also business issues, and the importance of the cost aspect in environmental protection is definitely increasing in the future as more developed and expensive technology will be needed. That is why these two decision factors should not be seen or approached separately. New approaches to combine environment and economics are needed. Material flow models have proved to be a powerful tool for environmental decision making and they also offer a suitable basis for economic evaluation and decision making. (Pesonen 1998a)

The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data produced about the system, its logistics and flows, which in most cases is directly useful for economic calculations (Pesonen 1998a). Figure 2 presents the transactions between company and environment (Müller 1993). Impact of companies on the environment typically includes such flows as wastes and emissions. The environment, in turn, is the source of raw materials and energy to the economy.

Direction of transaction	To economy	To environment
From economy	Products and services	Emissions and wastes
From environment	Raw materials and energy	Ecology

FIGURE 2 Transactions between economy and environment (Müller 1993)

An important argument supporting the linking of economic variables to environmental information is the communicative value of monetary terms. Costs and revenues are concepts of the language used by management responsible for decision making. Speaking in terms of cash, savings and investments translates the environmental information into more

understandable form for the business decision maker (Bundesumweltministerium 1997).

The concepts of environmental material flow analysis can be modified for economic models with some slight changes. In economic terms process of origin would be the seller of the product  $x$  and process of destination the buyer of the same product. Cash flow (price) of the product  $x$  means revenue for the seller and costs for the buyer. (Pesonen 1998b)

The basic data needed for economic calculations of one single process are quantity ( $q$ ) and price ( $p$ ) of the product. Total costs for one process are:

$$TC_{\text{process } x} = q_{\text{process } x} \times p_{\text{process } x}$$

Correspondingly, the total costs of a built up system in a material flow model can be calculated. When the costs of each process are known adding these together will give us the total costs of a system (for instance total manufacturing costs of a product):

$$TC_{\text{system}} = TC_{\text{process } 1} + TC_{\text{process } 2} + \dots + TC_{\text{process } x}$$

(where  $x$  = number of processes).

Average costs of a system can also be calculated by dividing the sum of the costs of each process by the amount of import material to the system:

$$AC_{\text{system}} = \sum \text{process } 1 \dots x / q_{\text{import}}$$

As discussed above material flows offer quantitative data (which in most cases is directly useful for economic calculation) about the studied system. Cost data for the processes has to be collected and determined separately. (Pesonen 1998a)

### 3 RELIABILITY OF MATERIAL FLOW MODELS

Steen (1997) has separated three issues concerning the reliability of material flow models: sensitivity, uncertainty in input data and uncertainty in output data. He describes sensitivity as a derivative  $\delta y/\delta x$ , where  $y$  represents the result and  $x$  any input parameter. The parameter  $y$  varies with  $x$  according to the derivative. Values of such input parameters for which the results are very sensitive should be defined very carefully because errors in them cause great errors in the results. E.g. if the system seems to be very sensitive to the used interest rate, sensitivity analysis on different levels of interest rate should be run and special attention should be paid to the selection of the applied rate. Whenever there are uncertainties about the data quality it is possible to evaluate the reliability of the results using sensitivity tests. In such tests it is possible to see how dependent the results are on the used data (see e.g. Jönson 1996 or Wenzel et al. 1997). According to Weidema (1997) sensitivity analysis should also be used during the study to determine the system boundaries, i.e. the parts of the product systems which shall be included and the parts which may be excluded from further analysis on the grounds of insignificance. This kind of sensitivity analysis should be carried out for mass and energy flows (as well as economic variables when they are included in the study) and in comparative studies also for all important environmental parameters or data categories.

Uncertainty in input data refers to the uncertainty associated with the determination of a parameter value in the system. The input values are typically average values from the past, which can lead to major misinterpretations, especially when the studied system is part of very dynamic environment where rapid development and movements are common. Use of linear data also adds an extra error into the model. Especially in the case of dynamic material flow models the use of non-linear data, whenever it is available, should be promoted (see e.g. Pesonen et al. 1998). The implications of the use of linear vs. non-linear data in dynamic material flow modelling are discussed in depth in the next chapter. The ISO 14040 standard concerning environmental management, life cycle assessment and their principles and framework sets specific requirements for the quality of input data needed for

the study. According to the standard *"Data quality requirements shall be defined to enable the goals and scope of the LCA study to be met. The data quality requirements should address: time-related coverage; geographical coverage; technology coverage; precision, completeness and representativeness of the data; consistency and reproducibility of the methods used throughout the LCA; sources of the data and their representativeness and uncertainty of the information."* (CEN 1997) In these requirements the importance of time-related and technology coverage of data is stressed, which in principle promotes the use of non-linear data within LCA research.

The results of a material flow model can hardly ever be made 100 % reliable, which refers to the uncertainty in output data. The results present forecasts of the future in often very complex situations based on past data. Even the best forecasts based on one single result value can usually be interpreted as expected values of the variables presenting the future (Vartia 1994). Decisions have to be made in a situation usually including remarkable uncertainty and based on not always so reliable forecasts. Because of this it is particularly important that the decision maker is fully aware of the uncertainty of the system and forecasts. In material flow studies the use of intervals in the results (and data) instead of single point forecasts could offer a more reliable and truthful picture about the results of the studied system. An interval offers the decision maker a range of possible outcomes and presents better the level of uncertainty than a single point forecast. In material flow modelling the use of intervals in data as well as in the results could therefore be considered. Steen (1997) has also pointed out how important it is to clearly state the uncertainty associated with the results. He has chosen another approach to the same problem. According to him there are two main reasons as to why using uncertainty and sensitivity analysis can improve the credibility of material flow analysis: it may show that the contribution of the uncertain input data to the outcome of the result is small or negligible or it may express the result as a probability, thereby stating the degree of uncertainty. The first point refers to sensitivity and the latter to uncertainty in output data. Steen has chosen to recommend the use of probabilities in presenting the uncertainty in results. The result of a statistical uncertainty analysis will be a confidence interval for the results of the study (Weidema 1997). Whether intervals or probabilities are a more suitable way of presenting the uncertainty in a single study is a detail to be considered in each case separately. Both do meet the basic purpose of stating to the decision maker how reliable the results are and how remarkable is the uncertainty associated with them.

## 4 NON-LINEAR FUNCTIONS IN MATERIAL FLOW MODELLING

Linear data, based on historical average data, is usually used for calculations in material flow modelling. Linear data refers to a situation where the input parameter value is considered to be constant over time. In reality, however, technology develops continuously, causing changes in the input parameter values over time. Weidema (1997) has claimed that *"Technology develops with time and often becomes more environmentally benign. The choice of technology is therefore of great importance for the results of the life cycle assessment."* He suggests distinguishing between several technologies:

- Worst technology (the technology which will give the largest environmental improvement if it was taken out of use)
- Average technology (the technology which is easiest to obtain information on from statistics and handbooks)
- Modern technology (the technology installed today by most enterprises when new investments are made - also known as BATNEEC, Best Available Technology Not Entailing Excessive Costs)
- Marginal technology (the technology which is taken into use or taken out of use if the produced amounts are increased or reduced, respectively)
- Best available technology (the technology which is relevant to use as a basis for comparison if the investigation has a slightly longer time horizon or is directed towards particularly environmentally conscious enterprises or consumers)
- Best technically possible technology (the technology which is not yet installed anywhere, but for which adequate information is available to calculate the potential environmental impacts)

Environmental policy, consumption patterns or other changes in the market can also be responsible for non-proportionally developing, non-linear input parameters. Temporal correlation represents the correlation between the

time period relevant for the study and the age of obtained data. Weidema (1997) argues that as technology develops very fast in some sectors of industry, 10 years' difference between the year of study and the year of data might cause the emissions and the production efficiency to be totally changed. In some cases the changes in parameter values can be extremely rapid and quantitatively significant, and thus the use of past average data may lead to significant misinterpretations. Especially in the case of dynamic material flow modelling the use of linear data can cause major errors in the results.

Different types of data uncertainty contributing to the overall uncertainty in relation to LCA have been specified in the Nordic Guidelines on Life-Cycle Assessment (Nordic Council of Ministers 1995). These are presented in figure 3. The use of linear data could be defined as one type of technical variance in time contributing to errors in results.

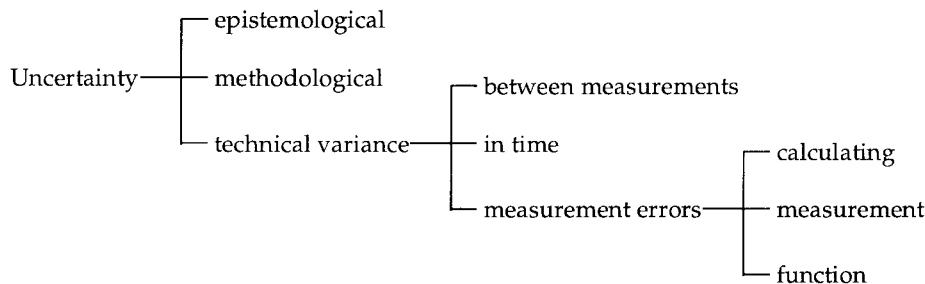


FIGURE 3 Different types of data uncertainty (Nordic Council of Ministers 1995)

The impact of linear vs. non-linear data on the results of dynamic material flow models will be further discussed using two examples from the Finnish printing paper industry: one focusing on environmental and the other on economic data (for environmental analysis see Pesonen et al. 1998 and economic analysis see Pesonen 1999). Material flows of Finnish printing papers in 1994-2000 were studied using the JTP-technique. The JTP-model is a dynamic material flow model designed for analysing complete material systems and forecasting the effects of different policy options in the future. The JTP-model takes into consideration several dynamic changes in the future and thus makes it possible to assess different policy options (see also Gronow & Pento 1995). The structure of the JTP-model is described in figure 4. Annual material flows are determined on the basis of variables from the collected data. They in turn are used to calculate different implications such as consumption of raw materials or energy, emissions, waste generated or changes in imports or exports. The model can be made dynamic by drawing the annual estimates together, which makes it possible to estimate changes in any of the variables in the future during a given period of time.

The main advantage of the JTP-model is that it allows the researcher to make detailed, quantified estimates and scenarios for the future. Several variables and their changes over time can be evaluated in chosen scenarios



simultaneously. The JTP-model gives the possibility to analyse dynamic changes of material flows in a multivariable case.

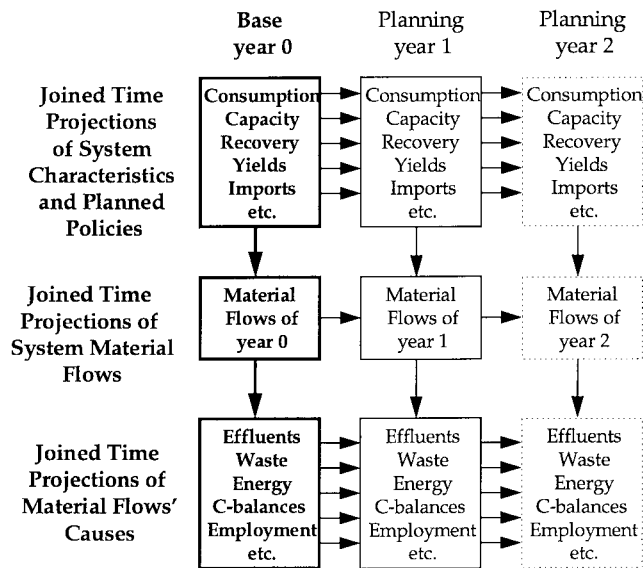


FIGURE 4 Structure of the Joined Time Projection -model (Gronow & Pento 1995)

#### 4.1 Environmental impacts of Finnish printing paper industry 1994-2000

Estimates of paper consumption were used to determine the annual material flows in the model. Paper production and de-inking capacities were taken into account. This basic data was used to calculate estimates of imports and exports of both paper and recycled paper, and of the amount of collected paper. Predictable changes in technology and their implications for material flows were included in the model.

In this study two scenarios of the material flows of Finnish printing papers in 1994-2000 were built. Selected production emissions ( $\text{COD}_{\text{Cr}}$ , Tot P,  $\text{SO}_2$  and  $\text{NO}_x$ ) were studied in these two scenarios:

- Basic scenario 1, where production emissions per ton paper produced were considered linear
- Adapted scenario 2, where production emissions per ton paper produced were considered non-linear

The basic scenario was built on the assumption that no major changes will take place within the industry during the study period. Predictable changes in paper consumption, composition of paper etc. were taken into account and

their implications for material flows were included in the basic model, but according to the basic assumptions e.g. no new emission clean-up technology would be built. The production emissions per ton of paper produced were considered to be linear in the basic scenario. This represents the assumption mostly used in material flow calculations. Emissions data per ton of paper produced for the selected compounds from the base year 1994 was used in this scenario throughout the study period.

The basic scenario was compared to the adapted scenario, which was based on the same data as used previously except for one change: the production emissions were considered non-linear (in this case decreasing). Actual emissions data per ton of paper produced was used for the period 1994-1996 and for the period 1997-2000 the emissions were estimated on the basis of the changes during the previous period. In the case of all of the selected compounds the emissions had decreased during the period 1994-1996. In the adapted scenario dynamic changes in the future were thus taken into consideration. This better represents the situation in reality and makes it possible to assess different policy options more reliably .

Pulping and papermaking processes consume large amounts of water. In Finland the forest industry is still the main cause of organic loadings to water systems even though it has been able to decrease its share considerably during recent years. Chemical oxygen demand and phosphorous were chosen for this study because they are mostly used in Finland as the compounds when setting limits to water emissions of pulp and paper mills (Finnish Forest Industries Federation 1996b). Sulphur compounds and nitrogen oxides instead represent the most important airborne emissions from the paper industry. The total amount of the following four compounds in production emissions were chosen to be compared in the basic and adapted scenarios: Chemical Oxygen Demand ( $COD_{cr}$ ), Phosphorous (Tot P), Sulphur dioxide ( $SO_2$ ) and Nitrogen oxides ( $NO_x$ ).

*Chemical Oxygen Demand ( $COD_{cr}$ )* is used to describe how much oxygen is consumed in the complete chemical oxidation of organic materials in waste water. Contrary to  $BOD_7$ ,  $COD_{cr}$  indicates the content of slowly degradable organic matter present in waste water. If oxygen demand is great, the receiving water may become depleted of oxygen, especially if under a layer of ice. Reducing the amount of oxygen-consuming substances in effluents has been one of the most urgent tasks of the Finnish forest industry, and these loads have been cut quite drastically in the past 20 years. (Finnish Forest Industries Federation 1996a)

*Phosphorous (Tot P)* is a nutrient element causing the eutrophication of water systems, together with nitrogen. In paper production emissions it comes mostly from wood raw material (Finnish Forest Industries Federation 1996b) during debarking and the production of groundwood and chemical pulp. Chlorine-free bleaching process requires additional nitrogen chemicals, which may increase the nitrogen loading of waste water.

*Sulphur dioxide ( $SO_2$ )* is a gas produced by burning sulphur-containing fuels and as a by-product in chemical pulping. It reacts with oxygen and water vapour in the air to produce sulphuric and sulphurous acids which dissolve in

rain, causing acidification of soil and water (Finnish Forest Industries Federation 1996a). Great attention has been paid to cutting sulphur emissions, in particular making improvements to the treatment of malodorous gases. As a result, total sulphur emissions have fallen in recent years even though production has increased simultaneously.

*Nitrogen oxides* ( $NO_x$ ) arise in the forest industry mainly from energy production during combustion and partly by reaction between oxygen and nitrogen in the atmosphere. The main method of lowering the nitrogen oxide emissions concentrates on the design of modern combustion technology. Improving clean-up methods cannot offer a solution here.

Total emissions for each of the studied compounds are presented in figures 5 to 8. In the case of all of the studied compounds the emissions in scenario 2 (non-linear emissions) were about 50 % lower than in the basic scenario 1 (linear emissions based on the data on the base year 1994):

- for  $COD_{Cr}$  55 % lower
- for Tot P 52 % lower
- for  $SO_2$  56 % lower
- for  $NO_x$  48 % lower

In basic scenario 1, with linear emissions, the changes in the total amount of emissions correlate completely to the changes in the amount of paper production. The slight decrease in the amount of total emissions within all studied compounds in the year 1995 can thus be explained by the decrease in the amount of paper production. From the year 1996 to the end of the study period paper production is estimated to increase slowly, which in turn means a slow increase in the amount of total emissions when those emissions are considered linear. In basic scenario 1:

- total chemical oxygen demand emissions increase from 123.045 kg in 1994 to 132.713 kg in 2000 (+ 8 %)
- total phosphorous emissions increase from 178 kg in 1994 to 188 kg in 2000 (+ 6 %)
- total sulphur dioxide emissions increase from 5.785 kg in 1994 to 5.986 kg in 2000 (+ 3 %)
- total nitrogen oxides emissions increase from 15.133 kg in 1994 to 15.942 kg in 2000 (+ 5 %)

In adapted scenario 2, with non-linear emissions, the amount of total emissions within all studied compounds decreased by about 50 % during the study period 1994-2000. The results of this scenario seem to present the development of actual emissions relatively well until the year 1996, which is the latest year for which emissions data was available. In adapted scenario 2:

- total chemical oxygen demand emissions decrease from 123.045 kg in 1994 to 59.545 kg in 2000 (- 52 %)

- total phosphorous emissions decrease from 178 kg in 1994 to 90 kg in 2000 (- 49 %)
- total sulphur dioxide emissions decrease from 5.785 kg in 1994 to 2.604 kg in 2000 (- 55 %)
- total nitrogen oxides emissions decrease from 15.133 kg in 1994 to 8.335 kg in 2000 (- 45 %)

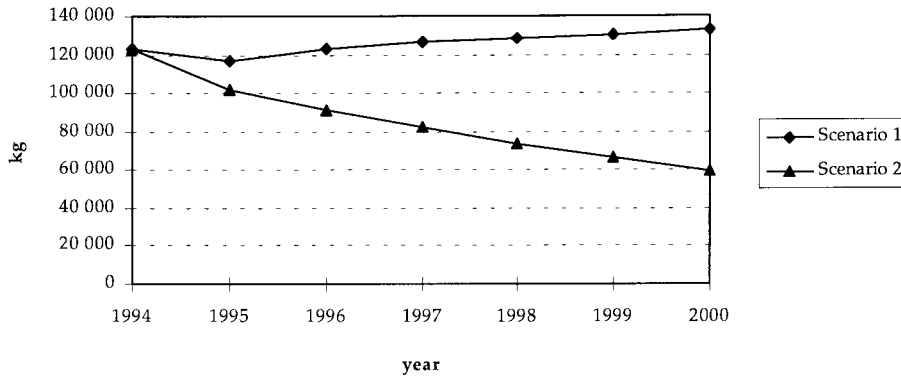


FIGURE 5 Production emissions (COD<sub>c</sub>) in the studied two scenarios 1994-2000

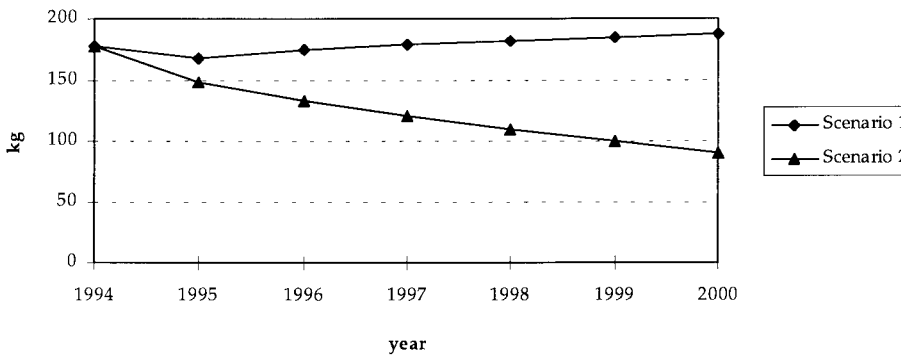


FIGURE 6 Production emissions (Tot P) in the studied two scenarios 1994-2000

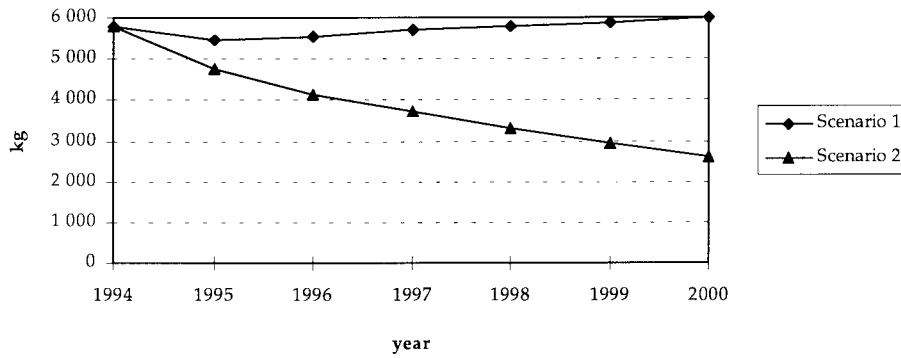


FIGURE 7 Production emissions ( $\text{SO}_2$ ) in the studied two scenarios 1994-2000

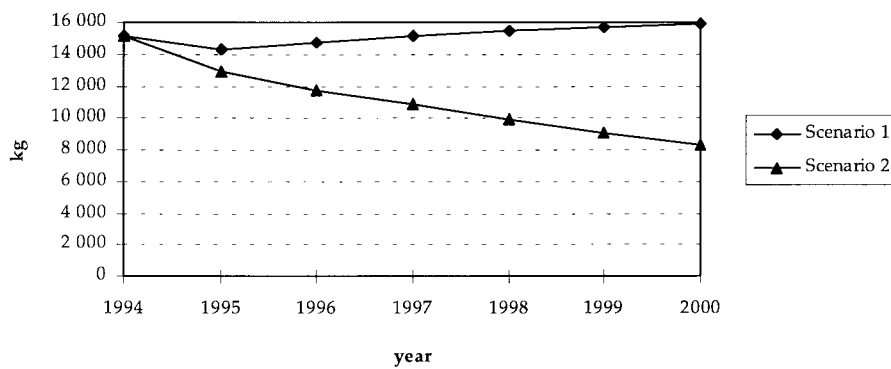


FIGURE 8 Production emissions ( $\text{NO}_x$ ) in the studied two scenarios 1994-2000

Figures 5 to 8 clearly show that when the production emissions are considered linear it can cause major errors when trying to assess the amount of total emissions in the future. In this case the reduction of production emissions during the study period has been relatively fast; when this decrease is not taken into account in the calculations as in the basic scenario, the error accumulates throughout the study period and ultimately leads to considerable error in the total amount of studied emissions. Using the basic scenario where emissions are linear for environmental decision making would lead to a notable misinterpretation of the forecast.

## 4.2 Waste management costs of Finnish printing paper industry 1994-2000

Waste management costs were calculated for the material flows of Finnish printing papers in 1994-2000. Waste management costs included all costs from collection and transport to final storage. As well as in the case of environmental impacts, also here two different scenarios were built up:

- Basic scenario 1, where waste management costs were considered linear
- Adapted scenario 2, where waste management costs were considered non-linear

The basic scenario was built on the assumption that the average waste management costs per ton of waste would stay constant during the study period. Changes in total waste management costs would correlate completely to changes in the amount of waste generated. In the adapted scenario, however, the costs of two waste management processes were considered non-linear, i.e. changing non-proportionally over time: collection costs of municipal solid waste and landfill costs. Several studies (e.g. Tanskanen 1996) show that average collection costs of municipal solid waste increase when the recovery rate of different waste fractions rises. In the model the recycling rate of printing papers was assumed to rise from 58 % in 1994 to 65 % in 2000. Using the data from Tanskanen's (1996) study, the average collection costs of paper were assumed to rise from 291 FIM/t to 298 FIM/t during the study period. Landfill costs, instead, are expected to rise in Finland in the coming years due to new demands made by the EU Landfill Directive (EC 1997), the proposal of which is now before the EU Parliament and Council. It would require all wastes to be treated before being landfilled. Prices for landfill disposal should cover the costs of closing the landfill site as well as management, and also cover at least 50 years of care after closure of the site. In addition the proposal aims to reduce the quantity of biodegradable municipal waste to landfills in an effort to reduce methane emissions. Methane from both new and existing landfills would have to be collected and used, or flared off. (EC 1997) These demands will have a great impact on the costs of waste management in Finland, because at the moment majority of the Finnish landfills do not meet the requirements set by the proposed Landfill Directive. Several estimates of future landfill costs in Finland have been proposed, but the actual level of price increase will first be seen in the coming years. In the adapted scenario landfill costs were expected to double during the study period from the current FIM 106/t to the predicted FIM 212/t.

Total waste management costs in both scenarios are presented in figure 9, and average waste management costs in figure 10. In scenario 1 (with linear costs) total waste management costs have increased by 51 % from FIM 144 million in 1994 to FIM 218 million in 2000. The increase in total costs can in this case be explained by the increasing amount of waste throughout the study

period. Average waste management costs in the first scenario have stayed at the same level: 5 % decrease from 431 FIM/t in 1994 to 408 FIM/t in 2000. This small change in the average costs is due to some changes in the composition of waste generated and the varying average costs of waste management processes used between the years.

Scenario 2 with non-linear costs shows a somewhat different picture: total waste management costs have almost doubled (+ 92 %) from FIM 143 million in 1994 to FIM 276 million in 2000 and average waste management costs have increased by 19 % from 431 FIM/t in 1994 to 515 FIM/t in 2000.

The differences between the costs in scenarios 1 and 2 can be explained by the error caused by the use of linear data in scenario 1. Both total and average waste management costs are 21 % lower in the end of the study period in 2000 in scenario 1 with linear data compared to costs of scenario 2 with non-linear data.

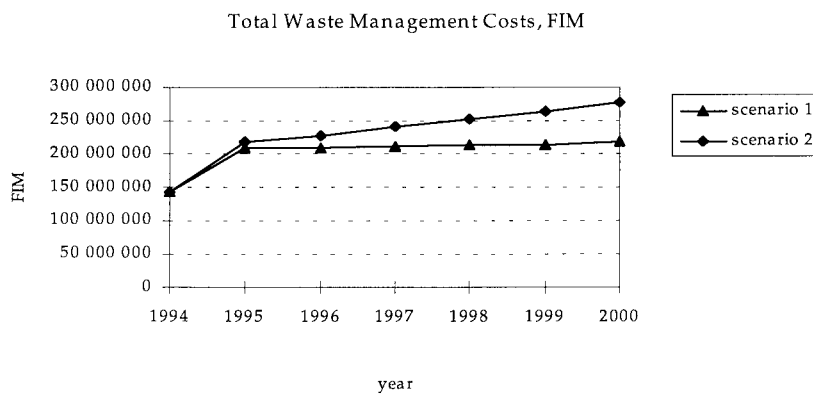


FIGURE 9 Total waste management costs 1994-2000

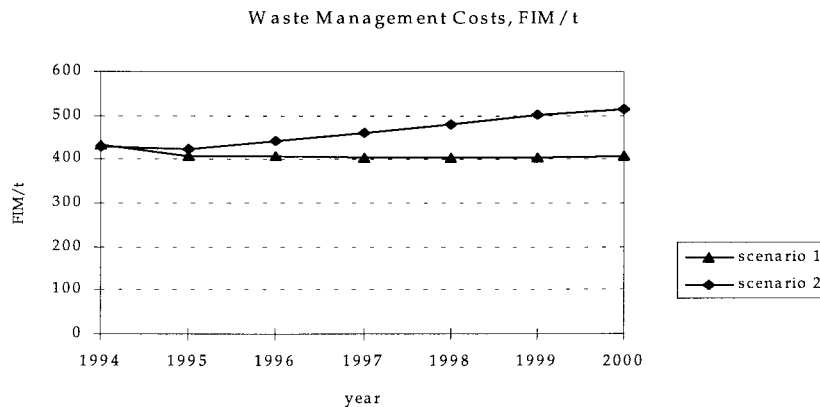


FIGURE 10 Average waste management costs 1994-2000

## 5 CONCLUSIONS

Linear input data is still mostly used for calculations in material flow modelling. The presented examples, however, clearly show that the use of linear data can be a major source of error in the results and can thus have a strong influence on the reliability of dynamic material flow modelling. In the presented cases the differences between the amounts of the studied emissions (COD<sub>Cr</sub>, Tot P, SO<sub>2</sub> and NO<sub>x</sub>) in the linear and non-linear scenarios were about 50 % depending on the studied compound, and the error in waste management costs in the linear scenario compared to the non-linear scenario was 21 %. These findings strongly suggest that in dynamic material flow modelling the use of non-linear data - whenever it is available - should be promoted.

There can be several factors responsible for non-linear, non-proportional development of input parameters. The non-linear development in the amount of emissions per ton paper produced was an example of technology change with extremely strong implications for the input parameter values. Two different reasons for non-linear behaviour of average costs were presented in the case of economic assessment: rising average collection costs, which are assumed to increase when the collection rate of paper rises as an example of a change caused by development in the scale of operations, and rising average landfill costs as an example of a change due to environmental policy.



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**HOW TO INCLUDE ECONOMIC DATA  
INTO LCA RESEARCH  
- SOME EMPIRICAL FINDINGS**

Hanna-Leena Pesonen  
Business Strategy and the Environment Conference Proceedings, Leeds, 1998



## **ABSTRACT**

Life Cycle Assessment (LCA) measures and assesses the environmental impacts of a single product or an industry along its life cycle. Recently several bodies (e.g. SETAC) engaged in the development of material flow models and LCAs have made recommendations about including economic and social variables in these models. Some theoretical research has been done in this area but there is still a great lack of empirical work.

This paper presents some of the first empirical findings of studies using material flow models as a basis for economic evaluation and decision making. Case studies used in this paper include Finnish and Austrian printing paper industries and waste management. The applicability of material flow models in economic decision making is discussed and some possible limitations are presented.

Process thinking has been applied to the selected case studies. Economic calculations using life cycle approach are based on the costs of each process along the product's value chain ('process' is defined here according to Baccini & Brunner, 1991 meaning transport, transformation and change of value of materials and goods). Total costs of all processes form the price of the product to the final consumer. The total costs of the system (costs of consumption) also include the costs of disposal.

## **1 INTRODUCTION**

The importance of environmental protection has recently gained increasing attention. Different tools of environmental management have been developed to better measure and reduce the environmental impacts of processes and products: environmental auditing, environmental impact assessment, life cycle assessment, risk assessment etc. According to the system boundary and level of the analysis different methods of material flow analysis can be used: Life Cycle Assessment (LCA) measures and assesses the environmental impacts of a single product or an industry along its life cycle, eco-balances concentrate on the environmental impacts of a given company and substance flow analysis (SFA) traces the path of a substance through the system (Pesonen, 1998a). Material flow models have traditionally concentrated solely on environmental analysis, but the idea of including also economic and social variables to environmental information has recently gained increasing attention.

## 2 LIFE CYCLE ASSESSMENT

According to ISO 14040 standard concerning environmental management, life cycle assessment and their principles and framework, LCA is defined as a technique for assessing the environmental impacts associated with a product (see also figure 1), by

- compiling an inventory of relevant inputs and outputs of a product system,
- evaluating the potential environmental impacts associated with those inputs and outputs,
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. (CEN, 1997)

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences. (CEN, 1997) Recently several bodies (e.g. SETAC, ConAccount and CHAINET) engaged in the development of the LCA technique have made recommendations about including also economic and social variables in the research. However, LCA has typically not addressed the economic or social aspects of a product (see e.g. CEN, 1997). Also the Nordic guidelines on life cycle assessment (Nordic Council of Ministers, 1995) exclude economic and social aspects from the scope of LCA. Its definition of LCA concludes with the remark: "It does not address economic or social effects". Applications of LCA include such areas as product development and improvement, strategic planning, public policy making and marketing (see figure 1). When making decisions in any of the previously mentioned situations, information about the economic consequences of the possible outcomes is, however, also crucial. E.g. decisions between different product alternatives and their marketing without detailed economic analysis sounds somewhat unrealistic.

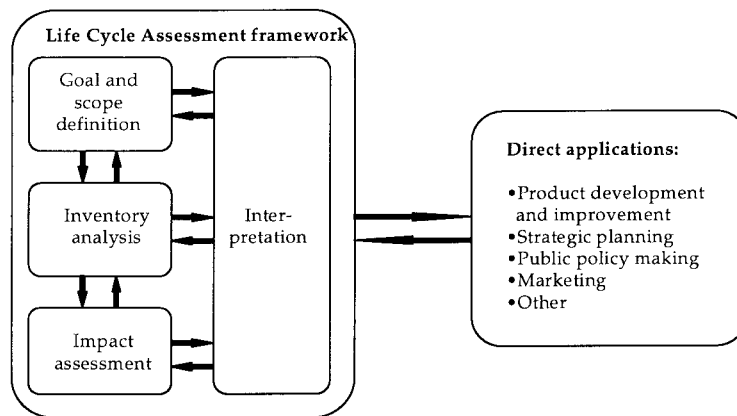


FIGURE 1 Phases and application areas of an LCA (CEN, 1997)

Some basic ideas and analysis of the interlinkages between material flows and economic development have been discussed in a previous article by the author of this paper (see Pesonen, 1998a). These are discussed in brief in chapter 5. First empirical studies on this theme include e.g. research of Kytzia (1997) on the possibilities of including economic data into a material management system in housing, Pesonen (1997) on the costs of chosen scenarios of waste management in Austria and two studies by Pesonen (1998b and 1998c) on the dynamic material flows of Austrian and Finnish printing paper industry, also including economic variables.



### 3 PROCESS THINKING AS A TOOL FOR DESCRIBING ENVIRONMENTAL VALUE CHAINS

Quality management has encouraged the use of process thinking instead of the traditional functional view of an organisation. When applying process thinking, activities and organisations are described as a chain of processes which are linked to each other by the products and services that they consume and produce. Products and services are results of the activities of each process. Figure 2 presents an example of a process. In addition to the end-user of the product, 'client' refers here also to the internal clients of a company, i.e. to the previous or following process or department in the whole chain of processes.

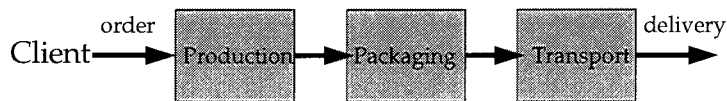


FIGURE 2 An example of a process (Kera, 1996)

Models of processes describe step by step what happens inside organisations, departments or teams. SFS (1998) uses the metaphor 'cartoon' when defining processes. This cartoon starts from the needs of a client and ends by satisfying these. Modelling the processes includes determining who are the clients (internal or external), what are their needs, which other stakeholders are included in the system, which departments/teams of our own organisation are involved, which external services and resources are used, what are our products etc.

The concept 'environmental value chain management' is used to describe the management of a whole product system from an environmental point of view (see e.g. Linnanen, 1995). The value of a product increases along its way through the chain of processes. The concept 'value added' is also discussed in chapter 5.

## 4 APPLICABILITY OF MATERIAL FLOW MODELS IN ECONOMIC DECISION MAKING

The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data produced about the system, its logistics and flows, which in most cases is directly useful for economic calculations (Pesonen, 1998a). Figure 3 presents the transactions between company and environment (Müller, 1993). Impact of companies on the environment typically includes such flows as wastes and emissions. The environment, in turn, is the source of raw materials and energy to the economy.

Direction of transaction	To economy	To environment
From economy	Products and services	Emissions and wastes
From environment	Raw materials and energy	Ecology

FIGURE 3 Transactions between economy and environment (Müller, 1993)

An important argument supporting the linking of economic variables to environmental information is the communicative value of monetary terms. Costs and revenues are concepts of the language used by management responsible for decision making. Speaking of cash, savings and investments translates the environmental information into a more understandable form for the business decision maker (Bundesumweltministerium, 1997).

The concepts of environmental material flow analysis can be modified for economic models with some slight changes. In economic terms process of origin would be the seller of the product *x* and process of destination the buyer of the same product. Cash flow (price) of the product *x* means revenue for the seller and costs for the buyer.

The common features and differences in the modelling of ecological and economic flows can be discussed by focusing on six separate issues: Types of cash flows or stock, Direction of the flows, Growing entropy of the flows, Input

vs. output of a process, Process as a black box and Impacts of material and cash flows. (Pesonen, 1998a)

Kytzia (1997) has separated three different types of cash flows or stocks in connection with material flows:

- *Cash flows connected with material or energy flows*: Such cash flows, which are directly connected with a material or energy flow, are included in the material management system.
- *Cash stocks connected with material stock*: Material accumulated in a given process form a material stock (definition according to Baccini & Brunner, 1991), e.g. real estate, machinery, raw material stocks or landfill. The value of such a stock has to be estimated in economic terms. The methods of economic cost and investment accounting are used for this purpose.
- *Immaterial cash flows*: Immaterial cash flows occur in case of services.

Cash flows are consequences of market transactions. The buyer pays the seller for a determined product (whether it is a physical product e.g. raw materials or machinery or an immaterial service e.g. financing, waste handling) which is purchased to satisfy his/her special needs. In the case of a physical product cash flow takes the opposite direction than the material flow in this market transaction. Services usually do not include any material but e.g. in the case of waste management some material activities are included. In this case the material flow is in the same direction as the cash flow.

According to the first law of thermodynamics entropy increases in the system. This means that the substances and materials are refined, mixed and distributed during the material flow so that in the end one single substance is almost impossible to trace and separate. When a substance or a material is being imported to the system it is more or less one consistent flow. Along the flow through the system it is spread over the whole system to various processes, possibly recycled etc.; finally in the export products of the system different import materials together compose very complex compounds. This is also true for cash flows. The payment for a product is further divided to subcontractors, raw material suppliers, financiers etc. Even though the directions of the material and cash flows are opposite the first law of thermodynamics applies in both cases.

The second law of thermodynamics (i.e. the principle that the amount of material and energy remains constant at any flow or process in a system) claims that the input and output of a process must be equal. For the material as well as energy flows this is true. For cash flows, however, this does not apply. In each process some value is added to the product. Riahi-Belkaoui & Fekrat (1994) define the concept of value added as "a measure of the total return generated in a firm through the utilisation of its productive capacity, i.e. labour and capital in the broad classical sense". Because of the value added within a process the input of cash flow has to be larger than the output. Output refers to the expenses of bought-in materials and services, and input to the sales revenue. Input - output gives the value added within one process. In reality, cash input

does not always exceed output in short run, but if the company is to stay alive, in the long run this has to be the case.

In the definitions of material flow models processes are considered to be black boxes. What is happening inside the process is not considered important; instead attention is paid to the output of a process. For material flows this practice is suitable because input and output are equal. In the case of cash flows the process has to be taken into account. As discussed above, a process is an active part of the system which adds value to the product during its production. Value is added within the process and so it cannot be seen as a black box when studying cash flows.

The outputs of each process in material flows are products (which were the actual goals of production and have some economic value), by-products (unintended products of production which also have some economic value) and/or emissions (unintended products with no or negative economic value). Emissions (to air, water or ground) are studied when trying to assess the impacts of the material flows of a system. The processes themselves do not cause any environmental impact but the material flows do. The impacts of cash flows are expressed as costs. Costs are in turn caused by the processes; not the cash flows. Processes add value to the product (and to the system) and cause costs.

## 5 EMPIRICAL FINDINGS

The empirical findings discussed in this chapter are based on three separate studies done by the author. The first one is part of a larger research project, ASTRA, done at the Technical University of Vienna in 1997 (Fehringner et al., 1997) where five scenarios of the Austrian waste management system were built up and compared using the following criterion for evaluation: requirements of the Austrian Waste Act and environmental and economic impacts of the material flows. The ASTRA study was conducted as a static material flow model where 1996 was set as the year of reference. The two further studies are dynamic material flow models of Austrian and Finnish printing paper industries in 1994-2000 (Pesonen, 1998b and Pesonen, 1998c), where the environmental implications of different recycling and waste management scenarios are compared. In addition to environmental impacts, both these studies also include economic evaluation of the studied scenarios. The results of these studies won't be discussed here in detail, because without any background information about the goal and scope definition or scenario development of the studies it would be quite meaningless to present them. Instead, some basic considerations with more general value about the lessons learnt during these studies are presented. Emphasis will be given here to economic evaluation.

The quantitative data from the material flow models about the amounts of materials in each process were directly useful for cost calculation. Cost data for the calculations was collected separately from various sources: interviewing different actors in the area (waste management plants, equipment producers and other experts), literature and previous research. All the scenarios in these studies included every phase of waste management from waste collection to final storage. Costs of each process (e.g. waste incineration) include investment and operating costs and possible revenues from the sold energy.

In all of the above mentioned studies the functional unit (quantified performance of a product system for use as a reference unit in a life cycle assessment study, definition by CEN, 1997) was determined as a ton of waste. The results of cost calculation were thus presented as ATS/t or FIM/t. This

made it possible to compare the results of chosen scenarios. In addition to this, total costs of the studied systems were also calculated.

In the ASTRA study the decision was made to use intervals instead of single point values for the cost calculation, because there was considerable variation in the cost estimates of certain processes collected from different sources. Interval (minimum, maximum and average costs) was determined for each process to offer a more reliable picture of the studied system. Correspondingly, also the results were also presented as an interval with an average estimate. Figure 4 presents the results of the cost comparison of the chosen scenarios in ASTRA project. The costs of all other scenarios except scenario 2b (all the waste generated in Austria is incinerated in incineration plants) are in the same level: 1.185 - 1.325 ATS/t (average being 1.247 ATS/t, +/- 5 %). This means that the costs of these scenarios cannot be used as a decision criterion for comparison and the decision should be made based on other criterion. (Fehringer et al., 1997 and Pesonen, 1997)

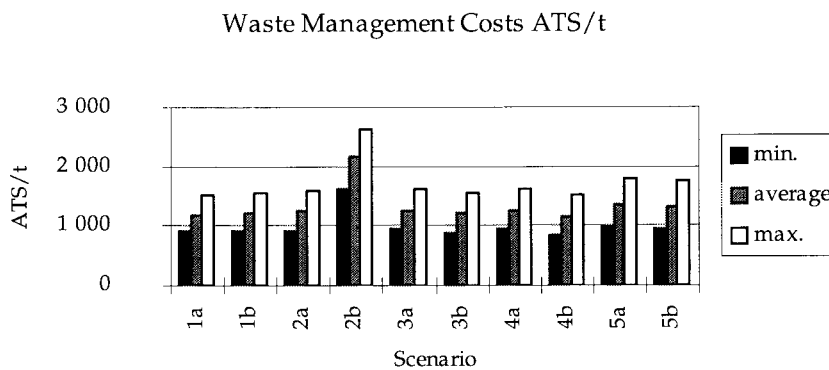


FIGURE 4 Waste management costs in Austria in the chosen scenarios in ASTRA study (Fehringer et al., 1997)

As well as in the case of static modelling in ASTRA project, same observations and conclusions also apply to dynamic research settings. Figure 5 gives an example of the results of total waste management costs of Finnish printing paper industry in 1994-2000 (Pesonen, 1998c). The development of the total costs (in this case increasing total costs due to the increasing amount of waste generated) throughout the study period and single cost units can be clearly distinguished from the presentation.

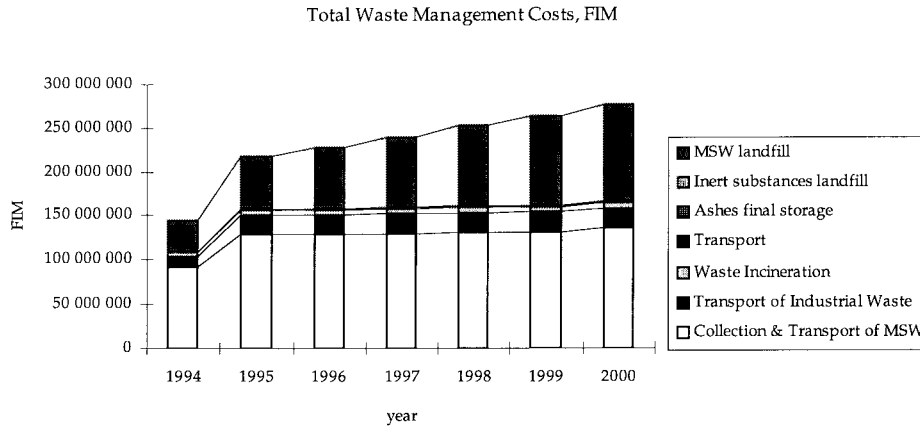


FIGURE 5 Total waste management costs of Finnish printing paper industry in 1994-2000 (Pesonen, 1998c)

## 6 CONCLUSIONS

Material flow models give a good basis for economic evaluation and decision making. LCA has not addressed the economic or social aspects of a product, but for decision making in the applications of LCA (product development and improvement, strategic planning, public policy making and marketing) information about the economic consequences of the possible outcomes is, however, also crucial.

Environmental value chain management and process thinking are logic tools for economic calculations combined with material flow modelling. Process thinking helps to identify the processes, products and flows in the system and serves as a suitable basis for cost analysis.

To make the results of different scenarios of a study comparable, it is extremely important that the basic assumptions (functional unit, system boundary, used interest rate and expected lifetime in investment calculations etc.) concerning each process are equal.

It is hardly possible to make the results of material flow model 100 % reliable. Even the best forecasts based on one single result value can usually be interpreted as expected values of the variables presenting the future (Vartia, 1994). This also applies to cost calculation. Therefore the use of intervals instead of single point values in the used data and results in material flow modelling is strongly suggested. An interval offers the decision maker a range of possible outcomes and better presents the level of uncertainty than does a single point forecast. It is particularly important that the decision maker is fully aware of the uncertainty of the system and forecasts.



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**FROM MATERIAL FLOWS TO CASH FLOWS  
- CASE FINNISH PRINTING PAPERS 1994-2000**

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R'99 Conference Proceedings, Geneva, 1999



## **ABSTRACT**

Material flows of Finnish printing papers in 1994-2000 are studied using the JTP -technique. The environmental and economic implications of two scenarios are studied. The basic scenario is built on the assumption that no major changes will take place during the study period. Predictable changes in paper consumption, recycling rate etc. are taken into account. Scenario two presents an alternative policy option with two changes to the basic model: the landfill gas is collected and incinerated and all the sludge from de-inking is thermally treated. Further, the applicability of material flow models in economic decision making is discussed.

## 1 INTRODUCTION

As the importance of environmental protection and early recognition have gained increasing attention, different tools of environmental management have been developed to assess the environmental impacts of products/companies/industries: environmental auditing, environmental impact assessment, life cycle assessment, risk assessment, cost benefit analysis, input-output analysis etc. Several different quantitative models are used to measure flows of products and/or substances through a defined system and to help in decision making on the basis of these inventories and the studied environmental impacts. According to the system boundary and level required different methods of material flow analysis can be used: Life Cycle Assessment (LCA) measures and assesses environmental impacts of a single product or industry along its life cycle; eco-balances concentrate on the environmental impacts of a given company; and substance flow analysis (SFA) traces the path of a selected substance through the system. Recently several bodies (e.g. SETAC, ConAccount and CHAINET) engaged in the development of material flow models have made recommendations about including also economic and social variables in these models. (see more in Pesonen, 1998a)

## **2 JOINED TIME PROJECTION -MODEL AS A TOOL FOR PLANNING ENVIRONMENTAL POLICY**

The JTP-model is designed for analysing complete material systems and forecasting the effects of different policy options in the future. It takes into consideration several dynamic changes in the future and thus makes it possible to assess different policy options (see also Gronow & Pento 1995). Annual material flows are determined on the basis of variables drawn from the collected data. They in turn are used to calculate different factors such as consumption of raw materials or energy, emissions, waste generated or changes in imports or exports. The model can be made dynamic by drawing the annual estimates together, which makes it possible to forecast future changes in any of the variables over a given period of time. The main advantage of the JTP-model is that it allows the researcher to make detailed, quantified estimates and scenarios for the future. Several variables and their changes over time can be evaluated in chosen scenarios simultaneously. The JTP-model also offers the possibility to analyse dynamic changes of material flows in a multivariable case.

### **3 MATERIAL FLOWS OF FINNISH PRINTING PAPERS IN 1994-2000**

The basic scenario was built on the assumption that no major changes will take place during the study period. Predictable changes in paper consumption, recycling rate etc. were taken into account, but no new de-inking capacity would be built and no major changes would take place in the waste management system. Scenario two presents an alternative policy option with two changes to the basic scenario: landfill gas is collected and incinerated, and all the sludge from de-inking is thermally treated.

In this study special attention was paid to the implications of material flows for waste management issues. One of the major environmental problems that the societies are dealing with in today's world is the enormous amount of waste we are generating continuously. Many countries face growing problems trying to manage the stream of solid waste in an economically sensible and environmentally safe way. The following three aspects were chosen to analyse the changes in the material flows of Finnish printing papers in the two scenarios:

1. The amount of waste landfilled
2. Environmental impacts of the waste generated - In this paper the environmental impacts of the studied scenarios were evaluated using the amount of greenhouse gases as a criterion for comparison.
3. Economic impacts of the waste generated



## **4 ENVIRONMENTAL IMPACTS OF THE WASTE GENERATED**

### **4.1 The amount of waste generated**

One aspect of the waste problem is that densely populated areas have serious difficulties trying to find suitable ground for landfills. Governments have reacted to this problem by setting various laws and restrictions concerning minimisation of waste, landfilling (location and safety), recycling rates etc. Paper and board form the second largest fraction of municipal waste after biowaste (on average 26 % of all municipal solid waste in the EU countries, 20 - 34 % depending on the country and the statistics, see European Commission, 1996) and this is why the decisions concerning recycling and waste management of this fraction have an important impact on the total amount of waste ending up in landfills.

Figure 1 presents the amount of waste ending up in landfills in the studied scenarios. Even though the recycling rate of paper increases throughout the study period, the total amount of waste landfilled (325.000 t in 1994 to 525.000 t in 2000) will continuously grow in the basic scenario, because the consumption of paper increases simultaneously. The largest single fractions of waste are paper (56 % in 2000) and sludge from de-inking (45 % in 2000). In the adapted scenario the total amount of waste landfilled is about 30 % less than in the basic scenario (240.000 t in 1994 to 360.000 t in 2000). Also the composition of landfilled waste has changed: the amount of incineration residuals increases during the period when the incineration rate grows and all the sludge is incinerated. In the last year of the model (2000) they already make up 19 % (178.000 t) of all waste landfilled.

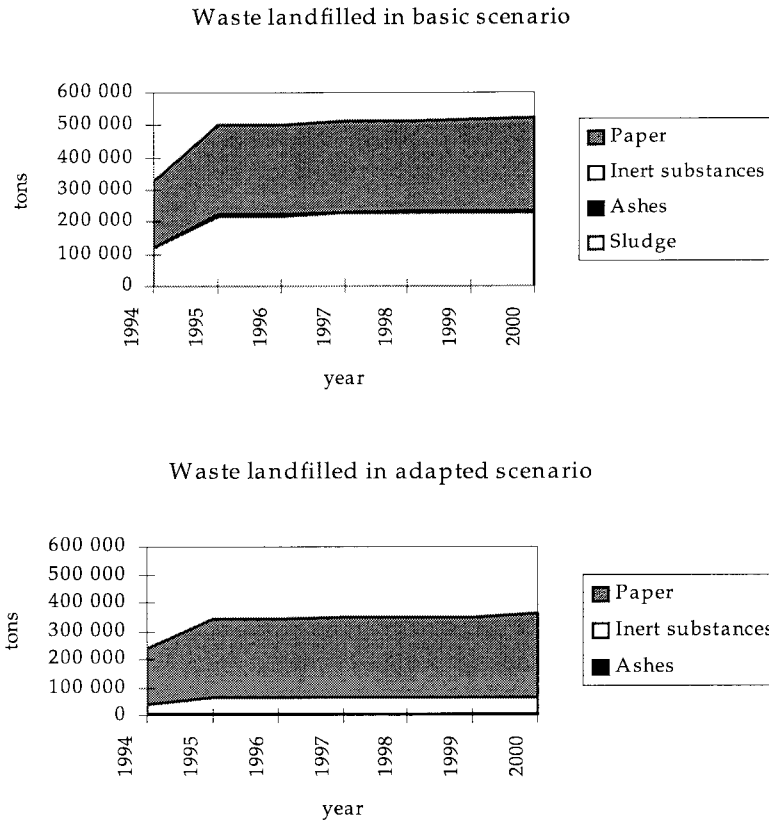


FIGURE 1 Waste landfilled in the studied scenarios 1994-2000

## 4.2 Contribution of the waste generated to global warming

Man-made global warming is attributed to the emission of gases which retain heat radiation which would otherwise be lost from the earth into space. The gases thereby contribute to the heating of the atmosphere. The most important greenhouse gases are carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), nitrous oxide ( $\text{N}_2\text{O}$ ) and halocarbons, (about global warming and greenhouse gases see e.g. Wenzel et al., 1997 and Hauschild & Wenzel, 1997). For the characterisation of the potential contribution of a given substance GWP (Global Warming Potential) factor is used.  $\text{CO}_2$  is set as the reference substance which means that the emissions of the given substance are expressed as so-called  $\text{CO}_2$  equivalents.

Paper is an environmentally friendly product made of renewable resources. During the last decade or two the paper and pulp industry has made great effort to decrease emissions to air and water and has succeeded in this depending on the emission, by up to 90 %. According to Pilz (1996) however,

the industry's emissions responsible for the greenhouse effect have gained little or no attention so far. The United Nations' Kyoto Conference brought up this important issue again. In this paper an attempt was made to assess the amount of greenhouse gases from waste management. CO<sub>2</sub> and CH<sub>4</sub> emissions from waste incineration and landfills were calculated to evaluate the environmental impacts of waste management in the two scenarios.

The following assumptions were made concerning the calculation of the greenhouse gases of waste management:

1. Only CO<sub>2</sub> and CH<sub>4</sub> emissions were taken into account.
2. GWP factor of 25 was used for CH<sub>4</sub> (GWP for time span of 100 years) as defined by the IPCC (Intergovernmental Panel on Climate Change). Results are presented as CO<sub>2</sub> equivalents. (for IPCC GWP factors see Albritton et al., 1995)
3. Only the emissions from waste incineration (emissions to air) and landfills (landfill gases) were considered in this study.
4. Moisture content was assumed to be 12,5 % for paper and 50 % for de-inking sludge.
5. Coal concentration was assumed to be 37,5 % for paper and 34,7 % for de-inking sludge (dry basis).
6. In landfill gas incineration 50 % of the produced CH<sub>4</sub> is collected and transformed into CO<sub>2</sub>. (Nordic Council of Ministers, 1995)

Only CO<sub>2</sub> and CH<sub>4</sub> emissions were considered in this study because they are the two most important greenhouse gases and also the main components of airborne emissions from incineration and landfills. Landfill gases consist of both CO<sub>2</sub> and CH<sub>4</sub>. The share of CH<sub>4</sub> in landfill gases was assumed to be 60 % (see e.g. Pilz, 1996). CO<sub>2</sub> is the main combustion component of carbon in the waste fuel. According to several studies it is found up to 98 % as CO<sub>2</sub> in the exhaust gas (Schachermayer et al., 1995 and Stripple, 1995). For CO<sub>2</sub> the emissions should be presented as a net contribution. This means that such emissions which utilise some of the existing natural flows of the carbon cycle (e.g. burning of biofuels, wood or straw) and would be broken down anyway are not considered as contributing to greenhouse gas emissions. Whether combustion of paper should be interpreted as the abovementioned type of process utilising existing natural flows of carbon cycle or not, is still unclear. Because the main raw material of paper is wood it would give an argument for not including this to contribution to greenhouse gases emissions. In this study, however, the CO<sub>2</sub> emissions from paper incineration are also defined as greenhouse gases.

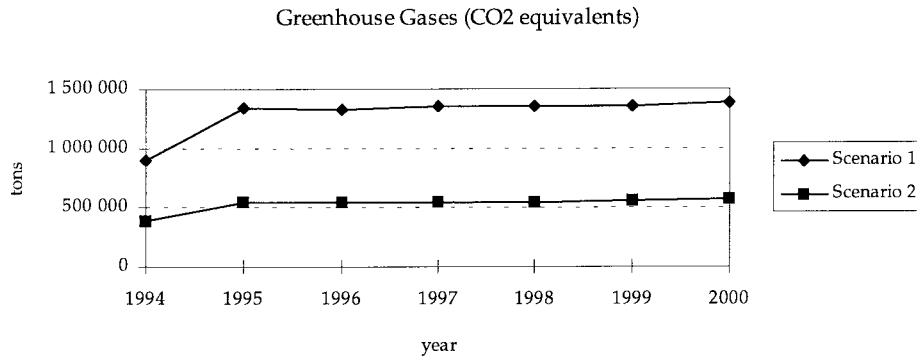


FIGURE 2 Greenhouse gases (CO<sub>2</sub> equivalents) from waste management compared in the studied scenarios

Figure 2 presents the amount of greenhouse gases emissions in both scenarios. It is clearly obvious that the amount of greenhouse gases emissions in the second scenario are far smaller than in the basic scenario. The two most important reasons for this are that in the basic scenario the amount of waste ending up in landfills is about 50 % higher than in the second scenario, and that in the second scenario landfill gas is incinerated. Both these changes decrease the amount of CH<sub>4</sub> emissions, which is a much stronger greenhouse gas than CO<sub>2</sub> (see assumptions above). In the basic scenario CH<sub>4</sub> emissions grow by over 50 % during the study period ending up at 54.000 t in 2000 whilst in the second scenario they are 38.000 t in 2000. The calculated CO<sub>2</sub> equivalents for the basic scenario increased from 897.000 t in 1994 to 1.393.000 t in 2000 (i.e. by 55 %) while the CO<sub>2</sub> equivalents of the second scenario ended up at 568.000 t in 2000. In 2000 CO<sub>2</sub> equivalents were 2,5 times higher for the basic scenario as for the adapted scenario.

## 5 ECONOMIC IMPACTS OF THE WASTE GENERATED

Waste management costs were calculated for both scenarios. Total costs in the two scenarios are presented in figure 3. Total waste management costs are growing fast in both cases throughout the study period (by 93 % in the basic scenario and by 82 % in the adapted scenario) due to the increasing amount of waste. The costs in the adapted scenario are higher during the entire study period due to higher costs of waste incineration compared to landfilling costs. In 2000 total costs in the basic scenario are 20 % less than in the adapted scenario.

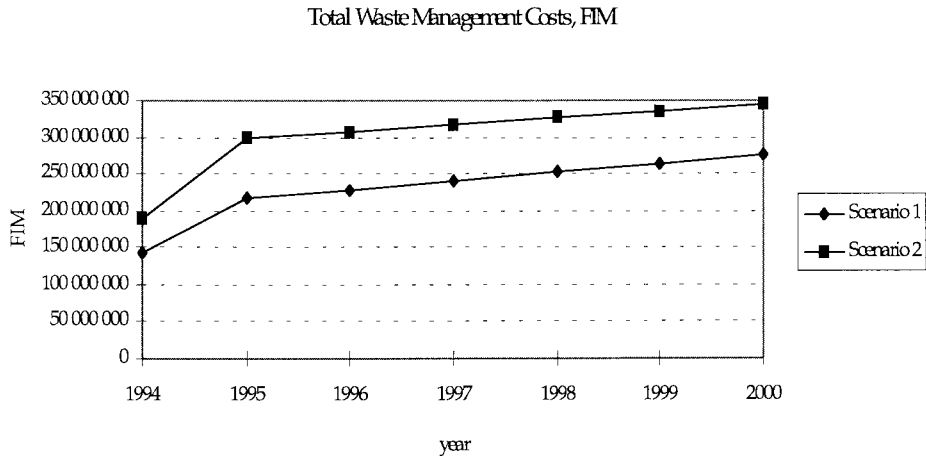


FIGURE 3 Total waste management costs 1994-2000 compared in the studied scenarios

## 6 DISCUSSION AND CONCLUSIONS

In the case study two different scenarios were studied for the Finnish printing paper industry and more closely their implications for waste management. The basic scenario with no major changes to today's policy was found to be 20 % cheaper than the adapted scenario where the share of waste incineration was increased and landfill gas was incinerated. The adapted scenario however proved to be a lot better from the environmental point of view: 50 % more waste was generated and 2,5 times more greenhouse gases were emitted in the basic scenario compared to the adapted one. The decision makers would in this case face the problem of valuation: are 20 % higher costs too much for the abovementioned savings in environmental impacts?

As discussed and presented above, dynamic material flow models are a powerful tool for planning future policy options. Material flow models have proved to be a powerful tool for environmental analysis and decision making and it is argued that they also offer a suitable basis for economic evaluation. The most important advantages of combining economic variables into material flow models include the communicative value of monetary terms to the decision maker as well as the basic quantitative data offered by material flow models about the system, its logistics and flows, which in most cases is directly useful for economic calculations. The balance between economy and ecology is an ideal situation often repeated in political discussion as well as in the strategic planning of a company. In reality, however, the technically or scientifically best solutions supporting the idea of sustainable development are often rejected by economists because these solutions are extremely expensive in economic terms. In fact, in most decision making situations we still miss decision aids which could offer information about both the environmental and economic impacts of the possible outcomes.

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**ECONOMIC CONSIDERATIONS  
IN JOINED TIME PROJECTION -MODELLING -  
CASE AUSTRIAN PRINTING PAPERS 1994-2001**

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## **ABSTRACT**

In this working paper material flows of Austrian printing papers in 1994-2001 were studied using Joined Time Projection -technique as a tool for dynamic modelling. JTP-model is a suitable tool for planning environmental policy at the national level. JTP-model considers whole industry at the national level which makes it possible to simulate the changes of several decision factors (technology development, changes in consumption, policy decisions intended to redirect the material flows etc.) simultaneously. In this study both environmental and economic implications of two scenarios were studied. The basic scenario was built on the assumption that no major changes will take place during the study period. The adapted scenario presents an alternative policy option with two changes to the basic scenario: more waste incineration capacity will be built and all the sludge from de-inking will be thermally treated. Three aspects were chosen to analyse the changes in the material flows of Austrian printing papers in the two scenarios: the amount of waste landfilled; environmental impacts of the waste generated; and waste management costs.

# **1 JOINED TIME PROJECTION -MODEL AS A TOOL FOR PLANNING NATIONAL ENVIRONMENTAL POLICY**

JTP-model has proved to be a more suitable tool for planning environmental policy at the national level than traditional Life Cycle Inventories. LCIs are applicable when analysing the environmental impacts of a single product in a static situation using historical average data. JTP-model, instead, considers whole industry at the national level which makes it easier to simulate more reliably the changes of several environmental and other decision factors (technology development, changes in consumption, policy decisions intended to redirect the material flows etc.) simultaneously. JTP-model takes into consideration several dynamic changes in the future (which usually is the case in reality) and thus makes it possible to assess different policy options. This is the main advantage of JTP-model compared to traditional LCI. (about JTP-model, see Gronow & Pento, 1995)

The structure of the JTP-model is described in figure 1. Annual material flows are determined on the basis of variables from the collected data. They, in turn, are used to calculate different implications such as consumption of raw materials or energy, emissions, waste generated or changes in imports or exports. The model can be made dynamic by drawing the annual estimates together which makes it possible to estimate changes in any of the variables in the future during a given period of time.

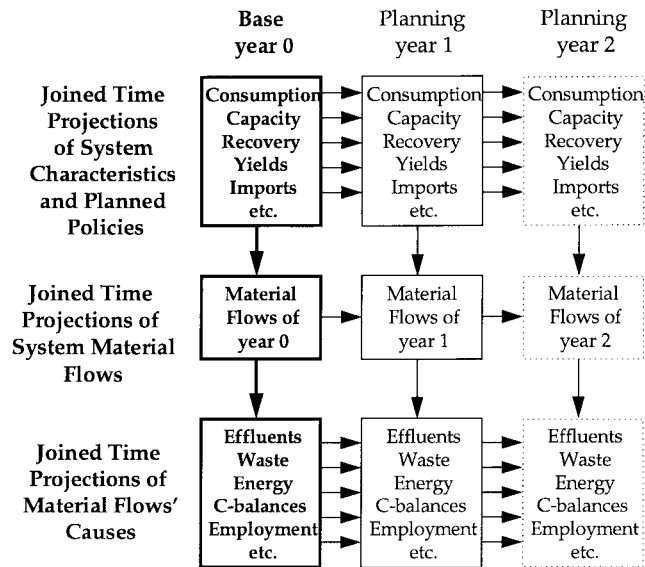


FIGURE 1 Structure of the Joined Time Projection -model (Gronow & Pento 1995)

The main advantage of the JTP-model is that it allows the researcher to make detailed and quantified estimates and scenarios in the future. Several variables and their changes over time can be evaluated in chosen scenarios simultaneously. JTP-model gives the possibility to analyse dynamic changes of material flows in a multivariable case.

Lack and inaccuracy of data is the biggest problem for JTP-model. This is a common problem for all material flow and LCI techniques and will not be discussed in detail in this working paper.

## **2 MATERIAL FLOWS OF AUSTRIAN PRINTING PAPERS IN 1994-2001**

Basic scenario was built on the assumption that no major changes will take place during the study period. Predictable changes in paper consumption, recycling etc. were taken into account, but according to the basic assumptions no new de-inking capacity would be built and no major changes would take place in the waste management system.

Following assumptions were made concerning the basic scenario:

1. Amount of recycled pulp in paper production will increase steadily (newsprint to 84 %, fine papers & magazine papers to 12 %)
2. Recovery rate of paper will increase to 75 %
3. No new de-inking capacity will be built; present capacity will be 100 % loaded
4. No major changes will take place in waste management system; waste incineration rate will be 26 %

Estimates of paper consumption determine the annual material flows in the model. Paper production and de-inking capacities are taken into account. This basic data is used to calculate estimates on imports and exports of both paper and recycled paper and on the amount of collected paper within the target country (this case in Austria). Predictable changes in technology and their implications to material flows are included in the basic model.

Adapted scenario represents an alternative policy option with two major changes compared to the basic scenario: more waste incineration capacity will be built (the amount of waste incinerated will rise from 26 % in 1994 to 50 % in 2001) and all the sludge from de-inking will be thermally treated. This simulation is an example of how the JTP-model can be used to compare different policy options considering simultaneously several changes which are facing the industry.

In this study special attention was paid to the implications of material flows to waste management issues. One of the major environmental problems

that the societies are dealing with in today's world is the enormous amount of waste we are generating continuously. Many countries face growing problems trying to manage the stream of solid waste in an economically sensible and environmentally safe way. Three aspects were chosen to analyse the changes in the material flows of Austrian printing papers in the two scenarios:

1. The amount of waste landfilled
2. Contribution of the waste generated to global warming
3. Economic impacts of the waste generated

## 2.1 The amount of waste generated

One aspect of the waste problem is that densely populated areas have serious difficulties trying to find suitable ground for landfills. Governments have reacted to this problem by setting various laws and restrictions concerning minimisation of waste, landfilling (location and safety), recycling rates etc. In Austria minimisation of landuse for landfill purposes is even included in the Austrian Waste Act which includes four goals: 1. protection of the people and the environment 2. saving resources and energy 3. minimisation of landuse for landfill purposes and 4. safe and sustainable final disposal for waste.

Paper and board form the second largest fraction of municipal waste after biowaste (in average 26 % of all municipal solid waste in the EU countries, 20 - 34 % depending on the country and the statistics, see European Commission, 1996) and this is why the decisions concerning recycling and waste management of this fraction have important effects on the total amount of waste ending up at landfills.

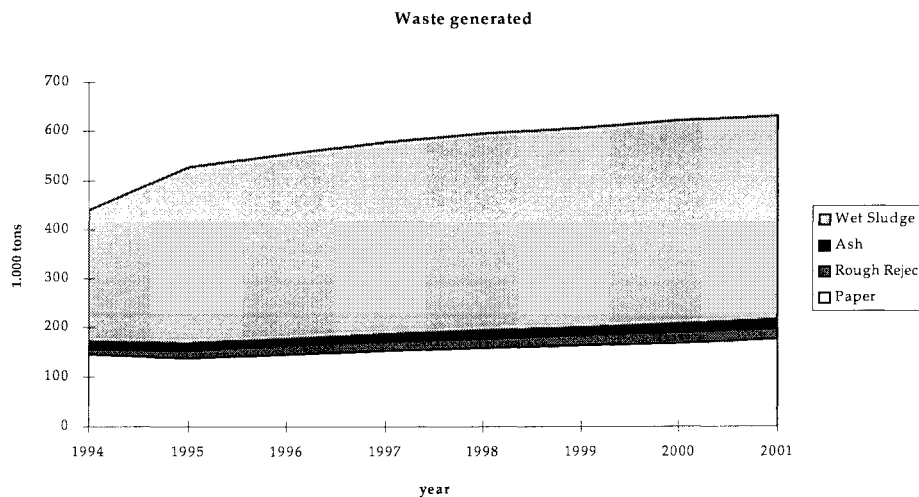


FIGURE 2 Waste landfilled in the basic scenario 1994-2001

Figure 2 presents the amount of waste ending up at landfills in the basic scenario. Even though the recycling rate of paper increases the total amount of waste landfilled (440.000 t in 1994 to 632.000 t in 2001) will continuously grow, because the consumption of paper increases simultaneously. Largest single fraction of waste is sludge from de-inking (66 % in 2001).

Figure 3 presents the corresponding situation for the adapted scenario. The total amount of waste landfilled is about 50 % less than in the basic scenario (245.000 t in 1994 to 288.000 t in 2001). Also the composition of landfilled waste has changed: the amount of incineration residuals (ashes) increases during the period when incineration rate grows. In the last model year 2001 it already makes 53 % (178.000 t) of all the waste landfilled.

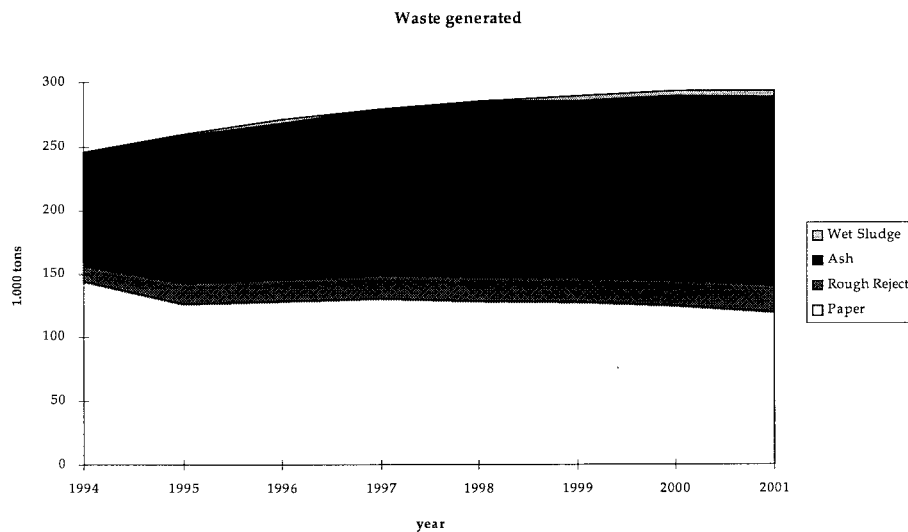


FIGURE 3 Waste landfilled in the adapted scenario 1994-2001

## 2.2 Contribution of the waste generated to global warming

The man-made global warming is attributed to the emission of gases which retain heat radiation which would otherwise be lost from the earth into the space. The gases thereby contribute to the heating of the atmosphere. The most important greenhouse gases are carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), nitrous oxide ( $\text{N}_2\text{O}$ ) and halocarbons. (About global warming and greenhouse gases see e.g. Wenzel et al., 1997 and Hauschild & Wenzel, 1997)

For the characterisation of the potential contribution of a given substance GWP (Global Warming Potential) factor is used.  $\text{CO}_2$  is set as the reference substance which means that the emissions of the given substance are expressed as so called  $\text{CO}_2$  equivalents.



Paper is an environmentally friendly product made of renewable resources. During the last decade or two paper and pulp industry has made great effort to decrease emissions to air and water and has succeeded in this depending on the emission by up to 90 %. According to Pilz (1996), however, industry's emissions responsible for the greenhouse effect have had little or no attention so far. United Nations' Kyoto Conference in 1998 brought up this important issue again. In this working paper the environmental impacts of the studied scenarios were evaluated using the amount of greenhouse gases from waste management as a criterion for comparison. CO<sub>2</sub> and methane (CH<sub>4</sub>) emissions from waste incineration and landfills were calculated to evaluate the environmental impacts of the waste management in the two scenarios.

Following assumptions were made concerning the calculation of the greenhouse gases of waste management:

1. Only CO<sub>2</sub> and methane (CH<sub>4</sub>) emissions were taken into account.
2. GWP factor of 25 was used for methane (GWP for time span of 100 years) as defined by the IPCC (Intergovernmental Panel on Climate Change). Results are presented as CO<sub>2</sub> equivalents. (for IPCC GWP factors see Albritton et al., 1995)
3. Only the emissions from waste incineration (emissions to air) and landfills (landfill gases) were considered in this study.
4. Moisture content was assumed to be 12,5 % for paper and 50 % for de-inking sludge.
5. Coal concentration was assumed to be 37,5 % for paper and 34,7 % for de-inking sludge (dry basis).

Only CO<sub>2</sub> and methane (CH<sub>4</sub>) emissions were considered in this study because they are the two most important greenhouse gases and also the main components of airborne emissions from incineration and landfills.

Carbon dioxide is the main combustion component of the carbon in the waste fuel. According to several studies it is found up to 98 % as CO<sub>2</sub> in the exhaust gas. (Schachermayer et al., 1995 and Stripple, 1995) For CO<sub>2</sub> the emissions should be presented as a net contribution. This means that such emissions which utilise some of the existing natural flows of carbon cycle (e.g. burning of biofuels, wood or straw) and would be broken down anyway are not considered as contribution to greenhouse gases emissions. Whether combustion of paper should be interpreted as the above mentioned type of process utilising existing natural flows of carbon cycle or not, is still unclear. Because the main raw material of paper is wood it would give an argument for not including this to contribution to greenhouse gases emissions. In this study, however, also the CO<sub>2</sub> emissions from paper incineration are defined as greenhouse gases.

Landfill gases consist of both CO<sub>2</sub> and methane. Share of methane in landfill gases was assumed to be 60 %. (see e.g. Pilz, 1996)

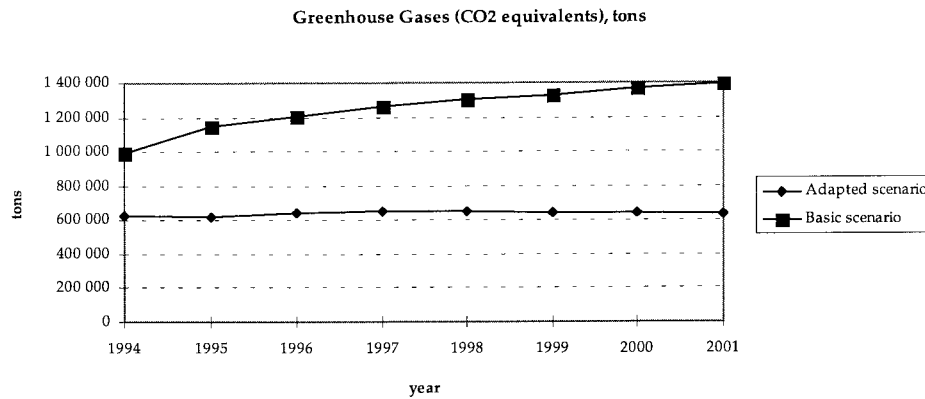


FIGURE 4 Greenhouse gases (CO<sub>2</sub> equivalents) from waste management compared in basic and adapted scenarios 1994-2001

Figure 4 presents the amount of greenhouse gases emissions in both scenarios. It is clearly obvious that the amount of greenhouse gases emissions in the adapted scenario is far smaller than in the basic scenario. The most important reason for this is that in the basic scenario the amount of waste ending up at landfills is about twice as high as in the adapted scenario and this causes greater methane emissions which in turn is a much stronger greenhouse gas than CO<sub>2</sub> (see assumptions above). In the basic scenario methane emissions grow by 40 % during the study period ending up at 53.300 tons in 2001 while in the adapted scenario they decrease by 15 % from 20.400 tons in 1994 to 17.800 tons in 2001. The calculated CO<sub>2</sub> equivalents for the basic scenario increased from 997.000 tons in 1994 to 1.388.000 tons in 2001 by 40 % while at the same time CO<sub>2</sub> equivalents for the adapted scenario stayed at the same level (about 600.000 tons/year). In 2001 CO<sub>2</sub> equivalents were 2,3 times higher for the basic scenario as for the adapted scenario.

### 2.3 Economic impacts of the waste generated

Waste management costs were calculated in both scenarios. Total costs in these both cases are shown in figure 5.

Total waste management costs are growing in both scenarios throughout the study period (by 39 % in the basic scenario and by 45 % in the adapted scenario) due to the increasing amount of waste. The costs in the adapted scenario are higher during the entire study period due to higher costs of waste incineration compared to landfilling costs. In 2001 total costs in the basic scenario are 20 % less than in the adapted scenario. According to the assumptions concerning the adapted scenario and the simulated policy changes in this case waste incineration will gain in importance as a waste management

method (up to 50% in 2001) and this is the reason why the costs in this case grow faster than in the basic scenario.

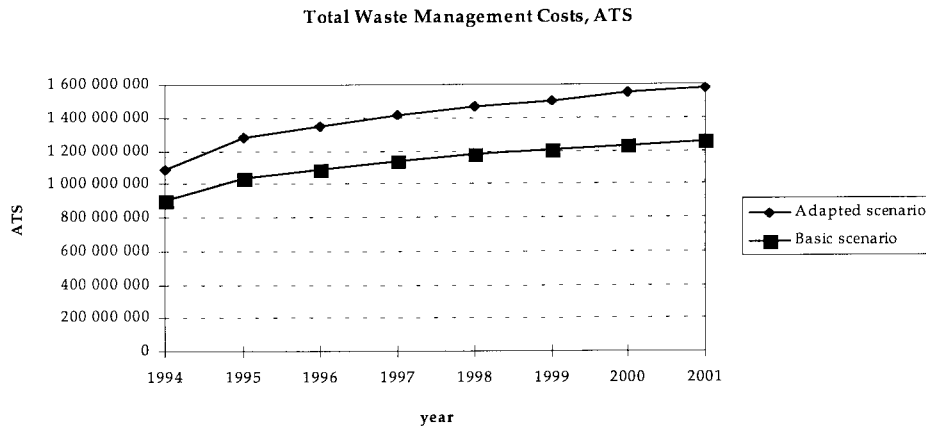


FIGURE 5 Total waste management costs compared in basic and adapted scenarios 1994-2001

The difference in the share of costs to different processes in the two scenarios is easy to recognise by comparing the figures 6 and 7. Figure 6 presents the costs of the basic scenario and figure 7 the costs of the adapted scenario. In the basic scenario landfill costs make naturally the largest part and correspondingly in the adapted scenario the costs of the waste incineration. In the adapted scenario the costs of other processes which gain in importance because of incineration (inert substances landfill, ashes final storage and their transportation) naturally increase but their share of the total costs is still quite small (13 % in 2001).

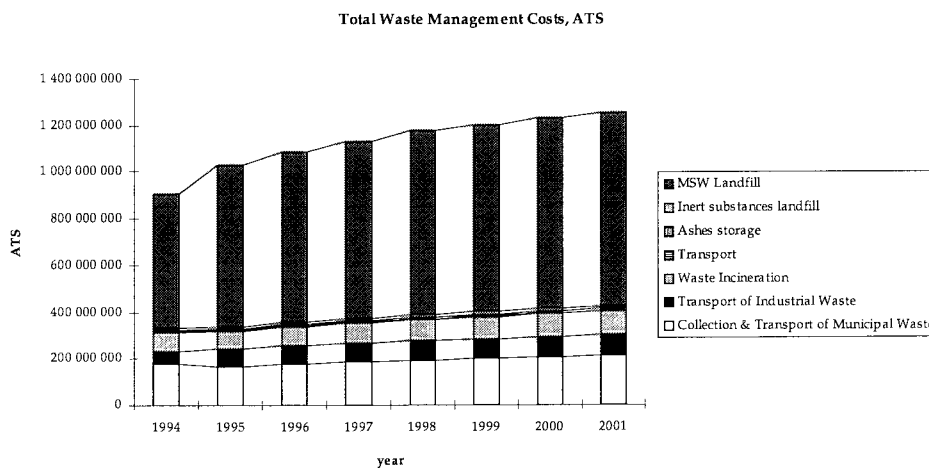


FIGURE 6 Total waste management costs in the basic scenario 1994-2001

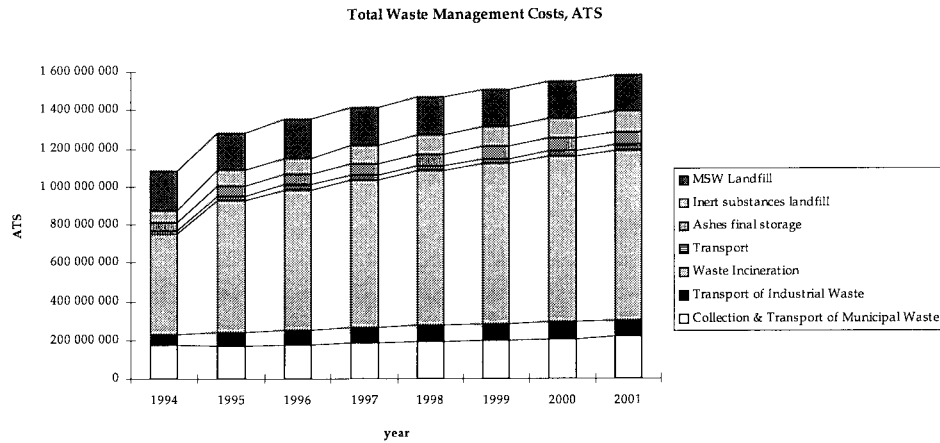


FIGURE 7 Total waste management costs in the adapted scenario 1994-2001

If we compare the costs/ton waste in the two scenarios, the increase of waste management costs is no more so fast as it seemed when studying the total, absolute costs. As already mentioned, the by far most important reason for the increase of the total costs in both cases is the increasing amount of waste. Figure 8 gives a very different picture of the situation compared to the total costs.

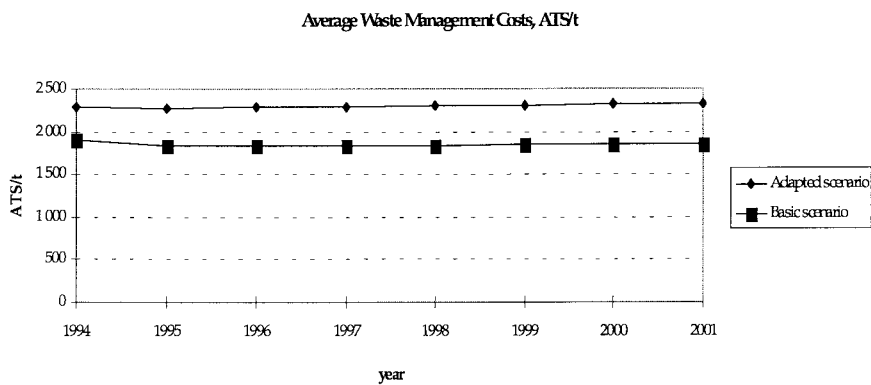


FIGURE 8 Average waste management costs (ATS/t) compared in basic and adapted scenarios 1994-2001

The average waste management costs have stayed at the same level in both scenarios throughout the study period. Only very slight changes can be seen: the costs of the basic scenario have decreased by 3 % and the costs of the adapted scenario have increased by 2 %.

### 3 CONCLUSIONS

Based on the experiences of this study dynamic material flow models proved to be a powerful tool for planning future policy options. In addition, they were able to offer a basis for both environmental and economic analyses and decision making. In the case study two different policy options were studied for the Austrian printing paper industry and more closely the implications to waste management. The basic scenario with no major changes to today's policy was found to be 20 % cheaper than the adapted scenario where the share of waste incineration was increased. The adapted scenario, however, proved to be a lot better from the environmental point of view: twice the amount waste was generated and 2,3 times more greenhouse gases were emitted in the basic scenario compared to the adapted scenario. The decision makers would in this case face the problem of valuation: are 20 % higher costs too much for the above mentioned savings in environmental impacts?

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