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Tito Gronow

Material Flow Models in Environmental Policy Planning

Case: Pulp and Paper Industry

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ABSTRACT

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The policy trend towards up-stream environmental solutions, i.e. pollution prevention at its source, tends to shift the basis for decision-making from an anticipatory understanding of the environmental effects of pollution to an overall assessment of production-consumption activities. Thus Life Cycle Assessment (LCA) and other Material Flow Models (MFMs) may provide new fields for policy development. This thesis explores the applicability of Material Flow Models (MFMs) to environmental policy planning, and applies in its research case analysis, scenario approach and secondary data analysis. The thesis analyses the applicability of the models to the material flows of a case industry, the pulp and paper industry. Various types of material flows are presented in the appended research articles, and their properties are compared for different functions of the industry. The appended articles are quantitative, and the research within the articles is deductive. The cross-article analysis is comparative, inductive, and qualitative research. Dynamic MFMs are in most cases more powerful tools for material flow management in environmental policy planning than static MFMs. Static MFMs serve well as identifiers for areas of improvement in a product's life cycle. The dynamism of MFMs proves to be of pivotal importance for environmental policy planning, particularly if many variables change under the analysis. Dynamic MFMs include a time horizon in their analytic framework and, thus, are able to predict and analyse changes and their impacts in the researched system. Linearity and stable external factors are found to be too strong an assumption in MFMs-based environmental policy planning.

Keywords: material flow models (MFMs), life cycle assessment (LCA), scenarios, policy planning, environmental management, time horizon, dynamic, static.

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FOREWORD

This thesis has been written during shorter and longer time intervals between 1995 and 2001. The thought process behind the thesis began in 1995 when the first article was formulated. In the beginning stages of writing this thesis, general knowledge of the research object as well as my understanding of it was limited. The writing process is now ending more than five years later, after the publication of four research articles and their analysis in this thesis. This process has taught me a lot, and I owe a great deal to many people and institutions that contributed toward my thesis and its completion.

First of all, I want to thank my wife Erna and my son Eugen for their help and support. Their patience and understanding allowed me to work on my thesis during many evenings and weekends. The completion of the work has so far taken more than the complete lifetime of my five-year-old son Eugen, who has also given me a necessary escape from the work when needed. In addition, Erna has been of great help in linguistical issues.

My supervisor Professor Tapio Pento at the University of Jyväskylä introduced me to the world of Material Flow Models (MFMs) and helped me to begin my research. I am also very grateful for his support, discussions, comments, corrections, and evenings filled with Finnish sauna and German beer during the writing process.

I also wish very warmly to thank my reviewers: Professor Peter Rogers, Gordon McKay Professor of Environmental Engineering of Harvard University and Professor Lassi Linnanen, Professor of Environmental and Quality Management of the Helsinki University of Technology. I met Professor Rogers first in Paris in 1996 where we both were doing consultant projects for the OECD. I have appreciated very much his kind attention since 1996, and this thesis has benefited much from his critical comments. I also owe many thanks to Professor Linnanen for his skilful and quick review of my thesis.

In addition, I thank Professor Hanna Pesonen from the University of Jyväskylä, who has been extremely helpful and often shared her time with me in sometimes very long telephone discussions on MFMs and many other issues. I also thank her for sending me countless articles and other materials, which assisted me adjusting the final content of my thesis.

Many thanks to the Academy of Finland, the University of Jyväskylä, the Finnish Cultural Foundation, and the Foundation for Economic Education. While writing my thesis, I first worked as a researcher of the Academy of Finland in an environmental management project, then as a lecturer at the University of Jyväskylä, and finally as an independent researcher sponsored by the Finnish Cultural Foundation and later by the Foundation for Economic Education. These institutions made it financially possible for me to write my thesis.

Furthermore, I wish to thank my colleagues at the Finnish Ministry for Foreign Affairs. Their friendship and discussion often enabled me to see my subject from other valuable perspectives. I also owe thanks to the various libraries from which I borrowed books and often returned them late.

Tito Gronow
Tehran, Easter Day, 15.4.2001

RESEARCH ARTICLES

The research for the thesis is mainly based on four appended articles prepared previously by the author. The articles aim primarily to examine the applicability of Material Flow Models (MFMs) for environmental policy planning in the pulp and paper industry. The articles are the following:

Article I Gronow, T. & Pento, T. 1995. Life Cycle Inventories and Joined Material Projections in National Environmental Planning. European Forest Institute's Proceedings No.8, 1995, Hamburg, pp. 225-240.

Article II Gronow, T. 1996. Les flux matériels des papiers d'impression en France pendant la période 1993-2000. Papier, Carton et Cellulose, Nov. & Dec. 1996. Paris. pp. 76-80, 101-106.

Article III Gronow, T. 1997a. Effluent Generation from Paper Production and Consumption in France. La revue ATIP. Paris. January 1997, pp. 32-37.

Article IV Gronow, T. 1997b. Effluents of Alternative Energy Sources in Swedish Paper Production. Energy & Environment, IV/1997, Essex. pp. 289-295.

The appended articles are referred to in this thesis either by their full titles, as appended research articles, or, particularly in references, simply as Article I, Article II, Article III, and Article IV.

CONTENTS

1 INTRODUCTION

1.1 The Outline of the Study

This thesis is prefaced with an **Introduction** chapter consisting of an overview of the regulatory trends in which Material Flow Models (MFMs) are emerging as new tools for environmental purposes. They are dealt with in Section 1.2 entitled **The Change of Approach in Environmental Planning**. The introduction continues with the presentation of the **Paper Cycle** in Section 1.3, which explores the different steps from cradle to grave of paper products so that the reader might understand the industrial context of this thesis as well as major environmental issues related to it. The **Research Area and Focus** are presented in Section 1.4.

Chapter 2 provides a general presentation of **Material Flow Models** (MFMs). Section 2.1 presents a **Short History** of Life Cycle Assessment (LCA) and MFMs. Section 2.2 aims to define what **Material Flow Models** are by highlighting the concept development, basic structure and function of LCA and other MFMs. Section 2.3 discusses LCA and MFM **Standardisation and its Limitations**, followed by a brief discussion of some of the major methodological limitations of Life Cycle Assessment (LCA); it also discusses limitations that have not been satisfactorily solved by standardisation and which are particularly important in a policy planning context. Section 2.4 is **a Review of Material Flow Models** in which the final choice of the two models best suited to tackle the research problem is justified in Section 2.5.

Chapter 3 highlights the focus of environmental policy planning from the point of view of Material Flow Models. In Section 3.1 the **General Context** for MFM-based policy planning is presented. Section 3.2 moves on to the **Application of Material Flow Models at the National or Industrial Level**, and also touches on the characteristics of successful MFM-based policy planning. In contrast, Section 3.3 discusses the **Application of LCA at the Corporate Level**.

Chapter 4 presents the **Methodology** of the thesis. The research method is first discussed, then key concepts behind the methodology, as well as some of their inter-relationships. Section 4.1 presents the **Research Design** of this thesis. Section 4.2 presents a **Case Analysis** that is one of the main tools in the methodological framework of the thesis. The focus is on theory building from case study research. In Section 4.3 the other main element of the methodological framework, **the Scenario Approach**, is presented and discussed. Section 4.4 discusses **Validity and Reliability** issues. Section 4.5 examines **the Limitations and Assumptions of the Research**.

Chapter 5 presents **a Comparison of the Chosen Models**, i.e. Joined Time Projection and KCL-ECO modelling techniques, which in the appended research articles have been applied by environmental planning in the pulp and paper industry.

The conclusions of the thesis — conclusions that address the research questions defined in the Section 1.4 — are drawn in Sections 5.1 to 5.5 by a comparison of the chosen models. In Section 5.1, chosen models are compared by first presenting **the Methodological Framework of the Models**. In Section 5.2, this is followed by a presentation of similarities and differences in the chosen models on the basis of their **Linearity Versus Non-Linearity**. In Section 5.3, the importance of the **Time Horizon** is discussed, followed by a presentation of examples from the appended research articles that are used to demonstrate the applicability of dynamic and static material flow models to environmental policy planning. In Section 5.4, the applicability of the models to environmental policy planning is further demonstrated in terms of different **Applicability Areas** of environmental management where material flow models are typically applied. In Section 5.5, the final **Conclusions of the Comparison of the Chosen Models**, which answer the main research problem are presented.

The four previously published articles on which the research is based are republished at the end of this thesis.

1.2 The Change in Environmental Planning Approaches

For most countries, the first wave of environmental legislation has traditionally focused since the late 1960s, on the end-of-pipe control of emissions such as waste water, dust, SO_2, etc., in an effort to protect human health and the local environment. The command-and-control environmental policy planning, required for the end-of-pipe approach, was dominant for more than two decades. While the volume of emissions and discharges has been substantially reduced, these achievements have also resulted in shifting pollution across media and high treatment costs. As the pollution limit values have become stricter, the marginal costs of effluent reduction have increased exponentially. (Rajotte & Gronow, 1996)

In order to avoid the costliest trade-offs associated with pollution control strategies, national legislation in industrialised countries has since the early 1990s been characterised by efforts to prevent pollution at its source (SPRU, 1996). Examples of pollution prevention at its source are the 'Precautionary Principle' and the 'best environmental industrial practices' schemes initiated by governments. These schemes contain many regulations and guidelines used in setting environmental rules. These rules, in turn, aim at sustainable behaviour and the prevention of harmful releases in the use of natural resources. This policy trend towards up-stream environmental solutions tends to shift the basis for decision-making from an anticipatory understanding of the environmental effects of pollution to a 'cradle-to-grave' environmental assessment of industrial processes. (Gronow & Rajotte, 1997)

Increasing awareness of environmental problems has raised national and international efforts in environmental policy making. The sustainability of economic and social development has become a high-ranking goal. It is even one of the leading ideas of Agenda 21, which was agreed upon at the UNCED-Conference in Rio de Janeiro in June 1992. At first glance, the idea of sustainable development seems to promise improved future conditions for products originating from sustainably produced renewable resources, in contrast with those of non-renewable, exhaustible ones (Thoroe, 1995). In the European Union (EU), the principle of sustainable development was further stressed in the Treaty of Amsterdam, which was signed in 1997 and entered into force in 1999.

Even though conventional policy tools, for example risk assessment and cost-benefit analysis, still provide essential guidance for setting environmental standards, they are generally based on an understanding of the ultimate fate of pollutants in local environments. The generation of waste is increasingly a public health problem, due to two factors in waste streams: waste volumes and toxic elements. (OECD, 1992)

To reduce waste volumes and toxic elements, the following should be undertaken by policy planners:

- Products should be encouraged to have longer life cycles;
- Products should be re-used or offered for secondary use;
- Dispersion in nature of products containing toxic substances should be prevented.

In waste management policy, economic instruments are not in general used extensively, although prices prove to be an important factor in proper waste handling. Waste management is an intricate field containing many pitfalls. One of the major problems from an environmental point of view is the often unknown synergistic effects of final waste due to many different substances in a specific waste stream. (OECD, 1992)

The need to promote internal, up-stream solutions to industrial pollution problems has prompted the development of a new set of analytical instruments that consider the impacts of the production and consumption cycle. Among these 'second generation' sets of analytical tools, Life Cycle Assessments (LCA) along with other Material Flow Models (MFMs), are emerging as a means of extending the capacity of producers and regulators to understand the overall environmental consequences of production-consumption activities. LCAs can facilitate the assessment of current policy decisions and even the forecasting of the environmental influences of a policy decision. Thus, information gathered through the LCA process may challenge pollution prevention strategies by considering the impacts of the full cycle of the production and consumption of products.

Focusing on the life cycle of products captures the process impacts, while the inverse is not the case. Specific policies and standards (e.g., waste management policy, recycling quotas, and "end-of-pipe" standards), may have negative trade-offs mostly in terms of displacing or even increasing the quantity and/or toxicity of environmentally harmful releases or practices (i.e. the closure on air emissions via control devices may increase energy uses and toxic waste). Also, specific policies and standards may lead to unintended environmental and social consequences, as well as act as barriers to international trade. Therefore, environmental policy that increases paper recycling in European countries may diminish exports from resource-rich countries, with potential adverse economic and environmental effects. (Reinstein, 1994)

1.3 Paper Cycle

The pulp and paper (P&P) industry has been chosen for this research as a case example because it is a large, well established industry that represents around 2,5 per cent of the world's industrial production (OECD, 1999). The P&P industry has invested in significant environmental improvements since the late 1970s (Pento & Karvonen, 2000). For example, water emissions have been reduced by 90 percent since the 1970s in Nordic countries (FEI, 1998, FFIF, 1999). In the 1990s, environmental investments have represented up to 19 per cent of the total investments in certain European countries (IIED, 1996). Nevertheless, the relative environmental friendliness of the P&P industry has been under debate in the political, popular, and even scientific arenas. An additional reason for choosing the P&P industry for this thesis is the existence of tools to measure the industry and its effluents and, consequently, to provide access to reliable data. The P&P industry has conducted Material Flow Model assessments and been a target for public policy based on Material Flow Models. The choice of the P&P industry also allows the researcher to focus on the environmental consequences of different policy scenarios.

The paper cycle, i.e., the different steps from cradle to grave of paper products, is briefly presented in this section in order to assist the reader in comprehending the industrial context of this thesis, as well as major environmental issues related to it. Thus, this section does not aim to present in detail the newest research on specific issues related to the paper cycle, but rather strives to provide a general overview of the different stages of LCA.

The paper cycle starts with forest management, i.e., the planting of trees, nutrient regulation, pest and disease control, land configurations, and wood harvesting (fibre production). This is followed by pulp and paper (P&P) production, the manufacture, distribution and consumption of products, the transport required between the different stages and the management of used paper products, reutilization, recycling, incineration or energy recovery, and, finally, landfills. Each of the stages of the cycle generates environmental impacts that are interconnected. This means that anything that changes in one element of the cycle may have repercussions on other elements both up- and down-stream. For example, when new types of papers are introduced, new printing methods may have to be developed with different impacts to the environment. This thesis pays particular attention to the following stages of the paper life cycle: pulp and paper production, energy production, recycling and disposal stages of the paper cycle.

1.3.1 Product Design

Environmental problems resulting from the paper cycle should preferably be resolved at the design stage of products and during associated manufacturing processes, as well as during the consumption and recovery processes. Finding internal innovative measures against polluting and/or waste-creating practices may lead not only to environmental gains but can often translate into more competitive products that lead to so-called win-win situations (Karvonen, 2000). MFMs may offer help in product design and product development to the extent that alternative processes may be more expensive or less environmentally friendly. Until the new technologies are demonstrated, though, consumers may be hesitant to change products.

The limitations of the current technology must naturally always be taken into consideration in product design. Product specifications and technological developments have major influences on how different paper types are produced. Product requirements are usually derived partly from market signals, e.g., brightness and strength. Printing paper manufacturing has developed toward lighter basis weights and smoother, brighter sheets which require brighter filler minerals and increased use of colour in printing papers. The printing industry demands lighter weights because it can thereby get more sheets printed for the same money. The paper maker wants to use more minerals because they cost much less than wood fibres and improve paper quality (Loughbrough, 1994, Linnanen, 1995). There are also increased demands from the manufacturers of copiers for brighter and more opaque paper. In order to improve profitability, some producers have also started to use new tree species such as aspen for papermaking.

The appended Article III, *Effluent Generation from Paper Production and Consumption in France* (pp. 35-37), highlights some aspects and limitations of the product design based on LCA. The total emissions of the P&P industry can be lowered in hypothetical scenarios by substituting one paper grade for another.

1.3.2 Forest Issues

Forestry is associated with several environmental issues such as: 1) biodiversity, 2) the reduction of nutrients and humus in the soil, 3) carbon cycle, 4) impacts on aesthetic, recreational and cultural values, and 5) occupation of the limited resource productive land area (Kellomäki, 1998). Forestry issues are multi-dimensional, and most of them are merely briefly discussed here because they fall outside the scope of this thesis. Nevertheless, certain processes including, harvesting, reforestation (including the use of fertilisers and growing) should be included in environmental policy planning with material flow models. This recommendation is consistent with standard 14040 of the International Standardisation Organisation (ISO, 1997), which states that the system investigated should be modelled in such manner that materials entering the system are drawn from the natural environment (Ekvall, 1999a).

The basic raw materials used in pulp manufacture are renewable lignocellulosic fibrous materials. In developed countries, wood is the main ingredient for pulping. Wood supply in developed countries is currently sustainable in the sense that cuttings are much below new growth (OECD, 1999). In many developing countries, wood is in short supply, and more than 45 per cent of the pulp is manufactured from other fibrous materials such as straw, bagasse, and bamboo (IIED, 1996). In spite of this, the non-wood pulp is not of economic or environmental importance in developed countries and, therefore, only wood-based pulp is researched in this thesis.

Since the mid-70s, much concern has been voiced about the environmental soundness of forest management in industrial countries (IIED, 1996). The unsustainable harvesting of forests may have an impact on the atmospheric concentrations of CO_2 (Kellomäki, 1998). This depends in part on how the timber resource is managed. However, as the scientific understanding of forest ecosystems remains limited, the choice of harvesting methods and how they are carried out, their short- and long-term consequences, and their environmental costs or benefits, are complex and controversial issues and depend in part on the specific conditions of local sites.

The P&P industry is often pointed out by environmental groups as a major contributor to the deforestation rates (Kroesa, 1990). However, the P&P industry claims that P&P production figures lead to another point of view: in the United States, the annual percentage of harvested timber that was used for pulpwood in 1999 amounted to 27 per cent (OECD, 1999), much of this in the form of by-products from sawmill operations (Rajotte & Gronow, 1996). The Japan Paper Association reported similar figures (25 per cent of timber harvest for pulpwood), claiming that 46 per cent of virgin domestic wood pulp and 50 per cent of imported virgin wood pulp came from low grade roundwood, unsuitable for lumber. Other sources of raw materials came from sawmill residues, logging residues, and damaged wood (JPA, 1997). According to the Finnish Forest Research Institute, about 90 per cent of harvests are used for industrial purposes, and 60 to 65 per cent of wood purchased by industry is pulped (METLA, 2000).

While these data suggest that pulp production does not represent a critical threat to deforestation globally, questions are still raised about the ecological impacts of local practices. Several harvesting methods exist, clearcutting being one of the most controversial. Because of the utilisation of clear cuttings, the forest industry has often been accused of sacrificing the biodiversity of forest ecosystems for the sake of fast profit (Council on Economic Priorities, 1992). It is mainly criticised for reducing a once-diverse ecological environment to a monoculture where few species can survive. It also causes erosion, sediment water pollution, and creates ugly landscapes.

The forest issue has important implications for the future of the P&P industry. As it stands, the strategy of some groups within the environmental movement links the ecological protection and enhancement of forests to an important reduction of the consumption of virgin fibre products. Increased attention to environmental issues has pushed some companies to apply for national ecolabels in order to improve the attractiveness of their products. The industry is becoming increasingly interested in forest certification issues (Valtanen, 1998).

Forest certification has been an issue of interest for environmental policy planners too. Forest certification focuses on forest issues and, therefore, the beginning of the P&P product life cycle. There are different types of schemes that aim to establish common rules for sustainable forest management. Nevertheless, there have been suggestions for a more comprehensive approach to forest certification, an approach that would examine other steps of the paper life cycle. (Valtanen, 1998) The different criteria of the different types of forest certificates can be relevant for the assessment part of MFMs (see Section 2.3.), but not for the inventory part of MFMs that are focused in this thesis.

1.3.3 Pulp and Paper Production

The P&P industry has long been a focus of environmental concern. Until the 1970s, the industry was weakly regulated and was then associated with some of the worst industrial environmental pollution in the world. Owing to a combination of regulation and effective industry innovation, the most urgent and obvious environmental problems have been successfully addressed. Regulations in many countries now strictly control the quantity and quality of different emissions. Chlorine in bleaching processes has been banned in many developed countries. Air emissions standards relevant to pulping processes generally limit unit output emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), and particles (TSP). Water discharges are controlled in many developed countries for total suspended solids (TSS), and organic content which is regulated through the implied biological and chemical oxygen demands (BOD and COD) (Hynninen, 1998).

Wood from forests is first converted into pulp in pulp and paper mills. Pulp is manufactured by separating the united fibres from one another. Fibres can get separated only if the gluing substance, lignin, between the fibres is either dissolved by cooking in chemicals or softened in a grinder or refiner. The first method is called chemical pulping, and the second is called mechanical pulping. The desired properties of the end-product determine whether chemical or mechanical pulp is used. (Sundström, 1999)

Industrial processes used to separate the fibrous and non-fibrous materials from wood fibre are responsible for large quantities of organic waste. In chemical pulping, large quantities of chemicals are used to dissolve the non-fibrous materials (e.g. lignin, gums, etc.). Both solvent and solute are then flushed out, using water. On a unit product basis, pulping therefore generates large quantities of contaminated effluent, which may (or may not) be fully recovered. The recovery of the used chemicals forms an essential part of any chemical pulping process (Sundström, 1999). One reason for this is economy; the chemicals and the dissolved lignin have significant economic value. All or almost all modern mills convert some quantities of these by-products in energy. Another reason for the recovery of chemicals is environmental protection. If allowed to escape into the environment, the effluent has high COD and BOD, which can cause the eutrophication of receiving water courses. In addition, the effluents contain chemical contaminants resulting from the pulping and bleaching processes. Among these are sulphur (S), which is environmentally acidifying, and clorine (Cl), which can react with organic matter to produce organo-chlorines (Hynninen, 1998).

The next step in the papermaking process is bleaching, which is done in order to increase the brightness of pulp, often much darker than the wood itself. In the late 1980s, there was great pressure from NGOs and, consequently, intervention from national and international regulatory bodies for substituting chlorine used in bleaching processes. The P&P industry shifted its processes and started to use extended cooking in combination with totally clorine-free bleaching agents such as oxygen and peroxide (Hynninen, 1998).

The aim of the papermaking process is to form a uniform web with desired properties of the fibres and other raw materials. The papermaking process itself includes the following major unit processes: 1) furnish preparation, 2) forming, 3) pressing and drying of the web, 4) coating in the case of coated paper, 5) calendering, and 6) winding and packaging (Leiviskä, 1999).

As different types of pulp have rather different properties, most paper grades are manufactured from a mix of pulp rather than from a single pulp. After the selection of appropriate pulps into a furnish, the fibres of the furnish are refined. The aim of the refining is to improve the bonding ability of the fibres and thus enable the formation of a uniform sheet with the desired properties. Thereafter, the furnish is screened and cleaned in order to remove fibre bundles and impurities from the furnish. This is followed by the addition of fillers and other chemicals. The filler suspension is prepared separately. The amount of fillers varies according to the paper grade but may be up to 30 per cent of the weight of the fibres (Ryti, 1988).

NGOs and consumers have loudly voiced forth their objection to the use of chemicals in the P&P industry. A Greenpeace report (1993), underscores that approximately 3.000 chemicals are being used for the production of paper, among them formaldehyde resins in chemicals for wet thickening; chlorine in chemicals for disinfecting; cadmium, chrome and chlorine amalgamations; as well as supposedly highly toxic dioxins in colour former. Greenpeace claims that many of these chemicals act as barriers to the recycling of paper products. Of course, this statement must be put in the right context: the P&P industry produces about 2.000 kinds of paper, each of them using only a few main chemicals (Baumann & Herberg-Liedtke, 1994). The corresponding share of the production of the chemicals is often included in environmental inventory analyses of the paper production.

After the furnish has been prepared, the web is formed in the wire section of the paper machine. This is the most important unit operation in the papermaking process. The fibre suspension is first diluted to a very low consistency, about 1 kg fibre per 200 kg water, and then distributed across the width of the paper machine and made into an endless stream of paper web on the fast-running wire. The water that drains from the wire is recycled. After this, the paper web is pressed dry. The rest of the water in the web is removed by steam-heated drying. Before reeling, the dried paper is often treated in a machine calender in order to increase the smoothness and make the paper thinner and less bulky.

The paper surface may be coated with a thin layer of pigment particles to improve its appearance and printability. After this coating, the paper is often supercalendered in order to make its surface glossy.

Because of the remaining ecological issues linked to P&P effluents, research and development (R&D) activities have been aiming toward closed-loop paper mills (Gleadows, 1993). Still, experts have stated that it would be difficult to fully recycle the effluents and, also, that new problems arise in the process.

1.3.4 Energy

The sector's demand for commercial energy does contribute to the atmospheric build-up of climate-relevant gases through emissions of carbon dioxide (CO_2), and represents a further aspect of the sector's potential environmental impact.

Both pulp manufacture and paper making are energy intensive; in particular, mechanical pulping requires lot of energy. The amount of energy needed in chemical pulp can be recovered from the non-fibrous organic wastes to meet these needs (Mauranen et al., 1993). In fact, chemical pulping is becoming a net electricity producer (Axegård, 1995). In addition, some paper companies have built combined heat and power (CHP) plants in order to supply steam and electrical energy for the company's own processes. These CHP plants may also supply electrical energy and district heat to the local community. On the other hand, it must be observed, that some companies are selling their power stations and concentrating only on P&P making.

It should noted here that a process with more than a single function, such as a CHP or energy used in more than one product, may lead to an allocation problem in the assignment of environmental loads of the energy used in a certain product (Frischknecht, 1998).

Several studies have raised the importance of the energy input in the LCIs of paper products. The energy input can represent a major share of the emissions (Article III, pp. 33-34). Most of these studies have focused on reducing the energy costs of a single product. Material flow model studies have also been used as a tool for national energy policy planning, as shown in the appended Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*. Average data is often used in studies, but it has recently been suggested that energy data from the specified technology should be used in the LCA, rather than average or marginal data for the geographical area (Kåberger & Karlsson 1998).

1.3.5 Transport

Making transport more environmentally sustainable represents a key challenge for the future. Moving people and goods already puts intolerable pressure on the environment, natural resources, and quality of life. All indications are that it will cause ever greater global environmental degradation unless ways are found to make transport activities cleaner, quieter, and more efficient. (OECD, 2000)

Transport-related issues are broadly included in MFM-based studies. Emission inventories are the most common transport-related application of MFMs and also the application used in this thesis. In addition, MFMs can be used in the transport context to modify the patterns, nature, and level of transport, as well as to examine technology-based solutions.

The environmental effects of transport in the P&P industry arise from the transport of wood and other rawmaterials (fillers, coaters, chemicals). Transport comprises shipment to the mill, the inter-mill moving of materials (sawdust from sawmill to pulp mill, pulp to paper mill), and the delivery of final products from mills to users. Transport is also needed in the recovery and sorting of used papers being delivered for re-use. Transport emissions can make up a sizeable portion of the emissions of a paper cycle. In MFM studies, transport is often regarded as part of the operation to which the transport is performed. (Strömberg et al., 1997)

Fuel consumption of vehicles by gross vehicle-weight categories, as well as data for unloaded vehicles, are generally available for transportation of P&P products and calculated in life cycle inventories. National estimates of fuel consumption expressed as kilometre per ton are given for railway freight, marine transportation, and pipelines. Transport issues may be pivotal for LCAs comparing emissions of alternative scenarios. (UPM-Kymmene, 1999)

The marketplace exhibits considerable, and often very complex, patterns of behaviour. Quite clearly, the industry is moving closer to the market, an example of which is the Nordic companies' acquisitions in Germany and France. This in turn means shorter transport distances for paper products.

1.3.6 Recycling

In some countries, waste paper accounts for more than 60% of the input materials in the production of paper and paperboard products. This figure is expected to increase to 70% in some countries in the near future (CEPI, 1998). At present, waste-paper use for the manufacture of new products is generally higher for packaging and paperboard material, followed by tissues and newsprint. It is lowest for other printing and writing papers. These differences are mainly due to factors such as the quality requirements of the final product, consumer acceptance, and the availability of well-sorted waste paper.

Achieving recovery goals depends on the existence of an efficient recovery system. Unlike solid waste collection in general, for which responsibility lies with the municipalities, waste paper collection has usually been a commercial business in the hands of private merchants and waste paper dealers. As a result, it has an important economic dimension in being driven by and satisfying the cost/benefit considerations of private enterprises. That, in turn, can have a significant impact on the stability of supply and prices, as well as sorting activities, since the resale price of waste paper is often low in relation to the cost of collection. This low price tends to act as a disincentive. Waste paper prices have become notorious for their rapid price fluctuations. For example, the price of mixed used sorted paper and board in Germany was a negative -20 to -30 DEM/ton in the first quarter of 1994, and exploded up to 150 to 175 DEM/ton by the fourth quarter of the same year (PPI, 2000).

The collection of used materials has been the target of many governmental initiatives through both voluntary agreements and mandatory objectives. The guiding motives behind recent government regulations for packaging waste differ, but it appears that environmental concerns rank very high. These are termed differently, i.e. the minimisation of waste destined for landfill and avoidance of environmental pollution. (OECD, 1995) The numerous recycling laws, ordinances, and administrative rulings that have been decreed in Europe and America since the late 1980s can be given as examples (Göttsching & Putz, 1994). The purpose of these provisions has been to direct a region or a nation toward sustainability by forcing the re-use of products or materials. This issue is discussed in greater detail in the appended Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning,* and practical applications are demonstrated in the appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000.*

Recycling is also the step in the paper cycle where most allocation problems occur. The allocation problem is discussed in Article I and to a minor extent in the appended Article III, *Effluent Generation from Paper Production and Consumption in France.*

Policy initiatives will establish new patterns of behaviour in the collection and trading of waste paper and its re-use in the paper industry. What impact those regulations will have is difficult to predict, since it will take some time before their effectiveness can be assessed. Increased recycling has several environmental implications, notably through transport (collection of waste paper), and energy consumption (increased consumption of non-renewable energy for recycling processes and reduced combustibility of waste stream, due to the reduction in paper content). A problem may arise in the enrichment of harmful substances such as cadmium in fibres. There is not "one technological panacea," but different treatments with different environmental and economic outcomes. The problem for policy-makers is to identify the optimal level to which paper recycling is environmentally sound, while taking into consideration the social consensus.

1.3.7 Disposal

Some studies have drawn attention to a number of environmental trade-offs that must be addressed when defining after-consumption policy. General opinion is often favourable towards recycling. All the disposal options should be known and discussed. It has been pointed out that recycling also is an industrial process. Even if recycling saves certain resources, it uses others (Boerner, 1994). Virtanen and Nilsson (1993) argue for paper incineration on ecological grounds, as a replacement for fossil fuels. The wood material contained in paper is a renewable raw material. In addition, the growth process of wood in trees absorbs coal from the atmosphere; thus, the incineration of paper does not necessarily speed up the greenhouse effect, but, on the contrary, can slow it down. A scenario maximising recycling could have both financial and environmental advantages (i.e., lower waste generation), but may notably increase the consumption of fossil fuels and thereby increase air pollution. Virtanen and Nilsson (1993) identify energy consumption as a key factor in the LCA of recycling schemes and they, as well as the appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, suggest that, under some circumstances, the burning of waste paper for fuel may be a more appropriate re-use from both financial and environmental considerations.

The research of the metabolism of landfills is still insufficient, and the design of landfills varies from country to country even in the European Union. Consequently, this means that the uncertainty regarding the emissions may be large. Still, it is clear that methane emissions from paper products decomposing in landfills are of importance for the environmental analyses of the paper industry. (Ekvall, 1999b, Galeano et al., 1996)

In general, there is an explicit approach in the solid waste management scheme where avoidance, re-use and recycling of materials rank higher, while heat recovery, incineration and landfills rank lower, as is the case in the EU waste hierarchy. These approaches introduce a joint responsibility of the entire supply chain of products and, to a certain extent, of the consumers who may be more or less involved, depending on their type of collection system (e.g., a waste management tax scheme as an incentive for consumers involvement in the program). (European Commission, 1999a, European Union, 1999)

The issue of different disposal options is studied in the appended Article II in scenarios with different paper recovery rates.

1.4 The Research Area and Focus

This thesis explores the applicability of Material Flow Models (MFM) to environmental policy planning in the pulp and paper (P&P) industry. The thesis is based mainly on four research articles prepared previously by the author and their comparison. In addition to the articles, the thesis reviews the use of LCA and other MFMs for policy-making in the P&P sector and analyses different types of MFMs.

This thesis strives to increase the knowledge and understanding of the use and applicability of Material Flow Models in environmental policy planning and to contribute to the scientific and practical discussion of the subject.

The main research problem is broken down further into the following more detailed issues, which this thesis strives to answer:

- What are common features and differences in modelling with the chosen material flow models?
- What is the role and importance of future-oriented material flow models in environmental policy planning? What is the role of the time

horizon? What are the advantages and restrictions of static and dynamic models?
- What are the applicability areas of the chosen models related to some common environmental policy issues related to the P&P industry?

Through addressing these detailed issues, answers are brought to the main research problem as well, i.e., the applicability of Material Flow Models to environmental policy planning.

2 MATERIAL FLOW MODELS

This chapter provides a general presentation of **Material Flow Models** (MFMs). Section 2.1. presents a **Short History** of LCA and MFMs. Section 2.2. aims to define what **Material Flow Models** are by highlighting the concept development, basic structure, and function of LCA and MFMs. Section 2.3. discusses LCA and MFMs **Standardisation and its Limitations**, followed by a brief discussion of some of the major methodological limitations of Life Cycle Assessment (LCA); limitations that have not been satisfactorily solved by standardisation and that are particularly important in a policy-planning context. Section 2.4. is **a Review of Material Flow Models** in which the final choice of the two models best suited to tackle the research problem is justified.

2.1 Short history

The first LCAs were created in the late 1960s and early 1970s (Hunt & Franklin, 1996). At the beginning of the 1970s, knowledge regarding the environmental impacts of industrial products on society was relatively limited. The first energy crisis in 1973 had a major impact on the introduction of LCA. It suddenly became important to know how much (fossil) energy went into the manufacture of industrial products. Originally, LCA was mostly used by environmental consultants for energy and other resource calculations. (Sundström, 1996)

In the late 1980s, LCA was "refound," and other MFMs were developed. Industrial firms and governments started to use LCA. The use of MFMs spread rapidly due to changes in pollution prevention and waste management legislations towards greater producer responsibility. The producer was beginning to be seen as responsible for the whole production chain, not only for the production plant. An example of this is the German packaging ordinance from 1990[1] (Bundestag, 1990). LCA was also used for energy inventories to reduce emissions and find alternative, environmentally friendlier or cheaper materials. In addition, cross-sectorial market competition and claims of environmental superiority of products of its own sector led to the more intensive use of LCA. (Hunt & Franklin, 1996)

In the beginning of the 1990s, researchers started to be interested in MFMs. The standardisation process of LCA started (see Section 2.3). During 1990s, industry supported LCA research financially, and industrial LCA practitioners became engaged in methodological debates. (SPRU 1996, Denison, 1996) In response to both the limitations and shortcomings in the LCA methodology and new challenges, new methodologies were developed. Some of their tools are consistent with traditional LCA and some differ greatly (Weitz et al., 1996).

Some analysts have suggested that the use of LCA has possibly already peaked, while others claim that LCA is "alive and well" (Kärnä, 1997). It has been suggested that industrial LCA practitioners may be taking a wait-and-see approach regarding LCA (or MFMs). New environmental policies may or may not encourage both public policy planners and the industry to increase the use of LCA (Curran, 1999). Hence, the future of LCA or MFMs is open. Fewer full-scale industrial product-based Life Cycle Assessments will probably be made, because the costs are high in money and time. In spite of this, customised or streamlined LCA models will most probably be used by companies. In addition, researchers continue with the methodological development of MFMs for wider purposes. (Weitz et al., 1996)

2.2 What are Material Flow Models?

Material Flow Models analyse the environmental effects that are created by the flows of materials and energy from their natural environment through production and consumption back to the natural environment. Material Flow Model-based analysis relies on the principle that human beings use materials from the natural environment in production and consumption activities. Raw materials are extracted from the natural environment into the anthroposphere. The materials enter into production processes that transform them into other materials or products, or transport them to other locations. This leads eventually to consumption, which is the ultimate driver of man-made material flows. Eventually, after disposal, the output or waste flows go back to the environment. (Pento, 1999)

The concepts of Material Flow Models and Life Cycle Assessment have developed and even to an extent "emerged" during the research process of this thesis, and they are still developing. When the research work of the author started in 1995, LCA was the dominating concept and was often understood to include all flow models. The acronyms LCA and MFMs were and still are used

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[1] Verpackungsverordnung

interchangeably, but along with the standardisation process of LCA it has become clear that LCA is a particular model among other models. On the other hand, the concept of MFM (Baccini & Brunner, 1991) is large and flexible and can be generalised to include many models (Pesonen, 1999a, Pento & Gronow, 1999). Thus, in this thesis, the concept of Material Flow Models is understood to be a generic title for different models including LCA. Material Flow Analysis is taken to mean any material analysis, whereas MFMs pertain to quantitative modelling.

Nevertheless, LCA is a widespread Material Flow Model, and its development has affected the development of other models. LCA is the only model for which an official standard has been developed under the authority of ISO. Therefore, the LCA and its limitations obtain more attention than the other models in this section.

In its simplest form, MFMs are material balance models which follow a product or a system during its entire life, i.e. from "cradle to grave." In principle, the 'cradle' is marked as the point where a raw material (e.g. wood) is taken from its natural environment including forestry issues. The 'grave' is where the product or its components are returned to the natural environment as waste. (Gronow & Rajotte, 1997) See Figure 1.

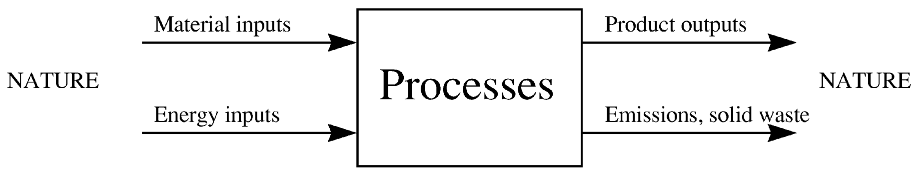

FIGURE 1 A material balance model

The use of a cradle to grave approach or Life-Cycle approach denotes the principle that a manufacturer (and his distributor) is (are) responsible for all environmental effects of a sold product, not only for those effects which arise at his production plant (Fava et al., 1994). In the case of the P&P industry, this means that manufacturers are held responsible for forestry issues, emissions from cradle to grave, and the disposal of end products and waste. In reality, the boundaries of a material flow analysis (MFA), are dependent on the objectives and the resources of the project. MFAs may be conducted from cradle to millgate (out), if the end product is under focus, from millgate to millgate if the production unit is under focus, or from mill gate to grave if the disposal options are under focus.

MFMs thus consist of complex processes and flows between the cradle and the grave. Processes are defined as transports; transformation and change of materials and goods; and flows as transports of products, materials, and energy between the processes (Pesonen, 1999c). MFMs are used to forecast and redirect the flows of an analysed product or system. This is also called Life Cycle Management or Material Flow Management.

2.3 Standardisation and Its Limitations

The relatively rapid spread of the use of LCA created a confusing situation towards the end of the 1980s, when environmental reports on similar products often contained conflicting results because they were based on different methods, data, and terminology. It soon became clear that there was a need for standardisation in environmental inventories and assessment (Heijung et al., 1996). Consequently, there have been different standardisation proposals for LCA, made by organisations such as SETAC (Society of Environmental Toxicology and Chemistry), starting in 1990, and ISO (the International Standards Organisation), starting in 1993. In addition to research groups, even industrial LCA practitioners have become engaged in methodological debates by sending experts to standardisation working groups and other forums.

The LCA methodology standardisation has established the four steps for conducting LCA. These steps are presented here because they may be applied more generally for other MFMs, even for those which are not product fixed. The first step is the determination of the goal definition and scope, which is followed by undertaking of an inventory. This second step is known in case of LCA as a Life Cycle Inventory (LCI). In this inventory all the material and energy inputs and outputs, as well as effluents and emissions produced by a product within boundaries that have been established case by case, are quantified and calculated. The third step Life Cycle Assessment is based on the inventory step. In the third step – also is called environmental assessment – the contribution of the items in the inventory is estimated to established classes of environmental problems, such as acidification or global warming. The assessment may in turn be followed by a fourth step called improvement assessment where environmental, technical, and economical improvements during the life cycle are suggested (Fava et al., 1994).

According to ISO 14040: "LCA is a systematic tool of assessing the environmental impacts associated with a product or service system to:

- build an inventory of inputs and outputs;
- make a qualitative and quantitative evaluation of those inputs and outputs;
- identify the most significant aspects of the system relative to the objective of the study.

LCA considers environmental impacts along the continuum of a product's life (i.e. cradle to grave), from raw materials acquisition to production, use, and disposal. The general categories of environmental impacts to which LCIs are related include resource depletion, human health, and ecological consequences.

LCA is a tool used to collect and interpret information for a variety of purposes. This information can be of assistance to those involved in:

- decision making;
- selecting relevant environmental indicators for performance

evaluation;
- marketing (claims or eco-label scheme).

The role of the main standardisation bodies SETAC and ISO is different. SETAC is a scientific organisation that gives guidelines for conducting LCA on a scientific basis. The proposals for the guidelines of SETAC are not seen as definitive by SETAC itself. The aim of the work of ISO has a more definitive and normative nature in creating an international standard. In spite of this difference, many of the same persons are working in both organisations.

In the framework of the International Standardisation Organisation (ISO), the ISO/TC 207 working party is dealing with standardisation in the field of environmental management tools and systems. Its mission is to provide global leadership in the understanding and development of international standards and guidelines in the field of environmental management tools and systems.

ISO 14040 – 14043 working groups under ISO/TC 207 work specifically with the standardisation of LCA. ISO 14040 focuses on environmental management – life cycle assessment – principles and framework, ISO 14041 focuses on life cycle assessment – goal and scope definition and life cycle inventory analysis. ISO 14042 focuses on life cycle assessment – life cycle impact assessment. ISO 14043 focuses on life cycle assessment – life cycle interpretation. (ISO, 1997, ISO 1998a, ISO 1998b, ISO 1998c)

The standardisation work in the working groups ISO 14040 – 14042 has progressed well and consensus was reached by 1998, while there were still considerable disagreements in the working group ISO 14043. (ISO 1998c, Lave 1995, Klüppel, 1998)

LCA standardisation has been primarily based on inventories and analyses of the products, services, or processes connected with each product (ISO, 1997, Fava et al., 1994). Both the ISO 14040 definition and the SETAC definition are close to the average single product LCAs. They exclude – depending upon the interpretation – material flow models that are constructed for national or industrial environmental policy planning. It has also been claimed that "the methodology for LCA being developed within ISO ignores the specific problems of forestry and forest products industry," including pulp and paper (Frühwald, 1995). Frühwald further states "that 'social aspects' or 'time effects' should not be considered in LCI and LCA. But these aspects are important in forestry."

There are still several limitations that have not been solved by standardisation, limitations relevant to the use of LCA when it is used in policy planning. Major questions that pose problems in LCIs concern the boundaries of the life cycle (see Article I, pp. 227-229), the allocation of emissions across the life-cycle to co-products, and along the life-cycle to recycled materials and the treatment of energy (see Article III, pp. 35-37).

According to ISO (1997), the systems boundary defines the unit processes that are included in the system to be modelled. Boundary rules also limit the scope or product system of the LCA, i.e., the avoidance of including all sub-systems or related industries in the analysis. The criteria used in setting the system boundaries will dictate the degree of confidence in ensuring that the results of the study have not been compromised and that the goal of a given study will be met. For example, when a paper mill uses a chemical, a boundary rule will exclude most of the life cycle of the chemical from the analysis. Different boundary rules will affect the inventory figures and may generate large inconsistencies in the inventory calculation. (Ekvall, 1999a, Weidema, 1997)

The allocation problems on which a compromise has been reached (ISO 1998a), leave certain methodological problems unsolved. Hence, there is a need to refine the methodology (Ekvall 1999a). To give an example, there is an allocation problem if virgin pulp-based paper products are compared with recycled paper products for the purpose of allocating an eco-label. All recycled products carry an ecological rucksack that contains a share of the effluent generation of the original product. In LCA inventories, the share of the effluent generation caused by the original paper product(s) is allocated to the recycled product varies from and 0 to 100 per cent. This in turn implies that the effluent loads and use of rawmaterials of an LCA can most often not be specified even if different solutions have been offered (Article III, pp. 35-37, Finnveden & Ekvall, 1998, Ekvall, 1999a).

LCAs have a major methodological problem when the product under analysis is part of a recycling system. Ideally, all material and energy inputs in LCA should be traced back to their extraction from the environment, and all releases should be traced back to the environment. This should be registered in the life cycle inventory. In reality, however, the grave of a product's lifecycle in a system with recycling is not uniquely determined, and the effluent and energy inventory cannot be exactly calculated. The product has multiple graves, which can be defined only stochastically. (Klöpffer 1996, Gronow & Pento 1995)

Issues related to energy remain non-standardised. According to ISO 14041, a criterion should be established to require the inclusion in the study of the energy inputs that cumulatively contribute more than a defined percentage of the product system energy input. In many studies, average data and assumptions about the type of energy (water, nuclear, or fossil) are used, which in turn affect the emission inventories of paper grades (ISO 14041).

In addition, the methodology of the impact assessment, i.e. the assessment of the environmental effects of the inventory items, is still in its relative infancy (ISO, 1997). Assessment results have wide variances, and are not conclusive, but only indicative (Helminen, 1998). As of now, it does not seem likely that a standardised methodology will be available in the next few years because too many questions are still under debate. The dilemma of global warming provides a typical example. There is currently no agreement as to the significance of the contribution by humans to global warming, nor of the influence of different types of emissions to the warming. Again, different and even opposing assessment results of the same inventory are possible, depending on the viewpoint adopted by the assessors.

2.4 Review of Material Flow Models

Many types of models analyse either physical or money fluxes, which are created by material flows in society. In order to achieve a more holistic view on their research work, many research groups have chosen to focus on an industrial, regional, national or even global level. Examples of such models range from the static material-cost calculations of managerial economics and microeconomics to the dynamic large-scale linear programming models of logistics. Some of these models have been adapted for environmental analyses by including a model structure, which counts the uses of virgin materials and the amounts of emissions which the fluxes create. Several new material flow modelling techniques have also appeared in recent years. Seven of these have been selected for a cursory introduction here. The seven were chosen because they are either new methods or are currently widely used, or because they seem to be highly useful for analysing the paper industry. The technical approach of each modelling method is shortly introduced below. A cursory review is made to indicate the uses that some of the modelling techniques have been put to within the forest industry. An article by Pento & Gronow (1999), including a larger typology, has been of great assistance in writing this section.

2.4.1 Total Material Requirement

The Total Material Requirement (TMR) technique (Adriaanse & al., 1997), calculates all raw material inputs, which are drawn from the natural environment by the production and consumption activities of a nation. The method does not account for any wastes or emissions. The TMR figures are derived using national industry statistics as a basis, which are then modified to fit the definition of the total material use. Total use is calculated as the sum of the rawmaterials that are taken from the natural environment, plus all of the side materials, burdens, and the like that are treated, disturbed, or moved at the extraction of the rawmaterials. The TMR of the forest industry thus includes both the tree trunk, branches, leaves, and needles which are left in the forest at harvest, and any part of the forest which is touched or moved, for example, by the making of roads in the forest for the harvest.

The TMR method provides a simple and easy to understand gauge for counting the environmental effects of a nation's economic activities. The simplicity of the method is also its main drawback, because the exclusion of emissions and waste as well as the calculation of all rawmaterials that are used on one scale, can be criticised as being too crude and leading to unwanted conclusions. For example, the harvesting of all biomass from the forest, including tree trunks, branches, and other materials for making products and energy generation would not alter the TMR count of the industry. Such practices, however, might create environmentally very undesirable effects. The removal of all biomass from the forest could reduce the amount of available nutrients and, worse, might drastically degrade its biodiversity. On the single scale of the TMR, a ton of renewable wood is equal to a ton of earth moved two metres in a road construction site or is equal to a ton of plutonium. Differential weighing of the tons would be an improvement. The reason for the identical weighing of all materials in the TMR is that a generally accepted weighing system does not exist.

2.4.2 Macroeconomic Environmental Input-Output Analysis

Macroeconomic Input-Output calculations, which were originally developed by Leontief (1986), have been routinely used in many OECD countries for many decades. Their objective is to calculate the economic functioning of the industries of a nation while explicitly accounting for their interdependence. The method is founded on a matrix that accounts the inputs that each industry needs from both the natural environment and from other industries. It also counts the outputs which it delivers to other industries. Inputs and outputs are then measured as transfers of money in the national accounts.

Leontief suggested that input-output calculations could also be used for environmental analyses (Leontief, 1986). One of his environmental input-output (EIO) methods involves the calculation of the input-output table on the basis of consumption and imports and exports, the derivation of the total production amounts, and the computation of the amounts of virgin materials used and emissions discharged at the production processes.

Such models are very comprehensive as they include all inputs from and outputs to the natural environment by a nation, and also outline the industrial and consumption activities.

The use of macroeconomic input-output tables for the estimation of emissions and virgin material use provide an analysis that takes into account all industrial activities, even those inter-industry transactions that do not show up in consumption at all (Konijn et al., 1995, Lave et al., 1995, Hendrickson et al., 1998). Most material flow models do not apportion any part of the steel industry's emissions to the forest industry, regardless of the large amounts of steel in its production equipment. Macroeconomic input-output models count all such investments and other interdependencies between production sectors.

Macroeconomic input-output models suffer from several disadvantages, some of which seriously hinder their use as environmental material flow models. First of all, the tables are usually based on the fluxes of money rather than on the physical amount of goods. Price levels will thus affect the estimation of emissions and the use of virgin materials, which is clearly illogical. The wild price swings of the forest industry, for example, have no effect on the amount of emissions per ton of products made in the industry. The deflation of the price changes with indexes will reduce this problem, but will not eliminate it. Secondly, the high aggregation level of the macroeconomic input-output tables and their aggregation methods make their environmental results prone to data difficulties and illogical aggregation. The forest industry is included in many input-output models as a single sector, and the amount of money made by the industry from its products is used as a base figure for calculating the SO_2 or BOD emissions of the industry. The composition of the products that are made by the industry is assumed to be constant because the changing proportions of, for example, mechanical and wood-free papers in the total amount of money generated, would alter these emissions. The assumption of constant proportions is incorrect in the forest industry, where the business cycles of the products do not move in unison. Another drawback of the input-output technique is that the calculation of post-consumer recycling and the generation of post-consumer waste are not easy to incorporate in the model. For example, the European P&P industry recycles more than 50 per cent of fibres, which makes the use of this method irrelevant.

2.4.3 Substance Flow Analysis

Substance Flow Analyses (SFAs) focus on one material input from the natural environment or on one product, whose fluxes across the anthroposphere they chart. The path of a single rawmaterial is traced often for toxic materials, such as cadmium, with the objective of identifying its uses, forms, and locations in which it is returned to the natural environment (Enquete-Kommission, 1995). Some researchers have attempted to tie the flows of money with the substance flows in order to develop a system that is capable of joining economic and environmental analyses (van der Voet et al., 1995).

The paths of a single product are usually tracked for the reason of finding out where the products actually end up as waste, and what their fate is in the environment. Such path analyses are often a first step in preparing other material flow models, and they are usually discarded, once more advanced models have been developed. The fluxes of papers in many countries have been studied (Bilitewski, 1993, Putz & Göttsching, 1992, Korhonen & Pento, 1999) and more comprehensive models of their flows are already available. The fluxes of some other products of the industry, such as saw goods, plywood, or boards, are less well known.

2.4.4 Life Cycle Assessment

Life Cycle Assessment (LCA) studies the virgin material use and the emissions and waste that are created along a product's life cycle from cradle to grave, and assesses their impact on the environment. The LCA approach is a less formal technique that studies the significant processes along the life cycle. Both techniques have been extensively applied to the products of the forest industry. (Virtanen & Nilsson, 1993, Kärnä et al., 1993, Kärnä et al. 1994, Bloemhof-Ruwaard et al., 1995, Frühwald & Solberg, 1995, Rajotte & Gronow, 1996, FEFCO, 1997, Woodward-Clyde, 1997)

LCA is used for operational improvements, environmental permit compliance, and communication needs. The identification of environmental "hot spots" along the life cycle facilitates risk assessments and the forward-looking product and process development to minimise existing suppliers' environmental risks. The Nordic pulp and paper firms, in particular, have performed a large amount of such work. An LCA study, followed by simultaneous assessments of economic and environmental costs within a mill and along some products' life cycle, has become the preferred method for operational improvement. A typical application concerns calculations that reveal both the economic and environmental returns of a particular investment to some process along the life cycle.

There are two main steps in performing a full LCA. A detailed inventory calculation of the material use, emissions, and waste that are generated by a product proceeds the assessment part of LCA. The main areas of inconsistency of LCI are the boundary rules (Ekvall, 1999a) and the allocation rules (Klöpffer, 1996).

The assessment part of LCA studies the impact on the natural environment of both the emissions and raw-material uses, which are counted in the inventory. Many approaches and quantitative valuation systems exist for this task, and the correlation between their results can be zero or even negative (Helminen, 1998). The valuation is and will, in all likelihood, remain a subjective art with no consensus over the best method. Some researchers have adopted a stance that the valuation and assessment should be left to the democratic institutions of societies, rather than having some specialists set their values on the environmental harms done. The limitations of LCA are presented in more detail in Section 3.4.

2.4.5 Industry Sector Life Cycle Assessment

Industry Sector LCAs are improved versions of traditional LCAs. Most of the errors producing boundary and allocation problems of LCA can be avoided by expanding the scope of the model from one product to several or all products of the industry. The aggregation of the products made by different mills may introduce errors, but these would not be large in the forest industry, where many of the products, though numerous, are rather homogeneous, compared to the greatly varying products of the plastic or even metal industries. Many material flow models have been made which analyse aggregated multiple P&P products (Virtanen & Nilsson, 1993, Kärnä et al., 1994, Pento, 1994, Kärnä, 1995).

The industry sector LCAs are equal to sectoral input-output tables, which are based on physical fluxes of the goods within the industry (Pento, 1998). Their use avoids many of the problems with product-based LCA's and potentially allows for the joining of micro-level industry data with macro-level, full-scale, economic input-output analysis. Industry-level analyses are also more amenable to policy purposes, because the actors who are to implement a policy are defined, and policies can be designed to affect their decision making.

2.4.6 Dynamic Flux Analyses

Two types of dynamic material flux analyses (DFA), have been proposed: comparative static and true dynamic models. Comparative static models consist of several cross-section material flux models of consequent time periods whose structure is identical. These models are set side by side, and the development of the fluxes across the time periods are compared (Frischknecht, 1998). Several model building techniques of this kind have been applied in the forest sector.

Kärnä and Pajula (1997) have analysed several paper products over two periods, using a base model and a model in which one flux had been re-directed by a small amount. This "delta" method calculates a type of partial derivative of one flux to a specified direction. It is thus capable of analysing small changes in which the overall material flux structure does not change to a large extent.

The second method builds comparative static models with uneven time periods and constructs cross-section models of periods, which are considered different changes and then compares the fluxes of these models. One application studies the environmental performance of a paper machine over its service life (Vasara & Jallinoja, 1997).

The third technique, Joined Time Projection, or JTP-modelling (Pento, 1994) has been employed to create fully dynamic full-scale comparative models of an industrial sector over several years, in which the structurally identical but different annual static models are grouped into a dynamic analysis of fluxes (Pento, 1994, Article I, Huuhtanen & Pento, 1995, Article II, Penttinen, 1997).

Another example of fully dynamic MFMs is linear programming (Kallio et al., 1987, Zhang et al., 1993). The theoretical basis of this dynamic input-output material flux models is straightforward, but difficulties in gathering the necessary investment and emission data, among other things, have hindered their empirical application (Pento & Korhonen, 1998). Large scale linear programming models of the forest industry, which have been developed in Europe and the United States since the 1970s have been modified to include environmental variables (Kallio et al., 1987, Zhang et al., 1993). These are able to cover several nations or market areas, and base their solutions over price endogenous economic optimisation by the actors included, but require large amounts of future demand and supply data, and tend to be rather sensitive to errors in the projections. An extreme example of backlashes is that one incorrect assumption may lead to the deletion of the P&P industry in a country during certain years.

2.4.7 Economic and Environmental Cost Models

Substance flow analyses and linear programming techniques have been employed in preparing models that measure both economic and environmental costs (EEC) and benefits. So far, these models have not generated many empirical applications. More current approaches utilise either the input-output method or the Joined Time Projection technique simultaneously to study the effects of material fluxes on economic revenues and costs, as well as emissions and waste generation (Pesonen, 1997, 1998a, 1999a, 1999c). Judging from the current state-of-the art, it appears that these techniques can be developed further to calculate cross-elasticities, such as profit/emission elasticity at each process along a material flow. Such elasticities would be of great informative use in investment calculations, operative improvements, and in the design of environmental policies for the industry.

2.4.8 Summary of the Characteristics of the Seven Models

The seven material flow models that were briefly outlined above differ in their characteristics. A model can study the flows created by a product, an industrial sector (including several or all of its products), or a nation. The fluxes of the model are measured either in physical terms (e.g. tons), or in money. Some of the techniques are capable of explicitly modelling post-consumer recycling, while others are not well suited for this purpose. Finally, some models cover both the inputs (i.e. the use of virgin materials form the natural environment), and the outputs (emissions and waste that are released from the anthroposphere). Table 1 broadly summarises in the characteristics of the seven material flow analysis techniques.

TABLE 1 Some characteristics of the seven material flow analysis techniques

Technique	Abbr.	Focus	Flux in	Recycle	Inputs	Socio-Econ.	Emission	Waste	Dynamic
1. Total Material Requirements	TMR	Nation	Tons	-[1]	Yes	No	-	-	-
2. Input-Output Analysis	EIO	Nation	Money	No	Yes	Yes	Yes	Yes	Yes
3. Substance Flow Analysis	SFA	Substance	Tons	Yes	Yes	No[2]	-	Yes	Yes
4. Life Cycle Assessment	LCA	Product	Tons	Yes[3]	Yes	Yes	Yes	Yes	No
5. Industry Sector LCA		Sector	Tons	Yes	Yes	No[4]	Yes	Yes	No
6. Dynamic Flux Analysis	DFA	Product / Sector(s)	Tons	Yes	Yes	Yes	Yes/No[5]	Yes	Yes
7. Economic/ environmental cost	EEC	Product / Sector	Tons & Money	Yes	Yes	Yes	No/Yes[5]	No/ Yes[5]	Yes

1 "-" signifies that the variable is irrelevant for the model or has so far not been used in research.
2 Predominantly no.
3 Refers to closed loop recycling.
4 A separated economic assessment is often followed. Social aspects such as labour are most often excluded.
5 Depends on the model.

2.5 The Justification of the Chosen Models

The choice of a model naturally depends on the objectives and needs of its user. Material Flow Models are used for multiple purposes in many areas. All of the models have their advantages and disadvantages. The characteristics of the seven different material flow analysis techniques, summarised in Table 1, were compared in the selection of the models for this thesis.

The framework of an academic thesis determines the focus and the breadth of the research. In this thesis, the research problem is related to the applicability of the researched models in environmental policy planning in the pulp and paper industry. The role and importance of the time horizon, the relationship between material flow management, and environmental decision making and the applicability areas of the chosen models related to some common environmental policy tools are examined. In order to be able to analyse in depth the research issues, the focus is on two models that have been chosen to be focused on and examined in detail.

When comparing the focus of the seven material flow analysis techniques, presented in this chapter (see table 1), TMR and EIO have the widest focus. EEC, Industry Sector LCA, and DFA focus on the (entire) sector and therefore particularly suitable for the objectives of the thesis while the focus of Substance Flow Analysis or LCA techniques is too narrow.

Due to the industrial context of the thesis, models based on tons are preferred to models based on monetary units, for there are large variations in the price of paper. The demand of paper in tons is more stable than the demand of paper in dollars. In addition, access to data indicated in tons is often better than access to data in monetary units.

In general, it may be stated that all the models require input data, whereas not all of them allow socio-economic and/or technical variables to be included. Nevertheless, in a policy-planning context it may be of crucial importance that the model used allows the examination of dependencies between different variables. TMR models are constructed in such a way that the inclusion of socio-economic and technical variables into their framework would be impractical. In contrast, the use and examination of socio-economic and/or technical variables is possible particularly in EIO Analysis but also DFA and LCA (Pesonen, 1999a). A separate economic assessment may be carried out on the basis of the output data in the case of Industrial LCA.

Emission limits have been an important part of environmental policy planners' work and the purpose of MFMs. LCA, Industry Sector LCA and EIO are the strongest techniques in emission calculations and analysis. In the case of the DFA technique, there are differences between the models as far as the emissions are concerned. Comparing two subgroups of DFAs, the "delta" method is able to produce more exact emission data than the Joined Time Projection (JTP) model, but only by analysing small changes in the overall material flux structure. The fully dynamic JTP model is able to analyse even large changes in the overall material flux structure, but focuses on the main material flows (Article I, pp. 233-235).

Recycling and waste streams are of particular interest for environmental policy planners, and therefore they are important for this thesis. TMR, SFA and EEC are not used to analyse waste streams, but the other models are able to handle them. Most of the models used today deal with recycling.

Two model types were chosen for this thesis. The first model is Dynamic Flux Analysis, applied with the Joined Time Projection method (see pp. 33-34), in the appended Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning* and Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*. The second model is Industry Sector LCA (see p. 33), applied with the KCL-ECO software in the appended Article III, *Effluent Generation from Paper Production and Consumption in France* and Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*.

The first model, i.e., Dynamic Flux Analysis, was chosen because it is considered to allow most closely the analysis of the research problem. Its characteristics are multifaceted and the model has previously been successfully applied to the pulp and paper industry.

In regard to the second model chosen, i.e., Life Cycle Assessment, a strong argument for its choice is the fact that LCA is generally the best known and most widely used model. This argument is respected even in this thesis. Forest industry firms and governmental agencies have worked mostly with Life Cycle Assessment, while the other models have been used predominantly by researchers and consultants. In order to overcome the limitations (see Section 2.3.), of traditional LCA, the improved version, Industry Sector LCA, is preferred in this thesis.

Industry Sector LCA is a static model whilst Dynamic Flux Analysis applied with the Joined Time Projection (JTP), method is a dynamic method. The comparison of these two models allows the analysis of the characteristics and applicability of static and dynamic models in environmental planning, which in turn permits a methodological analysis of static and dynamic models in general. This is important for resolving the research problem of the thesis.

3 POLICY PLANNING AND MATERIAL FLOWMODELS

This chapter highlights the focus of environmental policy planning from the point of view of Material Flow Models. In Section 3.1, the **General Context** for MFM-based policy planning is presented. Section 3.2 moves on to the **Application of Material Flow Models at the National or Industrial Level**, and also touches on the characteristics of successful MFM-based policy planning. In contrast, Section 3.3 discusses the **Application of LCA on Corporate Level**.

During the last thirty years, environmental policy planning has grown to be an important and large part of policy planning in general. Environmental policy planning may involve several different parties. The following parties may be involved: public policy makers at the international, national, and community level; political parties; agriculture; industries; non-governmental organisations; the research community; and even citizens (Sairinen et al., 1999). This thesis focuses on public environmental policy planning, both at the national and corporate level.

There are several different definitions of environmental policy planning and its function depending on the context (Munk Christiansen, 1996). In this thesis, the function of environmental policy is narrowed to how society and industry actively treat the environment. In pluralistic democracies, the primary goal of public environmental policy planners is to minimise environmental risks, and to protect public health, biodiversity, and sustainable development. On the other hand, public policy planners must guarantee favourable conditions for profitable industrial activities. The primary function of industry is profit making, but still both public and corporate environmental policy planning may have an important impact on profitability.

Environmental policy planning can involve a number ethical concepts and values that influence decision making. People can agree on facts and logic and yet disagree on policy due to different values. Setting public policy requires weighing and balancing competing values and choosing between them. (Lesser et al., 1997). This thesis concentrates on policy questions that material flow management provides answers for and on obtaining answers to those questions; thus, MFMs provide a quantitative basis for assessment and policy decisions.

This thesis finds it both natural and positive that MFMs are used by policy makers with different values and goals. Therefore, the assessment part of the flow inventories or any selection of a particular scenario are excluded from the thesis and left to policy makers.

3.1 General Context

As mentioned already in section 1.2, **The Change of Approach in Environmental Planning**, the end-of-pipeline policy has been or is being replaced with policies based on pollution prevention at its source in most countries. Technology-based approaches to standard setting predominate in the regulatory policy. Thus, LCA and other MFMs may provide new fields for policy development. Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning*, discusses the issue of policy planning with MFMs, as well as its main opportunities and limitations.

MFMs are an important tool for environmental policy planning and even for industry. The amount of LCA work alone that has been performed to this end has been multiplied many times in the last decade. In choosing the "greener" of two policies, it is necessary to know the indirect as well as the direct amounts of environmental interventions. Moreover, it is important to consider the future (downstream), fate of a product as well as its past, since every material product must eventually become waste. Curran (1999) claims that Clean Production and Pollution Prevention programmes have been of pivotal importance for the use and survival of LCA. Policy planners and analysts are also increasingly interested in forecasting future materials/energy fluxes on a regional and even global scale as a function of various regulatory and economic growth scenarios. MFMs are increasingly used as an information basis for future environmental policies. (Ayres, 1995)

At the moment, decision-makers strongly support the adoption of a preventive attitude to environmental problems. Curran (1997) has studied Life-Cycle based government policies in 14 industrialised countries and states that, although examples of use of LCA in policy making are increasing, there are still several barriers for the widespread use of LCA by policy makers. It has to be noted that Curran hardly considers policies involving only a part of the life cycle to be LCA-based policies (Curran, 1997). There also has been strong criticism against LCA from the European Commission on the grounds that it is possible to influence LCA results by selecting purposefully the assumptions and allocations (Vasara, 1999).

However, governments and international institutions such as the European Union establish policies with technologically proven upstream solutions involving process and product redesign and material substitution. LCA is now being incorporated as a basic requirement in legislation, including the European Union's Environmental Labelling Regulation (EC 880/92, March 23, 1992). According to the Commission of the European Union (1999), the EU is also incorporating the use of LCA in its goals for packaging recovery and recycling.

Thus far, chemical substances have been the object of the most elaborate form of life cycle assessments and management at both national and international levels. An example of this is chemicals used in agriculture.

LCA and the management of material and product flows are emerging as a viable framework in the development and implementation of environmental policy tools in other areas on a national level, such as public procurement rules. To name another example from the national level, the LCA principle (i.e., the principle of full producer's responsibility over the complete life cycle of the product), has been adopted in the German Verpackungsverordnung and its followers such as the Finnish Tuottajan jätevastuu. The German Kreislaufwirtschaft und Abfallgesetz make it the prime principle and it is incorporated in ECOTAX. (European Commission, 1999b)

Already in 1991, the authoritative German Enquete-Kommission "Protection of People and the Environment" (1993, 1995) considered material flow analysis and management as the prime vehicles on the road to sustainable development. It appears that future policies will have to be based increasingly on some type of modelling or on the flows of materials and products[2]. These are developing along the life-cycle approach. These tools are likely to provide the information needed to divert or close such material flows which waste resources or cause unnecessary environmental loads (Chilton, 1993). In addition, LCA/Material flow models offer policy makers the opportunity to involve interested parties (i.e. producers, distributors, consumers) in describing and proposing solutions to environmental problems that arise along the cycle. Some experts have applied them to define and to evaluate the associated social (Gronow et al., 1997) and economic (Pesonen, 1999a) implications.

MFMs have thus been used by policy makers in forming recycling regulations, waste management laws and regulations, in public procurement, and in creating eco-labels. In addition, MFMs have been the focus of policy-makers' attention as a means of developing environmental policy instruments such as forest certification, eco-management and integrated pollution prevention control (IPPC). Some of the policy instruments are presented in more detail in Section 5.4.

An OECD survey stated that LCA is a new tool for policy planners on different levels. Nevertheless, LCA remains a contradictory tool for environmental policy planning. (Rajotte & Gronow, 1996) At best, it can be helpful for environmental policy planning, but is not always used with full consideration. The methodological dilemmas of LCA used for policy planning have been discussed in Article I, pp. 227-228, 231-232, Article II, p. 78.

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2 The term "material flows" is used here to denote flows of both substances and products.

3.2 Application of Material Flow Models at the National or Industrial Level

It has been argued that the real challenge for environmental policy is to include environmental issues in economic policy so that they form a part of the daily gamerules of the economy and do not become trade obstacles. Thus, economic policy may become positive environmental policy. (Sairinen et al., 1999)

As stated in Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning* (pp. 232-233), public environmental planning must have several characteristics if it is to be successful. There must exist a clearly defined object of policy. This object can be the environment, a product, or an industry. The environment as object is impracticable when the policy has to be put into action. A policy can not be implemented unless there is an actor which is made responsible for the implementation. A product is often used as the object in environmental planning with or without MFMs. To name an example, more than half of American states have laws regarding the recycled material content of newsprint. Another product-based example is eco-labels.

Regulatory problems where the need for stricter environmental standards clashes with governmental industrial-policy concerns, have been researched by Cadot and Sinclair-Desgagné (1995). They proposed that the key is to find a path of regulatory change that is flexible enough to allow a firm to adapt through technical change, but does not create a moral hazard. Soininvaara (1993) suggests that industries are preferred objects of environmental policy, because industrial firms have the tools and organisations to make changes, and they can be either commanded or induced to take actions toward desired goals. In addition to technical and organisational arguments, the question of "liberating" consumers from the environmental effects of their own consumption, and the transfer of this responsibility to industry may influence the choice of industry over product as the object of environmental policy. Both industry-based and product-based system boundaries are used in MFM-based studies conducted for the purpose of policy planning.

Forecasting or constructing alternative future scenarios is important for any method of (national) environmental planning. The policy planner should be able to forecast and analyse the effects of different policy alternatives. A complete forecast of the future is not necessary. Instead, trajectories of the effects of different policies, as well as their sensitivity in reaching the specified goals, are of use (Article I, p. 233). The time horizon issue in the policy planning context is essential for this thesis and is considered in all the articles.

In addition, national and international organisations of the forest industry may employ MFMs for intra-industry monitoring of the environmental performance of firms within organisations, for preparing inter-industry environmental comparisons, and for influencing the policy processes of national and international public bodies such as the Commission of the European Union.

Effective MFM-based policy planning methodologies are needed, yet they are still in the development stage. Many issues are still open including coverage, the significance and credibility of "boundary determinations," and methods to deal with unknowns or impacts that are not readily quantifiable. To overcome criticisms, wide use of MFMs in policy making will require the development of widely recognised and accepted procedures capable of ensuring transparency through continuous and active participation of all parties concerned by the product/service under scrutiny (Weitz, 1996). Only by following such a path will parties such as consumer and environmental organisations, trade and producer associations, and trading partners be actively involved in the consensus needed for the conduct of an LCA. While the scientific verification of the LCA component can be approached through generally agreed upon "peer review" mechanisms developed in the professional arena, the development of life cycle management procedures will be required for placing LCA in context and integrating it with other socio-economic priorities.

3.3 Application of Material Flow Models at the Corporate level

LCA, as well as other material flow models, are used increasingly in various areas and at different levels in order to find out environmentally friendly solutions. Companies are still currently the main users of MFMs. Particularly larger, usually multi-national, companies apply LCA to their products (Curran, 1999). A Danish study shows that 22 per cent of large Danish companies use LCA in work related to the environment, and that only 4 per cent of large Danish companies have not heard of LCA (Madsen & Knudsen, 1996). Companies started to use LCA in product development not primarily because of environmental reasons, but due to their material and energy intensity inventories, thus attempting to improve their profits (Hunt & Franklin, 1996). LCA use for environmental policy has spread largely due to defensive reasons, especially to protect products from aggressive claims. (SPRU 1996)

Companies may have to decide whether they prefer to pay pollution taxes and gain a negative image or make emissions-reducing investments. Unfortunately, in the real world, as enforcement of environmental legislation is more often insufficient than not, what-if decisions are about whether to obey the rules and pay the investments required, or to break the rules, pay the possible fines, and lose image. As pollution taxes or permits leave opportunities to choose from, other environmental legislation is by no means meant to be optional. It is possible to misuse LCA and MFMs in these kinds of what-if decisions.

Added to this, Curran (1999) states that “the US is very regulatory driven, leaving few companies able to see the need or benefit of going “beyond regulatory compliance.” Often, for smaller companies, it is not so much a matter of need but of necessity where resources are limited, and they must use what they have to comply with existing regulations. Other larger companies, however, are seeing the possible benefits of looking holistically at their operations. To them, LCA is a way to be proactive in environmental management by heading off potential problems, as well as benefiting from an improved corporate image.

The growing awareness of environmental problems has raised the efforts of companies to use environmental arguments for offensive purposes. Today it is not only the technical quality of a product itself, but also the environmental quality and production process of the product that have been raised as themes in marketing activities. "Bio-" or "eco-"products are increasingly in demand by the market. The P&P industry has promoted labelling and certification activities in order to improve their environmental image and to give consumers information about the environmental effects of products and production processes (Thoroe, 1995).

Some firms in the forest industry have tried, since the mid 90s, to use their LCA results in communicating their environmental performance to the general public. However, the experiences were not all positive because the ambiguities of the LCA methodology led to situations where several parties presented conflicting results, and potential customers became confused. In addition, the LCA studies are generally costly in money and time. It appears that firms have reserved a passive role for LCA in their external communication plans: analyses are made to be used only if somebody else is presenting results that are considered erroneous or one-sided. (Article I, Pento & Gronow, 1999)

The strategic advantages of pinpointing environmentally sensitive spots along the life-cycle of a product can also be used to favour and pilot innovation and environmental R&D investment. This path provides the largest incentives for firms: there have been numerous cases in which environmentally preferable solutions also happened to be better solutions for energy and materials management within the portion of the life-cycle, which fall under a firm's responsibility. "Cradle to grave"-based analysis may also have other positive benefits. It may enlarge the inventory of costs and benefits, allocate such costs and benefits more closely to specific processes and products, extend the time horizon over which profitability is measured, and use multiple profitability indicators to capture indirect, less tangible, and longer-term payoffs to prevention instruments (Vicini, 1996). LCA and other MFMs thus bring together various factors affecting the company's overall performance. For instance, energy efficiency not only measures environmental friendliness, but also production efficiency, which naturally has straightforward economic implications.

In addition, the benefits from life cycle analyses are not restricted to the study itself or its results. Conducting an MFM or LCA study may have certain snowball effects for the corporations conducting the study. Certainly, environmental awareness, co-operation among actors, environmental management practices, and environmental management culture, as well as communication and reporting, can all be enhanced as a result of conducting or even attempting to conduct an LCA. (Pento & Karvonen, 2000)

Curran (1999) states that many companies either continue or are starting to use the LCA concept for internal checks on their performance, but are cautious in using the results in a public forum. Rajotte & Gronow (1996) point out that most of the studies on a corporate level remain entirely confidential (estimate: 95%). In most cases, companies use a traditional static LCA that is based on their own data and may, therefore, be very functional and precise. LCAs used in companies can be very useful, easy, and even precise tools for P&P industry due to the focus of P&P companies' inventories of often one product or one product group and one specific part of the life cycle.

4 METHODOLOGY

This chapter presents the **Methodology** of the thesis. The research method is first discussed and then the key concepts in the methodology, as well as some of their inter-relationships, are revealed. Section 4.1 presents the **Research Design** of this thesis. Section 4.2 presents a **Case Analysis**, which is one of the main tools in the methodological framework of the thesis. The focus is on theory building from case study research. In Section 4.3, the other main element of the methodological framework, **the Scenario Approach**, is presented and discussed. Section 4.4 discusses **Validity and Reliability** issues. Section 4.5 examines **the Limitations and Assumptions of the Research**.

4.1 Research Design

A research design has been described as the framework for methods of data collection, analysis, and interpretation (Rosing, 1978). Exactly which rules and measurement methods should be used depends on the goals of the project. The goal should consequently determine the choice of research method. The main types of research methods according to Rubenowitz (1980) are:

- explorative
- descriptive
- diagnostic
- hypothesis testing

As the research problem and the applied tools of this thesis are relatively new, and especially since the dynamic and future-oriented aspects of MFMs have not been well researched, the research method can therefore be best characterised as explorative. Explorative studies are particularly useful in increasing the researcher's knowledge of the research object. The researcher may use them to build and clarify concepts and establish research priorities.

Explorative studies are typically very flexible and only slightly dependant on previously determined instructions. They do not require extensive preparatory work (Rubenowitz, 1980).

There is an underlying risk with explorative studies to conduct research already conducted and to obtain research results already known and described. It has been the aim of the author to minimise this risk by following the development of the relevant literature during the research process.

The four previously published appended articles of this thesis form a loose entity that is strengthened by the preceding introductory, explanatory, and concluding chapters. The initial research problem has been developed when the knowledge base of the research object has been increased through the author's articles, including large empirical calculation work and other literature. Both research procedures and problems developed to some extent during the writing process, which is typical for explorative studies.

The methodology of the thesis is not fully fixed in established categories. The different stages of the methodology are influenced by both positivism and hermeneutics, deductive and inductive research. The four appended articles, particularly Articles II-IV, are highly quantitative. In their essence, they analyse different policy options and their outputs in numeric form. The research within the appended articles is also deductive. The broader research framework, presented in the theoretical/methodological part of the thesis preceding the appended articles, analyses different qualities of the researched material flow models. This larger cross-article analysis is comparative, inductive, and qualitative research presenting a theory regarding the applicability areas of static and dynamic material models. The comparison of the qualities of the MFMs is presented in the Conclusions of the thesis in Chapter 5.

The ideal of the methodological work of this thesis is that "a beautiful model is simple, fertile and unpredictable" (Lave & March, 1975).

MFMs are at the same time the analytical model used in the appended research articles and the object of the research. As analytical models, MFMs are a set of variables and their interrelationships. MFMs are designed to represent – in whole or in part – some real systems and processes. MFMs even present possible changes caused, for example, by a new policy. They are mathematical models explicitly specifying the relationships among variables in equation form.

In addition to MFMs, case analysis and scenario approach form two key elements of the research method of this thesis. Case analysis helps to understand the MFMs and their differences. Case analysis is practical because it offers a framework for comparison and further analysis of the four appended research articles. In addition, its contribution in theory building is important for the thesis. The scenario approach is found particularly helpful due to the research problem, which, to a large extent, is related to future-oriented MFMs and time horizon issues. Pesonen (1998b) states that the scenario approach offers the ground for systematic observation to be better prepared for alternative emerging circumstances. She also claims that scenario analysis may be used to actively construct one's own future in a turbulent environment.

4.2 Case Analysis

In general, case studies are the preferred strategy when "how" or "why" questions are being posed. They are also used when the researcher has little control over events, and the focus is on a contemporary phenomenon with some real-life context (Yin, 1984), as is the situation to a great extent in this thesis. Several researchers have developed the case analysis methodology. Yin described the design and basic methods of case study research (Yin, 1981, 1984). Eneroth (1984) presented a series of procedures on "how to measure beautifully" and how to analyse qualitative data. Eisenhardt contributed to the case study literature by making a "road map for building theories from case study research" and by positioning theory building from case studies within the larger context of social sciences (Eisenhardt, 1989). The theory building in this thesis follows the road map presented by Eisenhardt.

A scientific theory offers the mechanisms on how something takes place and/or how this phenomenon can be described. The theory is thus a creation of human intellect. It is a product of intuition, creativity, previous knowledge, and observable facts. The theory is the intellect's attempt to comprehend the reality. (Rosing, 1978, Trochim, 1999).

Eisenhardt states that theory building from case study research is especially appropriate in new topic areas. The resultant theory is often novel, testable, and empirically valid. Eisenhardt used in her article earlier pieces of the process outlined particularly by Glaser and Strauss (1967) and Strauss (1997) in grounded theory. "Grounded theory is derived from data and then illustrated by characteristic examples of data"; i.e., grounded theory relies on a continuous comparative analysis that is conducted on data and theory. It emphasises both the emergence of theoretical categories solely from evidence and an incremental approach to case selection and data gathering.

A case study is research that focuses on understanding the dynamics present within a single or a limited number of settings. Case studies can involve either single or multiple cases (Yin, 1984). In this thesis, a multicase design has been chosen where the cases consist of the previously written and appended articles. Material Flow Models that are used in the cases/articles have the advantage of being amenable to manipulation. However, replication of the same case has not been done. Instead, the cases are separate entities analysing different aspects of MFMs. The Joined Time Projection (JTP) technique presented in the appended Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning*, is subsequently followed by an empirical application of JTP in the appended article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*. The appended Article III, *Effluent Generation from Paper Production and Consumption in France*, and the appended Article IV, *Effluents of Alternative Energy Sources in Swedish Paper*

Production, are cases of practical applications of the Industry Sector LCA. Different qualities of the selected methods are brought forth in the appended articles. The applicability areas, as well as advantages and disadvantages of the methods are compared by analysing the cases. The findings of the comparison of the cases are related to the research problem and concluded in Chapter 5.

The theory generation from case study research "is begun as close as possible to the ideal of no theory under consideration and no hypotheses test," which is the ideal of experimental research in general (Eisenhardt, 1989). The selection of cases is an important aspect of building theory from case studies. However, the sampling of cases from a chosen population is unusual in theory building from case study research. Cases should be chosen for theoretical, not statistical, reasons (Glaser and Strauss, 1967). The choice and number of cases are related to the saturation of the theory (Yin, 1984). In this thesis, the four most relevant articles of the author, which in turn together form a loose entity, have been selected. The goal of case selection is to replicate previous cases or, as in this thesis, to extend emergent theory. In addition, cases may be chosen to fill theoretical categories and provide examples of polar types (Eisenhardt, 1989).

Concept building is the last phase in qualitative research. The aim of this phase data is to summarise and clarify what has been researched into a concept (Eneroth, 1984). In concept building, which is close to grounded theory, a comparison of theoretical categories and their properties (or qualities), leads to concept building, which in turn leads to a theory, as theories are based on a system of concepts.

Theory and data are continuously compared to suggest a theory that closely fits the data (Eisenhardt, 1989). The theory should be consistent with the inductive model of thinking in the qualitative method. Thus, theoretical insight may emerge during the data collection and analysis phase of the research. Theory and data comparison may be used relatively late in the research process in juxtaposition with theoretical dimensions initially presented (Creswell, 1994, Eneroth, 1984). In this thesis, this has meant that the formulation of the theoretical outcome of the research process has been a dynamic process where the original ideas and assumptions have been refined continuously. The refining has not occurred necessarily during the largely quantitative case studies/articles, but between the cases, and after the four appended articles were finished during the comparison work.

As a final step in theory building from cases, cross-case conclusions can be drawn and fitted into an existing explanatory or literature framework. These cross-case conclusions can then be converted into theory.

Case study research can involve qualitative data only, quantitative data only, or both. The combination of data may be highly synergistic. (Yin 1984) Qualitative data is useful for understanding the rationale or theory underlying relationships revealed in the quantitative data or may directly suggest theory that can then be strengthened by quantitative support (Jick, 1979). The analysis of data within a case is a key step of theory building from case studies. In this thesis, the appended research articles are largely quantitative, analysing different policy options and their outcomes. The analysis within the appended articles is deductive and quantitative. The cross-article/cross-case analysis is mainly qualitative; i.e., different qualities of the researched material flow models and their relationships are analysed inductively through comparison to research patterns.

4.3 Scenario Approach

Scenario Approach is one of the main methodological tools of this thesis. In general, the basic function of scenarios in this thesis is to highlight the problems linked to the different decisions related to environmental management in a pulp and paper industry context in a specific time. An attempt is made to envisage what the role of environmental policy planning and material flow models will be in certain hypothetical conditions, as well as the possible output if certain policy decisions are taken altering the material flows of the paper cycles. The policy alternatives and their outlined consequences help the policy planner – be he on a national or corporate level – make decisions for the final policy to be carried out.

The scenario approach has been offered as a solution for future-related policy planning in an environment where linear development has been replaced by discontinuous, partly chaotic development (Ruokanen & Nurmio 1995).

There are several slightly different definitions for the scenario concept, underlining different aspects of the scenario approach. Some of the most important – and for this thesis most relevant – issues regarding the scenario approach are presented here.

According to Kahn, a pioneer of the scenario approach, a scenario is "a hypothetical sequence of events constructed for the purpose of focusing attention on causal processes and decision points" (Kahn & Wiener, 1967).

In addition to the hypothetical nature of the scenario approach (i.e., scenarios are based on current assumptions of the future), a scenario is expected to tell us how to arrive at one situation from another (current) one. The nature of scenarios is both descriptive and prescriptive, as they are used in the formulation and testing of strategies. (Julien et al., 1979) This is typical of the heuristic nature of scenarios, whether informal or methodological, which in themselves are contested concepts (Lähteenmäki-Smith, 1999).

The different scenarios are the expected consequences of alternative paths to the future (Mannermaa, 1999). The scenario approach, as it is understood in future research, is based on the idea that the future is not predictable; therefore, the main purpose is not to predict or forecast the future. Instead, several different alternative paths to the future, called scenarios, are constructed. The scenarios may help to take action. Due to the process nature of scenarios, choices and decisions are seen as producing different outcomes that may all be equally possible, though dissimilar in their consequences. (Mannermaa, 1991, Mannermaa 1986)

A schematic process is typical to the scenario approach. Scenarios do not aim to describe in precise detail future development. Though a causal link can be present between different scenarios, it is not always a very clear or indeed straightforward one. An element of insecurity remains, as the type of information involved cannot be certain or fixed, emanating as it does from complexity and turbulence (Lähteenmäki-Smith, 1999). Thus, scenarios give guidelines of essential characteristics of the future development. A holistic view is also typical to the scenario approach; i.e., it provides broad descriptions of development processes. (Lifländer, 1994)

The development of scenarios includes several elements. Pesonen (1999b) summarises the most essential elements of scenario building in three steps:

1. defining the assumptions;
2. describing the possible future;
3. where relevant, presenting the development that may result in the realisation of this future.

The number of scenarios in any given study should be limited to a maximum of four; otherwise, the decision making will became excessively complicated (Wack, 1985). The ideal number of scenarios is one plus two, i.e., the surprise-free scenario and then two alternative scenarios that focus on critical uncertainties (Pesonen, 1998b, Wack, 1985, Meristö, 1991).

The time horizon for environmental scenario building has been suggested to be between three and five years. In a corporate context, the time span is often longer, between six and fifteen years. However, the time span of scenarios has to be determined separately in each case. (Pesonen, 1998b)

The use of scenarios began as a way of constructing alternative business strategies (Meristö, 1991). In the case of the pulp and paper industry, this approach is frequently used, especially by consultants. Soon the scenario approach was widened to public policy planning (Lähteenmäki-Smith, 1999). In fact, Sairinen et al. (1999) claim that both future research and the scenario approach are fashionable in policy planning.

The construction of scenarios as a methodological tool and life cycle assessment or material flow model studies can be combined. SETAC, one of the two major standardisation bodies of LCA, has even founded a Scenario Development Working Group that develops systematic scenarios as a basis for modelling product systems and environmental impacts. The task of the SETAC working group was then extended to include allocation, impact assessment, and other parts of actual modelling (SETAC, 1998), since modelling is necessary in the development of a scenario. (Pesonen et al., 2000)

It has been suggested (Pesonen, 1998b, Pesonen et al., 2000) that scenarios distinguish between two basic approaches in the context of life cycle analysis (LCA) research. Pesonen calls these two approaches the "What if"- and "Cornerstone"-scenarios.

The "What if"-scenarios are more widely used in LCA research. They are used to compare two or more alternatives in situations that are well known to the researcher. The "What if"-scenarios form a decision problem and defined hypothesis on the basis of existing data. The "what-if"-scenario is typically a comparison of existing systems, e.g. process alternatives and product modification, and the scenario provides operational information. (Pesonen, 1998b, Pesonen et al., 2000)

By comparison, in the "Cornerstone"-scenario approach, a couple of alternatives that can be very different are chosen in order to obtain a holistic view. These alternatives then serve as cornerstones of the studied field. "Cornerstone" scenarios offer strategic information for long-term planning. They are recommended when the field of research is new or complex. "Cornerstone" scenarios are developed in the course of studies conducted for the design and development of new systems, products, and technologies. They often serve as the basis for further, more specific "what if"-scenarios. (Pesonen, 1998b)

The appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, analyses material flows of the French printing papers and discusses important aspects in waste management and different disposal alternatives for P&P products in France. The appended Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*, compares environmental consequences of different energy alternatives for the P&P industry in the outphasing process of nuclear plants in Sweden. Thus, both Article II and Article IV can be seen as being "Cornerstone" scenarios due to their holistic nature. The appended Article III, *Effluent Generation from Paper Production and Consumption in France*, analyses emissions of the different stages of the life cycle of the French P&P industry and compares two existing systems: emissions produced with chemical vs. mechanical pulp processes. Thus, Article III is closer to a "what if"-scenario.

4.4 Validity and Reliability

Validity is regarded as the ability of a measure to measure accurately. Validation of the results requires that identical answers must be obtained from different sources. Reliability is regarded as the "consistency" or "repeatability" of the measures. A measure is considered reliable if it gives the same result over and over again, assuming that what is measured is not changing. Reliability is thus related to the quality of measurement. (Trochim, 1999)

To ensure the validity of this thesis, case studies and secondary data have been studied and compared. The previously published and appended Articles I-IV are seen as case studies. Case analysis, which is a main tool in the theory building of this thesis, is presented in Section 4.1. Yin (1984) states that validity and reliability issues in case research can be addressed by first developing the internal validity and reliability within the cases, and then developing the external validity and reliability of the research by comparing the cases. The case studies have an embedded unit of analysis within themselves that in this thesis is present in the appended research articles.

The MFMs presented in the appended Articles I-IV are then compared and analysed in this thesis in terms of the methodological framework and application areas, highlighting linearity and non-linearity, as well as static and dynamic aspects, together with the time horizon issue in Chapter 5.

With regard to theory building from case studies, it should be mentioned that the aim of this thesis is not to maximise the precision of the projections and inventories presented in the appended Articles I-IV, but rather to present and compare certain qualities of the two chosen descriptive models. This presentation and comparison of the two descriptive models may also be viewed as the measurement of convergent and discriminant validity.

Trochim (1999) defines convergent validity as measures of constructs that theoretically should be related to each other and which are, in fact, observed to be related to each other, i.e., correspondence or convergence between similar constructs. He defines discriminant validity as measures of constructs that theoretically should not be related to each other, yet are. In fact, Trochim refers to discriminant validity as measures of observed constructs that are not related to each other, i.e., as discrimination between dissimilar constructs.

In addition, secondary data, i.e., previous MFMs-related research has been presented and compared in order to improve the convergent and discriminant validity of this thesis.

Explicit measurements are not undertaken in this thesis to compare the two chosen model types. The qualities and the application areas of the models proved to be relatively different; therefore, a numeric comparison of the cases has been excluded from the scope of this thesis. As a result, it is difficult to verify reliability in the context of a theoretical-conceptual approach. Due to the explorative nature of this thesis, the reliability and validity of the cases has not been tested by numerous replications of the cases. Such testing is left for future research. Data evaluation has instead been performed by the researcher in a comparative qualitative manner. (Eneroth, 1984)

4.5 Limitations and Assumptions of Research

The limitations and assumptions of research may contribute to one's finding or missing what is essential. In this thesis, several limitations and assumptions have been made.

In order to facilitate the in-depth analyses of the research issues, only two types of models were chosen for study.

The research is limited to the study of the manufacturing processes of printing, writing, and tissue papers and their material flows and emissions. These flows can be seen as separate entities representing a major part of the P&P industry, both in terms of quantity and in terms of profit making. Other material flows and their environmental impacts are not investigated in this thesis. Also not included in the research are carton, board, converted products, other wood-based products, or other industries. This exclusion should not have any significant influence on the results of the appended research articles or the thesis, for the direction of material flows is from the researched paper grades to carton and board grades and converted products. To correctly analyse the potential impact of the sawdust input in the researched flows from other wood-based industries would require separate research. In addition, the material flows of the P&P products are easier to follow and analyse than, for example, those of the steel or plastic industries.

Environmental impact assessment is still under development and demands subjective evaluations (ISO, 1998c). The focus of the thesis is on the inventory part of LCA and other MFMs (see Section 2.3, Article IV, p. 294). The environmental impact assessment consequently falls outside the limits of this thesis.

Furthermore, the thesis assumes that pluralistic democratic society in, largely, a market economy (i.e., an economy where a large share of economic activity takes place through markets and where citizens can participate in governmental procedures leading to policy making), will not change drastically in the near future. Much of the substance of the thesis could be applied in other political/economic conditions, but these aspects are not covered in this thesis.

5 COMPARISON OF THE CHOSEN MODELS

This chapter presents a **Comparison of the Chosen Models**, i.e., Joined Time Projection and KCL-ECO modelling techniques, which in the appended research articles have been applied to environmental planning in the pulp and paper industry.

The conclusions of the thesis – conclusions that address the research questions defined in the Section 1.3 – are drawn in Sections 5.1 to 5.5 by a comparison of the chosen models. In Section 5.1, the chosen models are first compared by presenting **the Methodological Framework of the Models**. This is followed by a presentation of similarities and differences of the chosen models in terms of their L**inearity Versus Non-Linearity** in Section 5.2. In Section 5.3, the importance of the **Time Horizon** is discussed, followed by a presentation of examples from the appended research articles that are used to demonstrate the applicability of **Dynamic and Static Material Flow Models** to environmental policy planning. In Section 5.4, the applicability of the models to environmental policy planning is further demonstrated in terms of different **Applicability Areas** of environmental management where material flow models are typically applied. In Section 5.5, the final **Conclusions of the Comparison of the Chosen Models** answering the main research problem are presented.

5.1 Methodological Framework of the Models

This section compares the methodological framework of the JTP model and the KCL-ECO model. Both modelling techniques are compared with Leontief-type Input-Output models (Leontief, 1986) because the methodology of both models can be derived from environmental Leontief-type Input-Output models.

The major finding of this Section is that the JTP model differs significantly in two respects from environmental Leontief-type Input-Output models, as well as the KCL-ECO model: non-linear formulas are included in the methodological framework of the JTP model. The assumption of stable external factors creates another difference in the methodological structures of, on one hand, the Leontief-type Input-Output models and KCL-ECO model and, on the other hand, the JTP model. The KCL-ECO model, as well as other static LCA models, represent present conditions (Article I, pp. 231-232), whereas the dynamic JTP model is able to deal with unstable external factors within the time horizon (Article I, p. 233-235).

The technical calculation methodology of the JTP model and KCL-ECO are principally the same. Both techniques can be seen as variants of environmental Leontief-type Input-Output models. A brief comparison of the mathematical structures of the models is presented in Appendix 1. As already mentioned in Section 2.4.2, Macroeconomic Input-Output calculations, which were originally developed by Leontief (1986) have been routinely used in many OECD countries for many decades. Leontief also showed how the Input-Output structure could be used to analyse environmental consequences of production and consumption at the macroeconomic level. Input-Output calculations have recently experienced a renaissance in environmental economics and policy planning (Lesser et al., 1996). Their use in the construction of Life Cycle Inventories was first demonstrated by Heijungs et al. (1992) and, thereafter, modifications and improvements have been suggested by several researchers.

Environmental input-output analysis first counts the fluxes of materials, i.e., goods, substances, energy and water between the various sectors of a system, and then quantifies the inputs from and outputs to the natural environment, which are caused by the fluxes (Schroder, 1998). All relationships between the material fluxes and the concurrent fluxes from/to the natural environment are assumed to be linear.

The relationship between the three methods is illustrated in Figure 2. The I-O matrix of the upper left corner shows the material flows that are generated by a (simplified) printing paper industry and its products. Each horizontal product row contains an equation that shows the amounts (in tons) of different inputs that are needed to produce a ton of the product. The emissions, which are generated in the production process, are given in the emission matrix (ton of emission/ton of product). The vertical columns of the flux matrix count the input materials, and the virgin material matrix shows the amounts of inputs which are needed by each input (tons of virgin material/tons of product).

Leontief's original construction of an environmental I-O table was identical to that of Figure 2, but it was not an industry-to-industry flux matrix with fixed coefficients. The KCL-ECO model employs a similar approach, but is constructed as a very detailed product-to-product matrix. Each product with its associated emissions and virgin material inputs is presented as a module. The relationships between products from a flux matrix of linear relationships. The resulting matrices can be very large (2500 x 2500), and the calculation of solutions with normal matrix techniques is sometimes difficult, due to over - or under - specifications of the matrix (Leontief, 1986, Lave et al., 1995, Hendrickson, et al., 1998). A general overview of the KCL-ECO model is presented in Appendix 2.

The JTP model is built with the same structure of equations, but some of them are non-linear. For example, the equation of de-inked pulp (DIP) (8:1 in Figure 2.) shows often that the yield of DIP in tons, is not a constant in its relation to the amount of used paper in tons but varies also as a function of the composition of the used paper and the intended use of the DIP. The JTP model is capable of incorporating complex relationships between the products of the matrix, and can thus depict true processes in a material flow system more accurately. This improvement is achieved at the expense of computational difficulties in deriving solutions.

JTP models are solved in a sequential heuristic process, in which the equations of the matrix are grouped into subsets that are solved separately; the common solution is obtained by fitting the subsolutions together in a heuristic process. For example, domestic consumption of newsprint must equal domestic production, minus exports, plus imports. Most equations follow this principle, with the exception of processes in which there are inputs and outputs of other materials. Thus, the de-inking of used papers yields de-inked pulp in a non-linear way, because the pulp can not contain all the minerals, which are in the rawmaterial. The amount of the minerals, which are removed in the process, depends on their proportion in the rawmaterial.

Process:Product																Emission			
Input \ Output	1:1 Fuel	2:1 Electricity	3:1 Transport	**4:1 SW pulp**	**4:2 Tall Oil**	5:1 PGW	6:1 HDW pulp	7:1 Prec. CC	8:1 De-ink pulp	9:1 Newsprint	10:1 Magas pap	11:1 Newspaper	12:1 Magasine	**13:1 Used paper**	**13:2 Waste pap**	Total output	e1 BOD	e2 COD	e3 SO_2	e4 NOX
13:2 Waste paper																	X	X	X	X
13:1 Used paper		X							X										X	X
12:1 Magasines														X	X				X	X
11:1 Newspapers														X	X				X	X
10:1 Mag. papers													X				X	X	X	X
9:1 Newsprint												X					X	X	X	X
8:1 De-Inked Pulp										X	a8:1,10:1					d8:1	X	X	e8:1,3	X
7:1 Precip. CC											a7:1,10:1						X	X	X	X
6:1 Hardwood pulp											a6:1,10:1						X	X	X	X
5:1 Pressur.grwood										X	a5:1,10:1						X	X	X	X
4:2 Tall Oil																				
4:1 Softwood pulp										X	a4:1,10:1						X	X	X	X
3:1 Transport				X	X	X	X	X	X	X	a3:1,10:1	X	X	X	X		X	X	X	X
2:1 Electricity				-X	X	X	-X	X	X	X	a2:1,10:1	X	X				X	X	X	X
1:1 Fuel			X														X	X	X	X
Virgin material																				
b4 Hardwood							X													
b3 Softwood				X	X	X														
b2 Limestone								X												
b1 Oil	X	X									b1,10:1									

FIGURE 2 Life Cycle Inventory as a Static Input-Output Table (Pento, 1998)

The aggregation principles of the three modelling techniques – i.e. Input-Output calculations, the JTP model, and the KCL-ECO model – differ in that the JTP model and KCL-ECO focus either on a single product, several products, or an industry, whereas I-O models usually consider larger economic entities.

All material flow models limit the size of the flux matrix arbitrarily. A traditional macroeconomic industry-industry matrix is limited to a country or a region. This is because such matrices are constructed from national accounts or similar regional accounts, and the direct joining of accounts of several countries is technically odious. The boundaries of the JTP and KCL-ECO models are set in the manner described in ISO 14040; i.e., rational consideration is given to the size of the model vis-à-vis the inclusion of environmentally important consequences of the product(s) under analysis. The constructors of these models explicitly recognise the fact that their models include only the most relevant flows. National environmental I-O tables are still made under the assumption that they are more comprehensive and are somehow impervious to the boundary issue. (Lave et al., 1995, Hendrickson, et al., 1998)

This is clearly not the case, for example, in the P&P industry. Any figures of the U.S. national I-O table exclude the emissions of the Canadian pulp industry, although a large portion of U.S.-made papers derive their pulp from Canada. The exclusion of imports and exports makes the environmental I-O tables of the EU countries irrelevant, because of the high proposition of intra-EU flows. For example, the Finnish P&P industry exports over 90 per cent of their products.

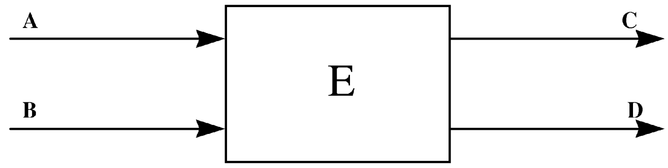
The original Leontief environmental I-O technique is superior to the product-product matrix approaches, such as the KCL-ECO or JTP models, in its ability to explicitly account for investments and indirect effluents of each sector's material flows. It is possible to augment the ISO 14040 KCL-ECO approach with investments and indirect effects, but this is seldom done because the amount of needed data grows rapidly and the construction of models becomes very tedious.

A simple summary of the technical properties and practical capabilities of the models could be defined as: a national industry-industry I-O model, especially if constructed in financial terms, which is a long-term macroeconomic tool that is poorly suited for product-level work. The JTP and KCL-ECO models can provide accurate product-level environmental information, but are less suitable for long-term macroeconomic analyses.

When using input-output analysis, some shortcomings indirectly occur that are linked to the hypothesis of the analysis method. According to Holub & Schnabl (1994) these shortcomings are:

- Assumption of unchanging input coefficients or linear production technology in the whole sector;
- Assumption of stable external factors;
- Limitation weaknesses of production capacity.

In the context of MFMs, and of particular relevance to this thesis, is the issue of linearity and the assumption of stable external factors are serious shortcomings affecting Leontief's Macroeconomic Input-Output matrix calculations. The basic structure of Input-Output material balance calculations is also demonstrated in figure 3. where E is the sum of the inputs A and B, and the sum of outputs C and D is equal to E. The formulas are linear. Non-linearities are not considered in the calculations.



E = A + B

C + D = E

FIGURE 3 Linear formulas in the calculations of Input-Output material balances.

Linearity makes a difference to the methodological structures of the chosen models. The KCL-ECO programme is based on a set of consecutive linear production functions that are arranged into a product-by-product matrix. Solutions are obtained by an inversion of the matrix and can not be calculated if non-linearities are present. In contrast, the JTP model is calculated in a heuristic interactive manner that allows the use of non-linear production functions and/or effluent coefficients. The heuristic interactive manner, in this context, signifies that the equations of the JTP model require that all its material balance equations are satisfied. A balance (equilibrium) can be achieved in many ways. An example is given by the increased collection of used papers which in turn increases the amount of de-inked pulp. It is not economical to export this pulp, and it has to be used locally. The model does not specify where the pulp is to be used, but leaves this decision to the user, who can "spend" the pulp as a rawmaterial in newsprint, magazine papers, fine papers, or hygiene tissues. The issue of linearity versus non-linearity is studied in more detail in section 5.2.

The assumption of stable external factors creates another difference in the methodological structures of, on one hand, the Leontief-type Input-Output models and the KCL-ECO model, and, on the other hand, the JTP model. The issue of stable external factors is studied more in detail in section 5.3. in terms of the time horizon and in section 5.3.1. in terms of static and dynamic aspects of MFMs.

5.2 Linearity Versus Non-Linearity

This section discusses the importance of linearity versus non-linearity in the data and equations in and between the processes of MFMs. Recent relevant methodological discussion is referred to. The types of parameters used in the chosen models are briefly discussed. This section makes the claim that linearity is too strong an assumption for the parameters and formulas used in MFMs. Some examples from the appended Articles are presented to demonstrate the importance of non-linearity in the context of MFMs and differences between the chosen models.

Static MFM models, LCA models in particular, assume that data and equations, both in and between processes, are based on linear and static relationships. As an example of this, Heijungs (1997) bases his methodology for the solution of the attribution problem on linear relationships between the analytical rate of production and analytical rate of emission, and between both 1) the analytical rate of emission, and 2) the analytical environmental impact.

Frischknecht (1998), together with many LCA researchers, further claims that the assumption of linear relationships "may also be applied for an analysis of a change in the current situation (where additional economic activities are attributed to additional environmental problems)." Nevertheless, Heijungs (1997) admits that the dramatic improvements of the environmental performance of industrial facilities within a few years from the starting point of the analysis, do not fit into his quasi-stationary state assumption. Frischknecht (1998) states that system models for (very) long-term planning "used to analyse changes; however, different kinds of non-linear and dynamic aspects may become relevant."

The issue of linearity is slowly becoming a topic of interest for LCA standardisation. It was stated during a recent Danish-Dutch workshop on LCA methods, in which several authoritative persons involved in LCA methodology development and standardisation participated, that "fixed variables don't exactly describe reality. Non-linear process models should now be allowed. In the past we allowed only linear models, but various software packages already have options for non-linear process modelling" (Saur, 1999).

The issue of linearity versus non-linearity can also be approached in terms of parameters used in MFMs. The mathematical structure of the material flow models may be categorised according to the types of parameters used. The categories presented by Fahrmeir (1989) are found useful in this context. Fahrmeir distinguishes four types of parameters:

1) parameters that are constant over time and over units;
2) parameters that are constant over units but time-varying;
3) parameters that are cross varying but constant in time;
4) parameters that are cross- and time-varying.

In the case of the two models chosen in this thesis, the parameters of KCL-ECO are cross-varying but constant in time, whereas the parameters in the JTP model are cross- and time-varying. Due to this, the most significant difference between the JTP model and the KCL-ECO model is that the latter uses only linear formulas in its calculation, while the first uses not only linear formulas in calculation, but also non-linear formulas. ("Non-linearity" in this instance refers to the relation between process inputs and outputs and not to economic non-linearities).

Pento & Karvonen (2000) demonstrate that the large non-linear effects of technology changes over time on emission coefficients and their effects on life cycle inventory calculations have a strongly negative impact on the validity of LCAs. Due to non-linearities, the current fixed co-efficient matrix employed in LCA studies is not a valid measure of the environmental impact of a product system. Pesonen (1999b) compared selected production emissions in two scenarios of Finnish printing papers in 1994-2000. In her basic Scenario 1, production emissions per ton of paper produced were considered linear, and in the adapted scenario 2, production emissions per ton of paper produced were considered non-linear. Pesonen's inventories (See Figure 4) "clearly show that when the production is considered linear it can cause major errors when trying to assess the amount of total emissions in the future." This thesis also considers linearity to be too strong an assumption for the parameters and formulas used in MFMs.

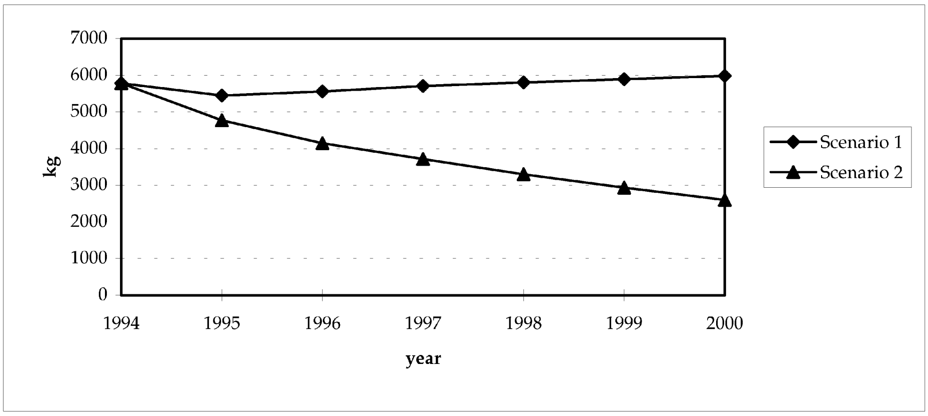


FIGURE 4 SO_2 emissions 1994-2000

In the context of the P&P industry, de-inking recovery calculations are essential. When referring to the appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000* (pp. 80, 104), the issue of linearity becomes of particular importance in the context of fibre and mineral recovery. A share of fibres and minerals are in circulation during several years. A part of the de-inked pulp is reused in the manufacturing of new paper, which in turn is de-inked. Because of this continuous cycle of reuse and de-inking, printing and writing papers in France and other central European countries consist of significant amounts of fibres and minerals that have been recycled not only once but several times. In the case of minerals, increased recycling increases the amount of minerals in paper. The mineral recovery calculations in scenarios portrayed in the appended Article II (pp. 103-104) are non-linear in relation to many variables.

The calculations in Scenarios A, B, and C of the appended Article II (pp. 101-106) demonstrate that the de-inking yield does not increase in the same proportion as recycling increases. In addition, the appended Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning* (p. 235-236), demonstrates that the amounts of different types of waste do not evolve in the same proportion. Therefore, the relationship is non-linear. The JTP model's non-linear formulas allow precise de-inking calculations, whereas this is not the case with the KCL-ECO model. The JTP model also includes non-linear formulas in its projection calculations, i.e., how the annual material flows, which are determined on the basis of the set parameters, are simulated for the future years in the planning horizon.

The issue of non-linearity versus linearity is strongly related to dynamic and static characteristics of MFMs. Therefore, this issue is further elaborated in Sections 5.3 and 5.4 of this thesis where the time horizon and the applicability of dynamic and static MFMs are discussed.

5.3 Time Horizon

In this section the significance of future scenarios and time horizon in the current MFM research is discussed. A typology for historic LCIs and LCIs that take into account effects of possible actions, i.e., models aiming to cope with the time horizon, is presented. The author of this thesis presents two categories: static and dynamic MFMs. Similarities and differences between dynamic MFMs and categories presented previously by other researchers (table 2.) are discussed. The new category – dynamic MFMs – is considered to go beyond the previously proposed categories by studying systems, in which many factors change simultaneously over time. In addition, the significance of time horizon in environmental policy planning with MFMs is demonstrated by examples from the appended Articles.

The major finding of this section is that a future-oriented environmental policy action should have a time horizon included in the method. Nevertheless, the role of the time horizon may differ to a large extent depending on the focus and the assumptions of the study. Static MFMs have a limited ability to study changes, while dynamic MFMs can better study the continuous changes in technical and environmental conditions of consumption and production on the time horizon.

Weidema (2000) states in the editorial "Increasing Credibility of LCA" of the International Journal of Life Cycle Assessment, that "Among one of the target audiences, industrial designers, it has been demanded that LCAs should reflect better the relevant future scenarios." He continues to state that the relevant time horizon and future scenarios, including the dynamic interactions of different developments, are often disregarded in currently published LCAs. In the ISO 14041 standard, the distinction between retrospective and prospective assessment is not completely clear. In spite of this, the ISO 14041 standard is a reflection of the different needs for allocation methods for co-products among these two retrospective and prospective types of LCAs (Weidema et al., 1999).

A time horizon is thus becoming increasingly important among LCA and MFM researchers. Several researchers have recently paid attention to the time horizon issue, even though research regarding the importance of the time horizon is just beginning to emerge.

Different names are used to distinguish between LCIs that rely on historic data and conditions, and LCIs that take into account the time horizon. Ekvall

(1999a) and Weidema (1998) have even presented application typologies for these LCAs (See Table 2.). Ekvall (1999a) uses the general concepts of "descriptive LCA" and "change-oriented LCA" to describe present time and future time-oriented models. Tillman (1998, 2000) calls the two different categories "retrospective LCA" and "prospective LCA." Weidema (1998) names them "information-oriented LCA" and "change-oriented LCA", whereas Baumann (1998) uses the names "life cycle accounting" and "life cycle assessment." Hofstetter (1998) uses the names "attribution case" and "change-oriented case." Baumann (1996) calls the two categories "exploratory" and "comparative LCA." Frischknecht (1998) calls the first category "status quo type (type 0)" but in the second category he makes "the main distinction between a system model used for a structural analysis and for planning analysis of short-, long- or very long-term changes" (types 1 to 3). Frischknecht calls the very long-term LCA type "quasi-dynamic analysis." The author of this thesis uses the categories of "static and dynamic MFMs" (Article I, pp. 231-232, Article II, pp. 78).

TABLE 2 Modification of the typology for descriptive and change-oriented LCA presented.

Ekvall (1999a)	Descriptive LCA	Change-oriented LCA
Tillman (1998, 2000)	Retrospective LCA	Prospective LCA
Weidema (1998)	Information-oriented LCA	Change-oriented LCA
Baumann (1998)	Life cycle accounting	Life cycle assessment
Hofstetter (1998)	Attribution case	Change-oriented case
Baumann (1996)	Exploratory LCA	Comparative LCA
Frischknecht (1998)	Type 0 LCA	Type 1-3 LCA
Gronow	Static MFM	Dynamic MFM

Source: Ekvall (1999a).

The author of this thesis uses the following typologies for the two chosen material flow models:

1. the KCL-ECO LCA is referred to as a "static material flow model";
2. the Joined Time Projection model is referred to as a "dynamic material flow model."

These categories are partially the same as the other categories mentioned in Table 2. Static MFMs have a limited ability to study changes, while dynamic MFMs can better study the continuous changes in technical and environmental conditions of consumption and production on the time horizon.

There are slight variations in the typology, but a common denominator among the first category of LCIs is that they study an implicit referential situation (Heintz & Baisnée, 1992) in order to increase knowledge of the researched phenomenon. In contrast to the first category of the typology, the second category compares different scenarios and studies the effects of a possible action.

Researchers have typically studied small incremental changes (see Section 2.4.6 of this thesis), (e.g. Weidema et al., 1999, Kärna & Pajula, 1997) and "have usually been concerned with changes only in some parts of the system and the consequences of those changes, which implies that a change-oriented approach may be used for those parts of the system and a descriptive approach for other parts" (Tillman, 1999). Technical change has currently been included in LCA in static comparative analyses, or static LCIs of different time periods have been analysed in a comparative fashion. In LCIs, two or more fixed coefficient matrices are compared over time and the change in the results is considered as the advancement of technology (Pento & Karvonen 2000). This still does not quite capture the inherent dynamism of industries.

The present research regarding a change-oriented approach is in fact closer to the static, linear KCL-ECO model of the appended Article III, *Effluent Generation from Paper Production and Consumption in France* and Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*, whereas the JTP model goes beyond this and studies several continuously changing variables (Article II, p. 79). The dynamic JTP model is thus more amenable to the study of changes than the ISO standardised LCAs, due to its ability to handle multiple changing variables, and because some of the functions of the JTP model may contain non-linearities (see Section 5.2).

For instance, in the JTP model, the yield percentage of de-inked pulp changes over time to facilitate the equalization of mass balances in the flux model. As an example, in the appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, the yield percentages of de-inked pulp, particularly in newsprint and magazine paper, increase constantly from year 1993 to 2000. In the "active recovery" scenario B, the use of de-inked pulp in newsprint and magazine paper increases gradually from 60 to 68 per cent and from 2 to 12, respectively. In the "high recovery" scenario C, the increase is even more pronounced. The recovery percentages of newsprint and magazine paper approach 70 per cent. The use of de-inked pulp in newsprint increases from 60 to 80 per cent and in magazine paper from 2 to 15 per cent.

It is worth noting that the environmental effects of the three different policy alternatives of the appended Article II may not be unambiguous. For example, if the paper recovery rate is increased, the amount of paper waste decreases, but the amount of de-inking sludge increases considerably. In scenario C of Article II, there are 403.000 tons less paper waste and 1.670.000 tons more sludge in 2000 than in 1993 (p. 106).

In the appended Article III, *Effluent Generation from Paper Production and Consumption in France*, where the KCL-ECO model is applied, the percentage of de-inked pulp in newsprint is fixed to 60 per cent and the percentage of de-inked pulp in household and sanitary paper is fixed to 40 per cent during the period of 1992 to 1997, whereas the other paper grades are virgin pulp-based, and no material is recycled (Article III, p. 33). In the appended Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*, the de-inked pulp percentages are fixed in the same manner as in the appended Article III.

Alternative energy sources are compared in the appended Article IV. By comparing the two coal energy alternatives: 1) coal energy with high cleaning technology with reduction of particles by 99 per cent, and 2) coal energy with low cleaning technology with reduction of particles by 90 per cent, it is possible to analyse the change of one parameter, with *ceteris paribus* assumption, applying the KCL-ECO model (Article IV, p. 292). The change of the ability of reducing particles is analysed in form of air emissions. For example, in Swedish paper production, NOx and emissions are 17,34x10^3 tons in the coal alternative 1 and 21,96x10^3 tons in the coal alternative 2, and the SO_2 emissions are 28,44x10^3 tons and 37,41x10^3 tons, respectively (Article IV, pp. 293-294). However, the dynamics of the change can not be analysed with a static, linear model.

Ekvall (1999a), when referring to Baumann (1998) and Tillman (1998, 2000), points out another important common denominator for the first category, i.e. "descriptive" LCAs: They are distinguished by the way the definition of system boundaries and other methodological choices are made. The methodological choices should be based on established conventions and, typically, exclude system expansion. "This is distinguished from a prospective LCA carried through to assess the consequences of a change, where the system boundaries should be defined so as to include the activities that contribute to the environmental consequences of the change. System expansion is a characteristic approach in this case."

In fact, much of the research regarding future or change-oriented LCAs has focused on the system boundaries and allocation problems. This is not the main focus in this thesis, although the system boundaries have been enlarged to a national-industrial level particularly in both the JTP model (Article I, pp. 228-230, Article II, pp. 79) and in the KCL-ECO model (Article IV, pp. 289-291, Article III, p. 33). The following principle is also stated in Article I (p. 233): "A good method also analyses complete systems, as much as that is possible. In any case, separate analyses of interdependent subsystems is fraught with the risk of producing indeterminate results, and as a result, suboptimal policies." The main focus of this thesis thus goes beyond the system boundaries and allocation problems of LCIs to study the importance of the time horizon and the dynamic qualities versus static qualities of the chosen models.

Viewpoints on the Time Horizon Issue from the appended Research Articles

The discussion of the ways to incorporate the time horizon in material flow models above suggests several ways. The four appended research articles of this thesis have adopted different approaches, mainly following the principle that a future-oriented environmental policy analysis should explicitly incorporate a longer time period. Nevertheless, the role of the time horizon may differ to a large extent, depending on the focus and the assumptions of the study as is the case in Articles I-IV. The following examples from Articles I-IV outline the approaches taken.

Article I: Life Cycle Inventories and Joined Material Projections in National Environmental Planning

The problems of the time horizon or the lack of dynamism, is discussed in the appended Article I (p. 233), which states that "any method of the national environmental planning must also be able to forecast the effects of what different policy alternatives might cause. A complete forecast of the future is not needed, but trajectories of the effects of different policies, as well as their sensitivity in reaching the specified goals." Furthermore, functional qualities of the JTP model are described in pp. 233-234: The JTP model "facilitates the dynamic analysis of the material flows of an industrial system, in which many factors change simultaneously over time (Pento, 1994). This construction technique joins together a series of models, which each describe the material flows of a system in a given time period, such as a year. The models of different periods may be temporally connected with stock equations or like, or may be semi-independent, in which case there are only some or no intertemporal links between them. The technique is a type of quantitative scenario analysis, in which future projections are made of the parameters that largely define the annual material flows. Some of the parameters can be policy variables."

Article II: Les flux matériels des papiers d'impression en France pendant la période 1993-2000

The appended Article II is an empirical application of the dynamic JTP method presented in the appended Article I. Article II analyses the development of the material flows of the French pulp and paper industry during the period of 1993-2000 through three different recovery scenarios. In Scenario A, which is a laissez-faire scenario, paper recovery increases from 38 per cent to 44 per cent. In scenarios B and C (Article II, p. 101) the paper recovery rate is increased from 32 per cent to 47 per cent, respectively, to 55 per cent by policy actions.

The importance of the time horizon, which allows a continuous follow-up of policy actions and a possibility for correcting policy actions, increases when changes in material flows increase. "In the same way as the products and their material flows depend on the totality where they find themselves in a given moment, they depend equally on time. Life cycles can be long processes" (Article II, p. 80).

The JTP model permits the policy maker to make projections of policy alternatives and their effects. The circulation of pulps, fibres, minerals, papers, and wastes are followed on an annual basis. Capacity constraints and necessary investments are also portrayed annually. The increase in recovery further affects the composition of waste, recycling, incineration, landfills, imports, exports, and paper furnish. (Article II, pp. 78-80) The evolution is continuous during the studied seven-year period of 1993-2000.

The furnishes of the paper grades are forced to change significantly in scenario C of Article II (pp. 104-106) because of the rapid increases in the recovery rate. This is because the increased amount of the used papers is utilised as a rawmaterial of papers, which then changes the furnish. When the composition of the paper grades changes, detailed analyses of the material flows of the paper grades can only be conducted if the future effects of the policy action are clearly outlined and expressly calculated in the analytical framework. Otherwise, the policy action changes and, thus, superannuates the system under analysis.

Article III: Effluent Generation from Paper Production and Consumption in France

Even in the appended Article III, time horizon plays a significant role, although not the main role. "Life cycle inventory calculations are made…to determine the quantity of emissions caused by the production of several paper grades in France. The life cycle of each paper grade is first analysed from cradle to mill-gate. Then all paper grades are compared, and their emissions are combined with the results for France of FAO's Pulp, Paper and Paperboard Capacity Survey for 1992-97 to investigate how the quantity of emissions develops during the period" (p. 32).

Emissions of the French P&P industry studied in Article III increased during the period studied, in correlation to the increased paper consumption. The increases in emissions are quite large. For example, CO2 emissions increased from 520.380.000 tonnes in 1992 to 686.526.000 tonnes in 1997. "The FAO's projection makes it possible to follow how emissions develop. As noted earlier, technology does not change in the inventories…If the improved technology aspect were considered, the emissions might be somewhat lower. However, the calculations give the main directions of the development of the French P&P industry's emissions between 1992 and 1997." (Article III, p. 35)

The raison d'être of the inclusion of a time horizon in the inventories of Article III is to demonstrate LCA's ability to obtain "the main directions of the development of the French P&P industry's emissions between 1992 and 1997." The emission output thus permits policy makers to relate the future development of the emissions to a larger environmental policy planning context. In view of, *inter alia*, the 1997 Kyoto Protocol target of reducing greenhouse gases at least 5 per cent from 1990 emission levels during the period of 2008 to 2012, and "the 1990 EC agreement to stabilise CO2 emissions by 2000, the inventories indicate that new technology and strategies are needed if the French P&P industry is to help France meet the environmental commitments" (Article III, p.35).

Article IV: Effluents of Alternative Energy Sources in Swedish Paper Production

The model of the appended Article IV has a long time horizon from 1993 to 2010. Nevertheless, the time horizon plays a less significant role in Article IV than in Articles I-III because its focus is not on the time horizon, but on alternative energy sources due to the phasing out of nuclear power in Sweden. "The Swedish Parliament decreed after a popular referendum in 1980 that nuclear power would be phased out under a time frame that takes into account the national need for electrical power in order to maintain employment and welfare. The Parliament also decreed that the last nuclear reactor in Sweden should be shut down by the year 2010 at the latest" (Article IV, p. 289).

The effluents are calculated, using the Swedish pulp and paper industry as a case example. Life Cycle Inventory calculations are performed to determine the quantity of emissions that are caused by the production of main paper grades in Sweden. Scenarios are constructed in which nuclear energy is substituted by coal and gas. The emissions of different energy alternatives are compared across scenarios. (Article IV, 289, 293-294)

The inventories of Article IV are undertaken to assist environmental policy planning in the future. In spite of this, the time horizon is not included in the inventories of Article IV. It is difficult to foresee the development during the long-term time span of many variables affecting the outphasing of nuclear energy in Sweden. The focus of the research is on alternative energy scenarios and their emissions in which the technology, the paper furnish and the proportion of paper grades are assumed to remain constant. "Production level and production capacity in 2010 is obviously higher than in 1993, and the P&P industry's effluent generation and emissions will consequently also be higher, but this does not have much effect on research results. The focus of the research is namely on effluent generation depending on alternative energy scenarios in which the proportion of paper grades remains constant." (Article IV, p. 291)

The issue of time horizon is closely related to dynamic and static qualities of MFMs that is dealt with in the next section 5.3.1.

5.3.1 Dynamic versus Static MFMs

In this section examples from the appended research articles are used to demonstrate the applicability of both dynamic and static material flow models in environmental policy planning. The envisaged change aspects in the inventories are emphasised. The dynamism of MFMs prove to be of pivotal importance for environmental policy planning, particularly if many variables change under the analysis. Nevertheless, in certain cases static models are preferred.

Article I: Life Cycle Inventories and Joined Material Projections in National Environmental Planning, and Article II: Les flux matériels des papiers d'impression en France pendant la période 1993-2000

Examples from the appended Articles I and II are grouped together in this section, since they can be seen as an entity in terms of the dynamic aspects of the researched MFMs. Article I presents the JTP method, and Article II is an empirical application of the JTP method.

It is argued in Article I (p. 235) and Article II (p. 106), that too radical or too sudden a change in environmental policy without sufficient analysis and planning of potential re-directions of material flows may have a directly negative impact, especially if the effects of regulatory action are not known in advance. A practical example of this is given through the adverse effects of the German packaging ordinance of 1991 that forced raising the recovery rates of all packaging materials without providing a solution for their re-use. As a result, material began to accumulate in unofficial landfills and illegal dumps, and costs of the recycling system skyrocketed. The "garbage crises" in some areas of the United States have also been the result of unsuccessful policies that were set by authorities on environmental grounds. (Article I, pp. 226, Article II, pp. 76). The viewpoint expressed is that LCA can be used for environmental policy planning but "current (static) LCI-techniques do not provide for a policy's effect analysis. This can create huge unnecessary costs, when policies are put into effect using the society or an industry as an experiment ground" (Article I, p. 231).

Strengthening this viewpoint, Article I states on p. 232: A "drawback of a static industry-level LCI lies in its incapability to incorporate in its analysis dynamic changes which are expected to take place in the system in a future planning period. There will obviously be changes in consumption patterns and amounts, industry will modernise its capital equipment, new technologies will be introduced, and collection and recovery systems may change. Such changes will affect all parts of the system: material flows, yields, energy consumption, and the production of effluents and waste. An LCI, whose average figures are based on some functional unit, and made with the production equipment and technologies which existed in the industry at some time in the past, will overestimate all environmental loads from effluent production to energy consumption."

When changes within a policy are proposed environmental planning with dynamic material flow models allows one to generate solutions that are environmentally and economically sound. The methodological framework of the dynamic JTP model allows direct studies and scenario analyses of the effects of policies and programs of a sector. In Article II, using the scenario technique, projections are constructed and different policies can be formulated that optimise or compromise technologies, prices, qualities and quantities. (Article II, p. 80, Article I, p. 233-235)

Article II analyses the material flows of French printing papers during 1993-2000 through three different recovery scenarios. The B and C Scenarios in Article II are examples of environmental regulatory policy and long-term environmental planning. The scenarios clearly indicate the direction of development when a certain policy is chosen. The scenarios that were applied to the French P&P industry describe the effects of an increase in the paper recovery rate, which was relatively low in France in 1993.

The calculated emission and energy inventories of Article II are based on a constant demand projection that is the same for all the scenarios. The JTP model requires that all its material balance equations are satisfied. It does not specify where the pulp is to be used, but leaves this decision to the user, who can use the pulp as a rawmaterial of newsprint, magazine papers, fine papers, or hygiene tissues. To give a simplified example, in the "high recovery" scenario C (p. 101), a balance is achieved, when recovery of used papers increases gradually to 70 per cent, first by increasing recycling. De-inked pulp is used increasingly in newsprint and in magazine paper. However, the years 1995 and 1996 represented an exception in the general trend, due to the high price of de-inked pulp. In both newsprint and magazine paper, there has been a big increase of the use of de-inked pulp. The recovered magazine paper based de-inked pulp is mainly used in newsprint. At the same time, use of mechanic pulp has decreased. The amount of paper waste is low, but there are some 1.670.000 tons more sludge in 2000 than in 1993. In 1997, the recycling capacity was saturated, so that a new capacity had to be built (p. 106). Imports of newsprint decreased significantly – 30 per cent or 150.000 tons – and the amount of imported minerals decreased slightly due to the high recovery. Export of newsprint increased strongly from 473.000 tons in 1993 to 744.000 tons in 2000.

Policy consequences are indicated in terms of the major material flows, e.g., the development of imports and exports of raw materials and final products, the development of the paper furnish, generation of different waste types, and domestic production. Inventories are calculated for a set of effluents for each scenario. Some effluents and emissions would be higher and some lower if a certain policy had been chosen. In many cases the relationships between variables develop in a non-linear manner. Therefore, it is essential that the mathematical structure of the material flow model allows non-linear calculations.

A definite advantage of dynamic MFMs compared to static MFMs in contexts such as the French P&P industry, is that dynamic MFMs are able to include and forecast the effects of investments and technology changes, both of which may radically alter a sector's environmental performance in just a few years. The inventories of Article II offer basic quantitative data on the system, its flows and capacities. This data is directly useful for economical calculations. In 1993, in the beginning of the research period of Article II, the price of waste paper was very high, which limited the use of the recycling capacity to 20%-25%. Then, it was cheaper to use virgin pulp (Article II, p. 77). The price of used paper also affects investments in additional de-inking capacity and even incineration plants.

Technological changes (see chapter 5.4.4) do not play any major role in the inventories of Article II, but for instance in new French mills newsprint can be produced based entirely on de-inked pulp. In the "high recovery rate" scenario C (p. 101), recycling of paper increases rapidly so that a new recycling capacity had to be built in 1997 (p. 106). When the new capacity with better recycling ability was implemented, the effect of this on other flows could be analysed, so that if needed, the flows could be redirected.

Scenario C of Article II (pp. 104-106) is an example of radical changes in environmental policy where the total recovery rate is increased by a policy action from 30 per cent to 60 per cent. In this case, the high rise of the recovery rate demanded large structural changes and investments. In all three scenarios presented in Article II, there are multiple variables such as paper furnish, capacity constraints, exports, imports and waste generation, which are often affected by a change in another variable. The consequences of the alternative policy scenarios were followed during the researched period on an annual basis (pp. 78, 80). "In the same way that products and their material flows depend on the totality where they find themselves in a given moment, they are equally dependent on time. Life cycles can be long processes" (p. 80). Only a dynamic MFM with an acceptable precision can be used to analyse the development of the chosen policies in the scenarios.

Static LCAs commonly study only one average product at a time. "Traditional LCAs cannot analyse several dynamic and independent variables simultaneously. The perpetual dynamism of large systems questions a method supposing that the product does not influence the system or is not influenced by the system of which it is a part." (Article II, p. 78). In fact, effects of a new environmental policy decision may instantly superannuate the system structure of the static LCA and thus invalidate the whole inventory.

Article III: Effluent Generation from Paper Production and Consumption in France

The appended Article III demonstrates the usefulness of a static LCA in studying effluents of the French pulp and paper industry and in finding environmentally preferable production processes and products. The relative environmental friendliness of paper based on chemical pulp or on mechanical pulp is studied. Knowing the limits of present technology, static LCA may help to create inventories of the eventual environmental effects of the substitution of certain chemicals or even pulp, as demonstrated in pp. 36-37.

The allocation of the environmental burden of recycled paper products is briefly discussed. It is mentioned that "it is extremely difficult, if not impossible, to calculate what percentage of the effluent generation of paper that is (possibly several times) first produced, collected, and de-inked should be allocated to recycled paper....In LCA inventories the share of the effluent generation caused by the original product(s) and allocated to the recycled product can range from 0 to 100 per cent….Yet all fixed percentages between 0 and 100 are very subjective" (p. 34), and may lead to serious errors. The allocation issue is relevant regarding the dynamic versus static character of MFMs. The JTP model can handle the allocation problem by setting the system boundaries on an industrial level (Article I, pp. 227-229). For static models there is no general rule for the allocation problem, but solutions may be found depending on the goal of the study. In the inventories in Article III, zero per cent is chosen because it facilitates the calculations and because the focus of the comparisons is the virgin pulp-based paper grades (p. 34).

Some public policy planning aspects are also outlined in Article III. Even if the model used in Article III is not dynamic, the time perspective is partially included in the assessment by multiplying the emissions with the 1992 and 1997 production quantities. Article III investigates the evolution of the emissions dependent on production. In reality, the paper furnish also develops during the research period which, together with changes in technology, decrease the accuracy of the calculations based on a static LCA. In other words, "technology does not change in the inventories….If improved technology aspects were considered, the emissions might be somewhat lower. However, the calculations give the main directions of the development of the French P&P industry's emissions between 1992 and 1997" (p. 35).

People responsible for environmental policy planning for the French P&P sector should most probably develop new environmental policy options if the industry is to help France meet international environmental commitments, such as the need to stabilise and even reduce CO2 emissions and other greenhouse gases. It is stated that new technology and strategies are needed in the P&P sector to reduce emissions (p. 35). Nevertheless, if technology or other variables influencing other parts of the system, are added to the assessment, the need for a dynamic MFM increases.

Article IV: Effluents of Alternative Energy Sources in Swedish Paper Production

In the appended Article IV, effluents of alternative energy sources for the nuclear energy consumed in Swedish paper production during the time period starting of 1993 to 2010 are researched. Even if a change is studied, a static LCA may be considered more suitable for the inventories than a dynamic MFM in this particular case because the focus is on comparative emission calculations. In addition, Article IV can be considered as an indicative study in a situation where many essential questions regarding alternative energy sources and outphasing remain open and in which many assumptions have to made. Article IV could be followed by more detailed studies in which other variables such as technology are included and, consequently, a dynamic MFM is applied.

The inventories are made for four different energy scenarios for both 1993 and 2010 Scenario 1. "The current energy fuel structure continues with a share of nuclear power of 42,08%. (Scenario) 2. Nuclear energy is replaced by coal energy with high cleaning technology (reduction of particles by 99% and SO2, wet method, used chemicals Ca/S 1,05, reduction by 80%), (scenario) 3. Nuclear energy is replaced by coal energy with low cleaning technology with reduction of particles by 90%, (scenario) 4. Nuclear energy is replaced by natural gas. All the alternatives demand investments, but are feasible development routes" (p. 292).

In Article IV, the focus is on different energy sources, and the remainder of the life cycle is assumed to be the same. The changes are assumed to take place only in one part of the system. No efficiency improvements or changes in technology are assumed in the modelling principle. The furnish of paper end-products is unchanged in the inventories, and emissions develop in relation to the production level. Nevertheless, this is not considered to have a pivotal effect on the research results as they should not be seen as absolute. Instead, they should be viewed as being relative and indicative, pointing out the direction of emission development of alternative energy options. (p. 291)

In reality there are, of course, many variables that develop during the long-term time span. A scenario is always a simplification of the reality aimed to describe the future path of the research object from agreed-upon premises. Due to the precise focus and indicative nature of the study, as well as the many variables whose development is difficult to speculate, a linear, static LCA fulfils the aims of the study. In addition, it could be argued in this context that a multidimensional dynamic MFM could be an unnecessarily heavy tool compared with linear LCAs. Most probably, a better research methodology would apply both dynamic and static models to each case, but due to the nature of this thesis, and the fact that to a large extent it is based on previously written articles, this has not been possible.

5.4 Applicability Areas

In this section, the JTP model and the KCL-ECO model are compared in terms of applicability to the different areas of environmental management. Some of the common areas of environmental management where MFMs are currently applied are used to demonstrate the applicability of the chosen static and dynamic material flow models to environmental policy planning in the pulp and paper industry. The chosen areas of environmental management are:

1) waste management;
2) product and production-based criteria;
3) technical and capacity constraints;
4) process and technology based criteria.

The major finding of this section is that the dynamic JTP-type models should be preferred in technical and capacity constraints, process- and technology-based environmental management, and in some waste management applications. Static models seem to be more applicable to product- and production-based environmental management and in some waste management applications.

5.4.1 Waste Management

In this section the applicability of the chosen MFMs is studied in terms of basic waste management applications. The applications chosen in this section are 1) *Waste Prevention and Minimisation,* 2) *Disposal Alternatives of Waste,* 3) *Producer Responsibility*, and 4) *Precautionary principle.*

The major finding of this section is that a dynamic MFM is preferred if the focus of the policy action is on following and redirecting waste flows. A static MFM is preferred if the focus of the policy action is to point out the amounts of effluents, energy, and materials used and produced by the system in an historical situation.

Changing the policy patterns toward systems and products whose use and manufacture creates less waste and emissions is expected to result in considerable environmental improvement. The applicability of MFMs in waste management is obvious. They can be used in developing more environmentally friendly systems, such as the French paper industry in Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, or in the outphasing of nuclear waste in the Swedish energy alternatives in Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*, or in the improvement of products, e.g., by comparing emissions of paper based on chemical pulp with paper based on mechanical pulp processes (Article III, pp. 35-37).

Waste Prevention and Minimisation

The primary goal of waste management is the prevention and minimisation of the negative environmental effects caused by material flows, which are generated by the produced and purchased products in the region, nation or world. This goal necessitates MFM-based analyses to make sure that all relevant environmental effects are included and accounted for, and that its results do not re-direct material flows toward absurdities. Material flow changes can be unexpected and non-obvious and may sometimes produce endresults that are the opposite of those that were called for.

Both the appended Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production*, Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, and Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning*, demonstrate the applicability of MFMs in waste prevention and minimisation. In Article IV, the production of the main paper grades in Sweden causes annually 8,9 tons of nuclear waste. Three scenarios are made to analyse the effluents on other emissions from policies that would eliminate nuclear waste. Even the development of the magnitude of other types of industrial waste in different scenarios can be noticed. (Article IV, 293-294)

The inventories of Article II can also be helpful for policy makers interested in waste prevention and minimisation. Waste composition and its development can be studied with the JTP model. For example, in scenario A, "the annual material flow going to landfills include de-inking sludge, ash, effluents of de-inking, and paper. Approximately half of the waste is paper and the other half is mainly de-inking sludge" (p. 102). Scenarios A, B and C can also be studied in terms of waste minimisation: in scenario B, the amount of waste is lowest of the three scenarios, but on the other hand, the amount of sludge increases significantly (p. 103). The "high recovery rate" of Scenario C produces the most waste as compared with the other scenarios.

Article I presents a case where the waste production in Germany between 1993 and 2000 is researched with two alternative scenarios. Scenario 1 assumes that no policy actions will be taken concerning the recovery rates or incineration of papers, but that the development will continue in a laissez-faire situation. Scenario 2 assumes three policy changes: Paper recovery rates are increased by decree to 70 per cent by the year 2000. The mineral content of all papers is slowly reduced to correspond to a minimal thermal value of 17 GJ/t. And substantial amount of lowest grade waste papers is incinerated, together with the increasing amount of de-inking sludge. As a result of these policies, the total amount of waste generated in scenario 2 is only 30 per cent of the total waste generated in scenario 1, but there is a strong increase in ash in scenario 2. (Article I, pp. 235-236)

The scope of the KCL-ECO model and the JTP model is different regarding waste prevention and minimisation. The static KCL-ECO model is preferred in waste prevention and minimisation when the focus is on emissions and effluents of (preferably) a historical situation or historical data is acceptable for the results such as in Article IV. The dynamic JTP model should be preferred when the focus is on development of waste flows and waste composition as is the case in Article II and Article I.

Disposal Alternatives of Waste

The relative environmental friendliness of different disposal alternatives is an issue of interest for waste management in general and for the MFM-based inventories in particular. The appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, studies different disposal alternatives by counting the existing and re-directed waste flows. The inventories of Article II are preceded by a presentation of main environmental, technical, and economic aspects of the disposal alternatives, i.e. recycling, incineration and landfills as well as exporting (pp. 77-78).

In the "laissez-faire" scenario A of Article II (p. 101), an important share of old paper ends up in landfills together with other waste. The quantity of paper placed in recovery increases modestly in proportion to the demand. Only a minor share of all paper grades is recycled or incinerated. The quantity of recovered paper in exports increased 83.000 tonnes from 1993 to 2000 (pp. 102, 105). In the "active recovery" of scenario B (p. 101), an increased share of the recovered paper was incinerated and recycled particularly after 1997. The share of recovered paper in exports increased strongly (403.000 tonnes), from 1993 to 2000. (pp. 103-104) In the "high recovery rate" of scenario C (p. 101), both recycling and incineration of paper increased rapidly when the recovery rate increased. The recycling capacity was saturated in 1997 and new capacity had to be built. Exports of recovered paper decreased importantly compared to scenario B and scenario A. (p. 106).

In the appended articles of this thesis, the applicability of the static KCL-ECO LCA model to study waste disposal alternatives has not been analysed. However, Kärnä, Pajula & Kutinlahti (1994a, 1994b) and Pajula and Kärnä (1995) have studied with the KCL-ECO model, the relative environmental friendliness of recycling versus energy recovery in terms of CO_2 balance.

The environmental data of a static LCI is very useful as the basis of a waste management policy for it points out the amounts of effluents, energy and materials used and produced by the system. But it is deficient in the sense that it will not provide the planner of a waste management policy the possibility of simulating the effects on the system by some environmental policy. In contrast to the static KCL-ECO, the dynamic JTP model can handle even a large change in the analysed system such as increased recovery rate changing the paper furnish.

Producer Responsibility

According to UNEP, the principle of producer responsibility is becoming increasingly important in waste management In Western Europe. The general structure of producer responsibility programs is to place financial responsibility for recycling and disposal on the product and/or package manufacturer, and to internalise incentives for recovery, reuse, and recycling through taxes, fees, and deposits. Most systems encourage industry to form one or more recycling corporations that guarantee markets for the collected materials. Some systems, like that today in France, allow industry to make use of public sector waste management infrastructure – usually for a fee – with the goal of funnelling private funds to build or enhance public recycling infrastructures. (UNEP, 1998)

In addition, producer responsibility programmes are currently an applicability area mainly for static MFMs, which can be used to point out problem areas. Producers can use inventories calculated in LCI-type MFMs to assess different subcontractors. Producers may also attest their environmental claim to their customers with static MFM inventories.

However, the use of a static MFM in producer responsibility programmes does not necessarily give unambiguous results, due to the difficulties in allocating the emissions and effluents of a certain product to its producer(s). For example, the flows of printing and writing grades, form complex feedback loops in which a large part of them are recovered after consumption and are re-made into the same or other paper grades. Waste management based on the life cycle of such papers is not readily defined. The static LCA models in particular are not useful in this context, because the fibres from a piece of chopped wood can be manufactured into several types of paper with their subsequent recycling rounds, and therefore their grave can eventually represent any of a set of outputs to the environment. (Article II, p. 79, Article III, p. 34)

Precautionary principle

One of the principles of increasing importance in the context of waste management is the precautionary principle, i.e., that potential problems should be anticipated in advance (European Commission, 1999a). Therefore, the static nature of most material flow models often impairs their usefulness in waste management. The applicability of static models in waste management on a regional or national level is limited, because static models consider the product(s) or system only in the past tense. (Article I, 231-232) The dynamic inventories of systems conducted with the JTP model are seen as more appropriate for waste management, particularly when taking into account the precautionary principle.

The use of dynamic material flow models is highly recommended in waste management on the national or industrial level in order to avoid pitfalls. As discussed in Article I *Life Cycle Inventories and Joined Material Projections in National Environmental Planning* (pp. 225-226): "Numerous re-cycling laws, ordinances and administrative rulings, have been decreed in Europe and America in the past few years….Advance planning of many of these laws and ordinances appears to have been so insufficient that they have in some cases produced more problems than solutions." Alterations in disposal options, waste composition, and in the content of paper products may lead directly or indirectly to changes in the directions of flows, which in turn may also alleviate environmental problems.

In summary, the environmental data of a static LCI is very useful as a basis of waste management, for it points out the amounts of effluents, energy, and materials used and produced by the system. But it is deficient in the sense that it will not provide the planner the possibility of simulating the effects on the system by some environmental policy. The ability of the dynamic JTP model to include in addition, other decision factors of environmental data such as investments, operating costs, imports, exports, and employment (Article I, p. 234) makes the model a tool that is especially suited to the needs of waste management. To name an example, operating costs are included in the decision framework of the JTP model in Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*: when the price of the recovered paper increases, the producers use more virgin pulp (p. 102).

Dynamic models, such as JTP, allow the policy planner to follow in a holistic manner the direction of the material flows, redirect them into the desired direction, and to find a balance of environmental and economic interests. The basic idea of MFMs is to analyse quantitative data and redirect the flows in a more sustainable direction. Static models can also identify the problem areas in waste management systems, but their ability to assess different policy options and their impacts on determinated problems are much more limited. In systems where product mix or product contents (e.g., paper furnish) evolve rapidly, a dynamic MFM is actually the only realistic alternative to producing a life cycle inventory with an acceptable degree of precision.

5.4.2 Product-Based or Production-Based Approaches

Many environmental programmes affecting the pulp and paper industry are product-based or production-based. In this section, the applicability of the chosen MFMs is studied in their relation to four well known product or production-based approaches. The approaches selected in this section are 1) E*mission Control Schemes*, 2) *Integrated Pollution Control*, 3) *Recycled Content*, and 4) *Recyclability*.

MFMs and especially LCAs are often applied as analysis methods to help the decision making of these programmes. The major finding of this section is that static MFMs are generally preferred in this context because the focus of the policy action is related to the assessment of product or system emissions, and the time aspect is not significant. On the other hand, policies that are concerned with the recycled content of products may better be supported by dynamic MFM models. Within the P&P industry, this is pointed out by the rapid re-direction of flows when the furnishes of paper grades are changed toward more recycled pulps.

Emission Control Schemes

Paper production creates emissions and waste during its processes and transports, as well as during consumption activities along its life cycle. Policy makers have paid much attention to the emissions at production processes. A policy action should include at least some of these emissions if it is to be indicative of a product's environmental performance. It is cumbersome to consider all items of an inventory, but a set of representative criteria can be adopted.

One approach is to catalogue effluents by the media, as in the case of ecolabels: emissions to water (AOX, COD, BOD), and to air (CO_2, SO_2, NOx), and solid waste generation such as sludges and paper to landfill (Article III, p. 33, Article IV, p. 292). In eco-labels, a representative of each media is selected. In a situation where self-regulatory and governmental permits are applied, a static LCA is preferred to dynamic MFMs because the scope of the policy is related to products. Ecolabels demand precise emission inventories and are tied to products and processes (cf. Article III, p. 34, Article IV, p. 293). The time aspect is not significant in ecolabels. The inventories are made in a certain historical situation and ecolabels and their criteria are updated every two to three years (SFS, 1996).

Integrated Pollution Control

Emission permits that are issued by public bodies can also be operationalised at the mill level. The new integrated pollution control (IPC) laws, which already have been mandated in some countries, and the European Union IPPC directive 96/61, introduce a new control parameter:

(amount of harmful substance emitted) / (amount of product made).

For this parameter to actually be employed in future permits, firms will have to carry the large burden of collecting their emission and production data and allocating the emissions to the products. If these product-based emission control systems really become commonplace, firms will then have to collect data for the authorities, which they can also use for assessing emissions and waste along the life cycle of their products. This integrated pollution control may herald an increase in the use of LCA because the control parameter of the EU IPPC is nothing more than the emission coefficient of a linear LCI. As the time aspect is not significant here and precise inventories are needed, static LCA is more suitable than dynamic models.

Recycled Content

Some current paper product-related environmental programs, e.g., some public procurement programmes, use the recycled material content of papers as a criterion for identifying environmentally friendly products. The recycled material content of papers is particularly useful when waste avoidance is the paramount goal of general environmental policy. Recycled papers contain less virgin materials, they reduce flows of used papers to landfills, and the manufacture of papers from de-inked fibres requires less energy and produces fewer of some effluents (Article I, p. 235-236, Tiedemann, 1992, Huuhtanen & Pento, 1995). It must be noted that the recycled content criterion does not mention any of the other effects on the environment caused by a product. The producer who is the worst energy waster and polluter may be found acceptable, provided that enough of its fibres originate from used papers (Gronow et al., 1998).

The inventories in the dynamic JTP model can facilitate the study and planning of recycled content as a variable of paper making. In the appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, the recycled content of different paper grades can be followed in terms of the development of the raw materials of the produced paper and deployment of recovered paper. An increase in the recycled content of a product, i.e., an increase in de-inked fibre content in papers, will reduce the amount of virgin materials used. It can be noticed that the recycled content of news print increases in scenario A and particularly in scenario B when the recovery rate is increasing (p. 102-103). In scenario C, "the share of (recycled) fibres increases in news print and in magazine paper when the recovery rate increases strongly" (p. 106).

An increase in non-recyclable material content, such as mineral fillers in papers in scenario A from 1995 to 1997 (Article II, figure on p. 104), will frequently increase the amount of industrial waste produced at recycling. On the other hand, a decrease in non-recyclable material content may contribute to a reduction in the amount of industrial waste produced at recycling, as well as lower energy use and effluent generation (Article I, 235-236).

An unlimited increase in recycled content may also lead to an unfavourable waste equation, to the point where the amount of industrial wastes increase over the weight of recovered papers. In scenario C of Article II, the amount of the badly deployed de-inked sludge increases close to the amount of de-inked pulp. There are 2.338.000 tons sludge and 3.068.000 tons de-inked pulp in 2000, the last year of the research period (p. 106).

The relative environmental friendliness of two or several paper grades with different recycled content has been studied with static LCAs by several researchers (cf. Article III, p. 35-37). The researchers have been obliged, however, to develop different allocation rules in order to cope with the recycling issue (Ekvall, 1999b). In contrast to this, Article III (p. 34), argues that it is difficult if not impossible to compare the life cycle inventories of paper produced with virgin pulp and paper produced with de-inked pulp. An allocation problem arises from the emissions of de-inked pulp as a raw material of new paper. The potential of KCL-ECO software in emissions inventories is evident. A more complete analysis of the emissions of a system, including recycling grades, may be performed. Nevertheless, a comparison between paper made with virgin pulp and paper made with de-inked pulp is possible only if the researcher manages to bring forth an acceptable allocation rule.

Recyclability

The recyclability of materials contained in papers can at times be a vital factor in guaranteeing sufficient supplies and material flows for recycling at competitive prices, and in reducing the waste of non-recyclable materials. Some printed papers contain up to half of their weight in materials that can be recycled only to a limited degree, and may even hinder the recycling process. China clay, calcium carbonate, talcum, titanium dioxide, several types of latexes, a number of printing inks, UV-curable lacquers and films: all make for a high-grade technical product, but are mainly discarded as waste when wood fibres are de-inked for re-use. A product's technical suitability for recycling can usually be established with objective tests. Neither dynamic nor static material flow models are optimal in testing recyclability. Still, the dynamic JTP model allows us to follow the development of mineral fillers and coaters of (recycled) paper, as mentioned earlier, and on a national or industrial level it can indicate process disturbances in recycling.

5.4.3 Technical and Capacity Constraints

In this section the applicability of MFMs is assessed in relation to their ability in calculating technical and capacity constraints. The strong areas of both static and dynamic MFMs are discussed. Examples from the appended articles are presented in this section to demonstrate to the applicability of the chosen models. At the end of the section, the heavily capital-intensive nature of the P&P industry is briefly discussed in relation to modelling capacity changes.

The major finding of this section is that the applicability area of dynamic MFMs compared with static MFMs is larger in the area of technical and capacity constraints. Static LCAs may be used in technical constraint calculations in "hot spot" identification at the production unit or mill level. Dynamic MFMs are good in managing capacities on an industrial or national level. A JTP model allows the policy planner to follow closely the development of pulp and paper quantities and clearly points out the needs for new capacities.

At the production unit or mill level, static LCAs are considered a good tool for the identification of problem areas, i.e., "hot spots," in the life cycle of a particular product or system to which a technical improvement could be made. Static LCAs may be used in technical constraint calculations when precise data is available. Nevertheless, static LCIs do not give an indication of the potential needs of new capacities, and they cannot analyse the impact of a change in technical and capacity constraints.

The applicability area of dynamic MFMs compared with static MFMs is larger in the area of technical and capacity constraints. Dynamic models can be particularly useful in studying the effects on material flows in production capacities on an industrial or national level. The appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, stresses the need to involve capacity constraints in environmental policy planning. It is stated that "decision makers should first study all the alternatives for the deployment of recovered paper, the costs, secondary costs, actual capacities, and possibilities to increase capacities and the consequences of these decisions," in order to avoid environmental disturbances (p. 76).

Analyses of production capacities play an important role in applications of the JTP model. The material flows of any year under analysis are defined by the existing demand projections and flow direction. In the context of technical and capacity constraints, the JTP model accomplishes the following, providing:

- Projections of the needs for capacities of manufacturing process and disposal capacities;

- A basis in determining the amounts of imports and exports of papers and used papers;
- Limited to domestic reuse of collected papers.
  (Article I, p. 234)

A JTP model allows the policy planner to follow closely the development of pulp and paper quantities and clearly points out the needs for new capacities. In the beginning of Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, the different disposal alternative capacities in France, i.e., de-inking, landfill, and incineration capacities are discussed together with exports and imports of recovered paper (pp. 76-78). In the scenarios of Article II, the disposal capacities are further discussed. To name an example, in the "high recovery rate" scenario C: "Although there first exists a lot of de-inking capacity, all the capacity was saturated in 1997, after which new installations had to be constructed in order to satisfy the demand" (p. 106).

The inventories in Article II include paper machine capacities and technical constraints. For example, when the paper recovery increases rapidly in scenario C, new news print capacity has to be built (p. 101). Increased recycling increases also the amount of minerals. The mineral recovery calculations of the JTP model (Article II, figure in p. 104) are another example of calculations related to technical constraints. In practice, the JTP model does not allow the ratio of minerals, divided by the total weight of paper, to increase, for example, to over 4 per cent in the case of news print due to the technical quality requirements. The JTP model forces the policy planner to envision the flows of minerals to be arrested or redirected. In a similar way, in the case of magazine paper, the JTP model warns the policy planner if the furnish does not contain at least a certain mineral percentage.

In the context of technical and capacity constraints, it should also be noticed that the pulp and paper industry is heavily capital-intensive. The investment costs of a chemical pulp mill with an annual capacity of 300.000-400.000 tons of pulp are about 500 million USD and, if the paper production is integrated in the mill, the costs are about 200 million USD higher. In case of mechanical pulp, the total costs for an integrated mill are 400 million USD. In the case of a de-inked pulp-based mill, the total costs are 300 million USD. Therefore, large capacity changes require heavy investment in the resources and time of the company. Although investments are often made in existing paper mills by building a new production line, a single investment may have an important impact on the markets. It takes a long time on the markets for the new capacity to be absorbed. At the same time, new capacity depresses prices and profits. Consequently, modelling large capacity changes in the P&P industry is a difficult task requiring several different instruments of the policy planner.

5.4.4 Technology-Based Criteria

This section reviews the ability of the chosen MFMs to handle the Technology Based Criteria. The role of technology change in the context of MFMs is stressed. The chosen static and dynamic MFMs are related to technology categories suggested by Weidema (1997) in which environmental impact and time horizon differ from each other.

The major findings of this section are that 1) the dynamic JTP model offers a wider range of applicability regarding the technological categories previously suggested by Weidema (1997), 2) particularly when the time horizon becomes longer, it is evident that a dynamic MFM is needed to model the technology change, and 3) the impact of a technology change cannot be analysed with static LCAs, not even by using the concept of marginal technologies. The dynamics of the actual change, which is expected to take place in the system, are of the liveliest interest to the policy maker, but can only be analysed with a dynamic MFM.

The introduction of new technologies in the paper industry is beset by high capital costs, which subsequently make risks of unproved methods substantial. The technology risks of a large investment are combined with market risks when the acceptance and the price of the new paper grade is unknown. The high stakes and risks may reduce the manufacturers' incentives to invest in new and environmentally sounder products and processes. Therefore, an MFM's ability to analyse technology changes is of great importance.

Weidema (1997) states 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." Weidema suggests distinguishing between the following technologies:

- Worst technology (the technology that would result in the largest environmental improvement when it was taken out of use);
- Average technology (the technology on which it is easiest to obtain information 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 that 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 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).

A company must be able to compare and improve its products and processes improving the technology and thus making the products more environmentally friendly. The technology that allows the use of static LCA is the producer-mill specific, modern technology. However, in many cases, researchers must use historically average data, and consequently average technology is used in static

LCIs.

Frischknecht (1998) states that a static (descriptive) LCA tends to apply average technologies in the system model. The appended Article I, *Life Cycle Inventories and Joined Material Projections in National Environmental Planning*, argues that an LCI, whose average figures are based on some functional unit, made with the production equipment and technologies which existed in the industry at some time in the past, will overestimate all environmental loads from effluent production to energy consumption. The history of industries shows consistent improvements, which are in most cases expected to continue in the future. An case in point is that of the amount of AOX in the waste waters of an old kraft pulp mill using active chlorine, compared with those of modified, or new mills that use no chlorine in bleaching. (Article I, p. 232)

The data used in the modules of KCL-ECO (see Article IV, pp. 289-290) represents mostly yearly average figures of current average technology. The effects of changes can be modelled to a certain extent by constructing several static LCI-models using today's averages and modern technology or alternatively modern technology and best available technology.

An example of LCI with different type of modules is in Article IV, *Effluents of Alternative Energy Sources in Swedish Paper Production* (p. 292), the first of the coal energy with reduction of particles by 90 per cent and the second coal energy alternative with reduction of particles by 99 per cent. The first of the coal energy alternatives can also be seen to represent modern technology and the second coal energy alternative to represent the best available technology. In the case of the KCL-ECO model, the default of not being able to handle large changes is compensated with the separate simulation program called IMPACT of Jaakko Pöyry Consulting: thus "different agglomerate LCI-modules of almost any type of pulp, paper and board mills or their integrates may be calculated" (Kärnä, 1995).

The dynamic JTP model offers a wider range of applicability regarding Weidema et al.'s technological categories presented previously in this section. It can be used to simulate the effects on material flows, emissions, and virgin materials by best available technologies and even, in theory, best technically possible technologies when the time horizon is made longer.

When the time horizon is made longer it is evident that a dynamic MFM is needed to model the technology change and thereby affect changes in capacities and effluents. Radical changes due to technology may take place in the time horizon of a few years. An example is the case of the Finnish P&P industry, where BOD7 emissions per produced ton of printing paper declined from 10,1 kg/t in 1986 to 0,9 in 1997 (FEI, 1998).

In practice, a major problem in JTP modelling is the lack of data, especially that which pertains to environmental factors and technology change. A projection may show that material flows will be balanced when the furnishes of newsprint mills contain on the average 74 per cent of de-inked pulp. The availability effluent data for this kind of average is unavailable and has to be estimated with rather subjective methods. (Article I, p. 237)

Marginal Technologies

Frischknecht (1998) and Weidema et al. (1999) stress the importance of marginal technologies and suggest that technology changes in (static) life cycle inventories could be analysed by using the concept of marginal technology. Weidema et al. (1999) define marginal technologies as the technologies actually affected by small changes in demand are typically studied in a prospective, comparative life cycle assessment. Frischnecht (1998) claims that any change – whether short or long-term – will be compensated for by marginal technologies, but the technologies may, however, differ depending on the time horizon. Weidema et al. (1999) claim that using data on marginal technologies in LCIs therefore gives the best reflection of the actual consequences of a decision.

Pesonen (1999a) strongly criticises the use of marginal concepts in the context of MFMs. Pesonen points out that the concept of marginal technology "includes an inherent assumption that the capacity of the existing processes and technologies is 100 per cent 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."

This thesis suggests that dynamic MFMs should be used instead of the concept of marginal technologies to analyse technology changes. The inventories of the scenarios of the appended Article II, *Les flux matériels des papiers d'impression en France pendant la période 1993-2000*, support Pesonen's criticism of the marginal technology concept because most production sites use something less than the full 100 per cent of their capacities. For example, the de-inking capacity in the "high recovery" scenario C is saturated only in 1997 (Article II, p. 106). This means that small changes (referred to 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.

Another argument that advocates the use of dynamic MFMs is that a large change in the paper furnish may superannuate the overall material flux structure of an LCI. Still another argument for dynamic MFMs is that "the dynamics of the actual change which are expected to take place in the system will not be shown by these (static) LCIs, even though these are of the liveliest interest to the policy maker. One of the most important tools in national policy is to advance system changes that have environmental characteristics such as new technologies, better capital equipment, improved collection, and sorting methods" (Article I, p. 232).

5.5 Conclusions of the Comparison of the Chosen Models

This section provides the final conclusions of the comparison of the chosen models by answering the research problem, i.e., the applicability of Material

Flow Models (MFM) to environmental policy planning in the pulp and paper (P&P) industry. The results of the comparison in Sections 5.1.-5.4. are concluded and related to the more detailed research issues presented in Section 1.4.

- What are the common features and differences of the chosen static and dynamic MFMs?

Section **5.1 A Methodological Framework of the Models** demonstrates that the methodological principles in the JTP model and KCL-ECO are basically the same. Both techniques are variants of environmental Leontief-type Input-Output models. The inclusion of non-linear formulas in the methodological framework of the JTP model makes the most important difference between it and, on the other hand, environmental Leontief-type Input-Output models and KCL-ECO that only include linear formulas in their framework.

The assumption of stable external factors makes another difference to the methodological structures of, on one hand, the Leontief-type Input-Output models and the KCL-ECO model and, on the other hand, the JTP model. The KCL-ECO model as well as other static LCA models represent present conditions too (Article I, pp. 231-232), whereas the dynamic JTP model is able to deal with unstable external factors within the time horizon (Article I, p. 233-235).

When referring to section 5.2, **Linearity Versus Non-Linearity**, this thesis supports the claim previously presented by Pento & Karvonen (2000) and Pesonen (1999b), i.e., that linearity is too strong an assumption for the parameters and formulas used in MFMs. Linearity may be of crucial importance in a material flow model inventory. It is particularly important when recycling or technological change is included in the researched system. In case of policy planning, the application of only a linear part of a product's life cycle as a basis of national policy may lead to suboptimisation and even outright errors. Linearity is found to be too strong an assumption in an MFM or LCA context.

- What is the role and importance of future-oriented material flow models in environmental policy planning? What is the role of the time horizon? What are the advantages and restrictions of static and dynamic models?

The major finding of the research of this thesis is that dynamic material flow models should be preferred in environmental policy planning, particularly if the object of policy planning is to construct alternative future-oriented scenarios. Static LCAs should be used in future-oriented environmental planning only in very limited cases.

When referring to section 5.3, **Time Horizon**, the major finding of this section is that a future-oriented environmental policy action should have a time horizon included in the method. Nevertheless, the role of the time horizon may differ to a large extent, depending on the focus and the assumptions of the study. Static MFMs have a limited ability to study changes, while dynamic MFMs can better study the continuous changes in technical and environmental conditions of consumption and production on the time horizon. In addition, dynamic MFMs are considered to go beyond the categories previously proposed by other researchers (Ekvall, 1999a, Weidema, 1998) by studying systems in which many factors change simultaneously over time.

Static MFMs calculate the input and output of the defined system for a specific historical moment using often average data. Static MFMs, such as the KCL-ECO, may be very useful tools in environmental management in companies where environmental decisions are related to products and detailed data is available from the supply chain. A static MFM may be a good tool in identifying the "hot spots" in products and processes, comparing them, and, thus, in making them more environmentally friendly. A static MFM can even be used in a company to make an inventory and assess the environmental impact of its entire production at a certain time. Nevertheless, they fail to assess the development of the system over time.

Static LCA is applicable in a national context when the scope of the inventory is related to a single product, service, or process. Static LCAs may provide additional data for a specific policy-making situation. Static LCA may be utilised in stable situations when historical data is reliable and if the focus of an environmental policy planner is on pollution prevention and control of existing products, services or processes, for example in granting governmental permits, such as ecolabels, where the time aspect is not significant (see Section 5.4.2).

If the interest of the environmental policy planner is in the future development of material flows or in the effects of a particular regulatory action, a dynamic MFM is not only to be preferred, but it is in fact the only realistic alternative. Dynamic MFMs are more powerful tools for material flow management in environmental policy planning than static MFM because they include the time horizon in their analytic framework and are able, therefore, to predict and analyse changes and their impacts in the researched system. Even short term, in systems where the product mix or product contents, for example paper furnish, evolve rapidly, a dynamic MFM is actually the only realistic alternative to make a life cycle inventory with an acceptable degree of precision. Technical and capacity constraints, process and technology development, and other external effects increase the need of a dynamic material flow model in inventories in the long term.

Besides the strengths of the JTP method in long-term environmental planning, it is less useful in product-based, life cycle inventories. The JTP method and dynamic models in general may be used in analysing major material flows, but are too heavy as instruments for very precise short-term emission inventories and assessments (Section 5.4.2).

- What are the applicability areas of the chosen models related to some common environmental policy issues related to the P&P industry?

There is obvious, though partly still unused, potential for the applicability of static MFMs and dynamic MFMs to environmental policy planning in the pulp and paper (P&P) industry. The applicability areas of static and dynamic MFMs are relatively different in environmental policy planning. Both the static and the dynamic modelling techniques can be used to calculate inventories of industrial systems and for environmental policy planning, but their strengths appear to be in different areas. Both types of MFMs can be used as tools, both inside the companies and on a national level, but in different situations. The policy maker should be careful in his choice of an MFM.

In section 5.4, **Applicability Areas**, the JTP model and the KCL-ECO models are compared in terms of applicability to the different areas of environmental management. The major finding of this section is that the dynamic JTP-type models should be preferred in technical and capacity constraints, in process- and technology-based environmental management, and in some waste management applications. By contrast, static models are preferred in product and production-based environmental management and in some waste management applications.

The major finding of section 5.4.1, **Waste Management**, is that a dynamic MFM is preferred if the focus of the policy action is on following and redirecting waste flows. A static MFM is preferred if the focus of the policy action is to point out the amounts of effluents, energy and materials used and produced by the system in an historical situation.

The major finding of section 5.4.2, **Product-Based or Production-Based Approaches**, is that static MFMs are generally preferred in this context because the focus of the policy action is related to the assessment of product or system emissions, whereas time aspect is not significant such as in ecolabels or integrated pollution control. The inventories are made in a certain historical situation, and ecolabels and their criteria are updated every two-three years. However, recycled content, used as the basis for environmental policy, requires a dynamic MFM due to the rapid evolution of this content.

The major finding of section 5.4.3, **Technical and Capacity Constraints**, is that that applicability area of dynamic MFMs compared with static MFMs is larger in the area of technical and capacity constraints. Static LCAs may be used in technical constraint calculations in "hot spot" identification at the production unit or mill level. Dynamic MFMs are good in managing capacities on an industrial or national level. A JTP model allows the policy planner to follow closely the development of pulp and paper quantities and clearly points out the needs for new capacities. Nevertheless, a single investment in a new mill may have an important impact on the markets. It takes a long time in the markets for new capacity to be absorbed. Consequently, modelling large capacity changes in the P&P industry can be a very difficult task.

The major findings of section 5.4.4 **Process and Technology Based Criteria** are that 1) the dynamic JTP model offers a wider range of applicability regarding the technological categories previously suggested by Weidema (1997); 2) Particularly when the time horizon becomes longer it is evident that a dynamic MFM is needed to model the technology change; and 3) The impact of a technology change cannot be analysed with static LCAs, not even by using the concept of marginal technologies. The dynamics of the actual change, that are expected to take place in the system and that are of the liveliest interest to the policy maker, can only be analysed with a dynamic MFM.

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YHTEENVETO (Finnish Summary)

Materiaalivirtamallit ympäristöpolitiikan ja -toimintatapojen suunnittelussa

Case: Massa- ja paperiteollisuus

Ympäristöpolitiikan ja -menettelytapojen vallitseva suuntaus kohti ratkaisuja, joissa pyritään saasteentorjuntaan saasteen alkulähteillä, muuttaa päätöksenteon perusteet saasteiden ympäristövaikutusten ennakoivasta ymmärtämisestä tuotanto-kulutustoiminnan kokonaisvaltaiseen arviointiin. Näin ollen elinkaarianalyysi ja muut materiaalivirtamallit voivat tarjota uusia mahdollisuuksia ympäristöpolitiikan ja -menettelytapojen kehittämiseksi.

Tämä väitöskirja kartoittaa materiaalivirtamallien soveltuvuutta ympäristöpolitiikan ja -menettelytapojen suunnittelussa. Tutkimusmetodeina on käytetty case-tutkimusta, skenaariotutkimusta ja sekundääritiedon analysointia. Väitöskirja esittää lyhyesti useita materiaalivirtamalleja, joista on valittu kaksi mallia tarkempaan analyysiin. Valitut mallit ovat dynaaminen Joined Time Projection-malli ja staattinen KCL-ECO elinkaarianalyysimalli. Näitä kahta mallia vertaillaan analysoimalla niiden soveltuvuutta ympäristöpolitiikan ja -menettelytapojen eri osa-alueisiin. Massa- ja paperiteollisuuden materiaalivirrat on valittu esimerkiksi. Väitöskirja perustuu pitkälti väittelijän aikaisemmin kirjoittamiin, liitteinä oleviin neljään artikkeliin. Artikkelit ovat suureksi osaksi kvantitatiivisiä ja artikkelien sisäinen tutkimus on deduktiivista. Artikkelien välinen tutkimus on vertailevaa, induktiivistä ja kvalitatiivista tutkimusta, jonka avulla muodostetaan teoria.

Dynaamiset materiaalivirtamallit ovat useimmissa tapauksissa tehokkaampia välineitä ympäristöpolitiikan ja -menettelytapojen suunnittelussa kuin staattiset materiaalivirtamallit. Staattiset materiaalivirtamallit soveltuvat hyvin löytämään parannettavia alueita tuotteen elinkaaressa, mutta niiden käyttö teollisella tai kansallisella tasolla on rajoitettu, koska niiden analyysi perustuu historialliseen dataan. Materiaalivirtamallien dynaamisuus osoittautuu keskeisen tärkeäksi tekijäksi ympäristöpolitiikan ja -menettelytapojen suunnittelussa varsinkin, kun useampi muuttuja muuttuu analyysin aikana. Dynaamisissa materiaalivirtamalleissa aikajänne on mukana mallien analyyttisessä rakenteessa, mikä mahdollistaa muutosten ja niiden aiheuttamien vaikutusten ennakoimisen ja analysoimisen tutkitussa systeemissä. Väitöskirja pitää lineaarisuutta ja vakaita ulkoisia tekijöitä liian voimakkaina olettamuksina materiaalivirtamalleihin perustuvassa ympäristöpolitiikan ja -menettelytapojen suunnittelussa.

ABBREVIATION LIST

AOX	Adsorptive organic halogen
BAPEDAL	Indonesian Environmental Agency
BATNEEC	Best Available Technology Not Entailing Excessive Costs
BOD	biological oxygen demand
Ca	Calcium
CEPI	Confederation of European Paper Industries
CHP	combined heat and power
Cl	clorine
CO_2	carbon dioxide
COD	chemical oxygen demands
DEM	Deutsche Mark (German currency)
DFA	Dynamic Flux Analysis
DIP	de-inked pulp
EC	the European Community
EDF	Environmental Defense Fund
EEC	Economic and Environmental Cost
EEP	economic - environment production
EFI	European Forest Institute
e.g.	exempli gratia (for example)
EIO	environmental input-output
EU	the European Union
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (the European Federation of Corrugated Board Manufacturers)
FEI	the Finnish Environmental Institute
FFIF	the Finnish Forest Industries Federation
i.e.	id est (that is)
IIED	International Institute of Environmental Development
INSEAD	Institut Européen d'Administration des Affaires
I-O	Input-Output
IPC	integrated pollution control
IPPC	integrated pollution prevention control
ISO	the International Standardisation Organisation
JPA	Japan Paper Association
JTP	Joined Time Projection
KCL-ECO	LCA model constructed by the Finnish Pulp and Paper Research Institute
LCA	Life Cycle Assessment or Life Cycle Analysis
LCI	Life Cycle Inventory
METLA	Metsäntutkimuslaitos (Finnish Forest Research Institute)
MFMs	Material Flow Models
NGO	Non Govermental Organisation
NOx	nitrogen oxides

OECD	the Organisation for Economic and Commercial Development
P&P	Pulp and Paper
PPI	Pulp and Paper International
R&D	Research and Development
S	sulphur
SETAC	Society of Environmental Toxicology and Chemistry
SFA	Substance Flow Analysis
SFS	Suomen Standardoimisliitto (the Finnish Standardisation Association)
SO_2	sulphur dioxide
SPRU	Science Policy Research Unit
TMR	Total Material Requirement
TSP	Total suspended particles
TSS	Total suspended solids
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environmental Programme
UNIDO	United Nations Industrial Development Organisation
USD	United States Dollar

APPENDIX 1

The Structure of the LCI and JTP Models

The structure of the Input-Output, LCI and JTP models is presented in this appendix. The objective is not to present a comprehensive mathematical comparison of the models. Rather, a general mathematical format is presented, from which all three models can be derived. Verbal comparisons of the models, their applicabilities and their use areas have been presented in Chapter 5. The mathematical structure and the economic basics of the LCI and JTP models have been presented by Pento (1998). This appendix is a simplified version of Pento's (1998) presentation.

A short-term production function of economics models is a process, which transforms physical quantities of input products and materials into physical quantities of output products (Mansfield, 1991). If D_i and D_o are the quantity vectors of input and output products, the production function is:

$$G_k \{ D_o \} = F_k \{ D_i \} \qquad (1)$$

The analysis of both economic and environmental outcomes of a process requires the expansion of (1) environmental variables, and whose functions have to be nested over the life cycle of the product. Let vector D_{ok} denote quantities of output products of the process k, D_{ik} the quantities of input products from the earlier processes, R_k quantities of materials derived directly from the environment, and H_k the amounts of effluents which are emitted by the process to the natural environment. The short run economic-environment production (EEP) function of a process is then:

$$G_k \{D_{ok}, H_k\} = F_k \{ D_{ik}, R_k\} \qquad (2)$$

This function shows the maximal quantities of outputs D_{ok}, which can be made from the inputs { D_{ik}, R_k } and the minimal emissions H_k which are generated by the process in this conversion. Static LCI applications simplify (2) with *ceteris paribus*, and consider long-term production factors fixed, and ignore their inputs and emissions (Mansfield, 1991, Reeve, 1994). The functions G_k and F_k are thus reduced to linear and homogeneous relations between separable input and output variables.

Let D be a vector of all products made or used in all processes of the life cycle. Each of the k = 1 ... K processes inputs products from the other processes and/or virgin materials from the natural environment, and makes n = 1 .. N_k output products, many of which are used as inputs by the other processes. The process ok produces the quantity $d_{ok:n}$ of the output product n and uses $d_{ik:s;\, ok}$ of the input product s from the process ik, the amount of $r_{m,ok}$ of the virgin material m , m = 1 ... M, and emits the quantity $h_{p,ok}$ of effluent p. Following the boundary principle of microeconomics, the EEP function of this process is given as a material balance equation (Ayres, 1989):

$$\sum_{n}^{Nk} d_{ok:n} = \sum_{ik}^{K}\sum_{s}^{Nk} d_{ik:s;ok} + \sum_{m}^{M} r_{m,ok} - \sum_{p}^{P} h_{p,ok} \qquad (3)$$

This function shows the material balance of products, virgin materials, and emissions of a process. In LCI work, it is transformed to product functions by allocating all input and emission quantities of the process to the output product quantities. This is done with scalars so that the EEP function of a product can be given as a material balance equation:

$$d_{ok:n} = \sum_{ik}^{K}\sum_{s}^{Nk} z_{ik:s,ok:n} d_{ik:s,ok:n} + \sum_{m}^{M} u_{m,ok:n} r_{m,ok:n} - \sum_{p}^{P} w_{p,ok:n} h_{p,ok:n} \qquad (4)$$

The scalars $z_{ik:s,ok:n}$, $u_{m,ok:n}$, $w_{p,ok:n} \geq 0$, and for every input product $d_{ik:s}$, material r_m, and emission h_p of every process:

$$\sum_{n}^{Nk} z_{ik:s,ok:n} = 1 \ , \ \sum_{n}^{Nk} u_{m,ok:n} = 1 \ , \ \text{and} \ \sum_{n}^{Nk} w_{p,ok:n} = 1$$

The vector D contains far too many products to be usable in practical work. Products are eliminated from the vector by applying established boundary rules. The allocation scalars z and u are a first-order decision rule for excluding side-products from the life cycle, typically when:

$$\sum_{ok}^{K}\sum_{n}^{Nk} z_{ik:s,ok:n} \cong 0 \ , \ \text{or when} \ \sum_{ok}^{K}\sum_{n}^{Nk} u_{m,ok:n} \cong 0 \qquad (5)$$

These rules are often augmented with others, such as if the cradle to the end of the process ik life cycle of the product ik:s does not give rise to noteworthy toxic or acidifying or ozone depleting etc. emissions, or if the natural environment contains large reserves of the material m.

Dynamic models such as the JTP model employ matrices A^t, B^t and E^t, and functional unit vectors Y^t for successive time periods t = 1 ... T, and enable time path analyses of each variable d^{*t}, b^{*t}, and e^{*t} within different scenarios of demand, permit policies, investments and like. (Compare with the functions in (2)). The matrices of the time periods are used to calculate:

$$D^{*t} = [I - A^t]^{-1} \times Y^t \ , \ B^{*t} = B^t \times D^{*t} \ , \ E^{*t} = D^{*t} \times E^t \quad (6)$$

The analysis of the functions in (6) can be made with the Joined Time Projection (JTP) technique in which all of the vectors and matrices of different time periods are first estimated, then calculated, and elements d^{*t}, b^{*t}, and e^{*t} of interest of the time periods are collected and joined in time sequence for a projective analysis.

Traditional input-output analysis arrives at the solution (6) with matrix inversion techniques. The JTP model uses a sequential heuristic method, which requires an active input from the user. This technique has the advantage that nonlinear and conditional equations (4) can be used, and a solution (6) can be arrived at.

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APPENDIX 2

KCL-ECO

The KCL-ECO life cycle assessment software has been developed by Dr. Anssi Kärnä and his research group at KCL, the Finnish Pulp and Paper Research Institute. KCL has worked with life cycle assessment related to forest products since 1993. KCL's involvement in ISO standardisation and international methods development have supported its research efforts.

The KCL-ECO programme can focus either on a single product, several products, or an industry. Each product with its associated emissions and virgin material inputs is presented as a module. The relationships between different products and fluxes are linear. The KCL-ECO model is constructed as a very detailed tool. Emissions are calculated from all elements of the life cycle and the results are indicated in terms of main air and water emissions.

The KCL-ECO programme consists of modules such as mills, which manufacture specific pulp or paper products or chemicals, or transport goods, or harvest wood, or generate power, or print papers, or operate landfills. Data of the modules are based on KCL's database, which contains data from the paper industry and related fields. The modules can also be modified by the user and new modules can be created.

The KCL research group has made extensive models of the Pulp and Paper industry with this software. For example, KCL-ECO has been used to build a model for wood fibre flows in paper and board production in Western Europe; a system comprising 660 modules (unit processes), 1900 flows and 7200 linear equations describing the system. Most of the errors producing boundary and allocation problems of LCA have been avoided by expanding the scope of the model from one product to several or all products of the industry.

KCL-ECO employs KCL EcoData that is a continuously updated LCI database designed in accordance with international recommendations. EcoData is primarily intended for life-cycle inventory calculations related to forest products. The data has been collected by using experts from various branches of industry together with publications and questionnaires. EcoData contains nearly 250 data modules covering all the relevant sectors related to the paper cycle.

KCL-ECO is an advanced user-friendly software with a fully graphical user interface. The newest version is called KCL-ECO 3.0 and it now includes also life cycle impact assessment, i.e. characterisation, normalisation and weighting. The inventories of this thesis have been calculated with version 2.0 of KCL-ECO.

KCL-ECO is presented more in detail in the following articles:

Ebeling et al. 1993. A comparison of primary and recycled fibre scenarios. Paperi ja Puu - Paper and Timber, vol. 75/No. 1-2

Kärnä, A. et al. 1994. Life cycle analysis of newsprint: European scenarios. Paperi ja Puu - Paper and Timber, vol. 76/No. 4

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Kärnä, A., Engström, J., and Kutinlahti, T. 1993. Sanomalehtipaperin elinkaarianalyysi. Paperi ja Puu, vol. 75.

Kärnä, A., Pajula, T. and Kutinlahti, T. 1994. Life Cycle Analysis (LCA) of printing papers. London: Paper presented at the 1st PPI Recycling Conference.

Kärnä, A. 1995. LCA-Inventories of Printing Papers in Finland. EFI Proceedings vol. 8. Hamburg: European Forest Institute.

Pajula, T. & Kärnä, A.: Life Cycle Scenarios of Paper. Proceedings paper from EcoPaperTech Conference in Helsinki, 6-9 June, 1995

Kärnä, A. & Pajula, T. 1996. An Application of the LCA Methodology in Paper System Analysis. Brussels: Paper presented at International Conference on Application of Life Cycle Assessment in Agriculture, Food and Non-Food Agroindustry and Forestry. Achievements and Prospects.

Kärnä, A. 1997. LCA research of the KCL. Presentation at The Forest Industry LCA Symposium. Espoo.

ARTICLE I

LIFE CYCLE INVENTORIES AND JOINED MATERIAL PROJECTIONS IN NATIONAL ENVIRONMENTAL PLANNING

By

Gronow, Tito & Pento, Tapio

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LIFE CYCLE INVENTORIES AND JOINED MATERIAL PROJECTIONS IN NATIONAL ENVIRONMENTAL PLANNING

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Abstract

The applicability of Life Cycle Inventory techniques and Joined Time Projection models to national material flow management is studied. The dilemma of system boundaries is first discussed. Results obtained from a subsystem LCI are indeterminate, yet a totally complete system is impractical. In addition, the objectives of national planning require that the system be limited to the nation. The static nature of traditional LCI's impairs their usefulness. Life cycle inventories and analyses serve well as an identifier of areas of improvement on a product's life cycle. Their applicability to regional or national environmental planning is however limited, because they are static, consider only one product, and that in the past time. Joint time projections of an industrial system are seen as more amenable for policy planning. LCI data is used as input to these projections, which consider complete systems and are capable of dynamic forward planning. The ability of joint time projections to include both environmental data and other decision factors, such as effects of a policy on investments and operating costs, imports and exports, and employment makes them a tool more suited for the needs of regional or national environmental planning.

1. *National environmental planning through material flow management*

In most countries environmental legislation has traditionally focused on protection, i.e. the prevention of hazards to human health and to the (local) environment. More recently, legislation has been introduced with the objective of improving sustainability. One example are the numerous recycling laws, ordinances and administrative rulings, which have been decreed in Europe and America in the past few years (Assmann 1993, Göttsching and Putz 1994, Laplante and Luckert

1993, Pento 1994). The purpose of these has been to direct a region or a nation toward sustainability by forcing the reuse of products or materials.

Advance planning of many of these laws and ordinances appears to have been so insufficient that they have in some cases produced more problems than solutions. For example, one of the main motives behind the German packaging ordinance of 1991 was the saving of landfill capacity in the country. The ordinance forced the raise of recovery rates of all packaging materials without providing a solution for their reuse. As a result, material began to accumulate in unofficial landfills and illegal dumps, and costs of the recycling system skyrocketed. In its early stages the ordinance probably caused more economic and environmental harm than good (Berliner Tagesblatt 1994, Buchner 1993, Economist 1994). The "garbage crises" in some areas of the United States were also the creation of unsuccessful policies which have been set by authorities on environmental grounds (Chilton 1992).

Traditional planning tools of economies, such as microeconomic analyses of markets, have proven insufficient in analyses of policies directed toward improving sustainability. As of now, it appears that future policies will have to be placed increasingly on some type of modelling of the flows of materials and products[1]. The authoritative German Enquete-Kommission "Protection of People and Environment" considers material flow analysis and management as the prime vehicles on the road to sustainable development[2]. On the national level these tools would provide information for actions to divert or close such material flows which waste resources or cause unnecessary environmental loads

A host of techniques for modelling national material flows and the environmental loads associated with them have been brought forward, such as Life Cycle Inventories (LCI) and Assessments (LCA) (Virtanen and Nilsson 1993, Daae and Clift 1994), Material Intensity Analyses (Schmidt-Bleeck 1993, Liedtke et al. 1993), Substance Flow Analyses (Udo de Haes et al. 1991, van der Voet et al. 1993), Material/Energy Balances (Ayres et al. 1989, Ayres and Norberg-Bohm 1994), Product Flow Paths (Bilitewski 1993, Putz and Göttsching 1993), Models of waste generation and waste flows (Baccini and Brunner 1990), Joined Time Projections (Pento 1994, 1995), and sectoral economic models with environmental variables (Zhang et al. 1993).

Two of these methods, Life Cycle Analyses and Joined Time Projections are analyzed here in regard to their applicability as tools for planning national environmental policy. The flows on printing papers in Germany is used as the application example.

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[1] The term material flows is used here to denote flows of both substances and products.

[2] Zur Konkretisierung und Umsetzung des Leitbildes einer nachhaltig zukunftverträglichen Entwicklung (Sustainable Development) ist eine Analyse der Stoffströme in betrieblichem, regionalem, nationalem und globalem Kontext erforderlich (Stoffstromanalyse). Entsprechende informationssystems sollen klare Konzeptionen zum Umgang für Lenkungsmöglichkeiten für die jeweils beteiligten Akteure geben (Stoffstrommanagement). Enquete-Kommission (1993), p. 18

2. Selection of system boundaries

There have been attempts of macroenvironmental planning through the simultaneous analysis of several large national material flows (Merten et al. 1994, Schmidt-Bleeck 1994). Until now, these analyses have been performed at a rather aggregated level, and their methodology and practicability and is still untested. The more common technique selects a subset of the flows by defining boundaries for each system which is to be modelled. In this approach the proper method would be to separate a subsystem, and to study all of its inputs and outputs with nature (SETAC, 1993). Unfortunately, the complexity and interrelatedness of many material flow systems, like those of the pulp and paper industry, makes even such an approach impracticable. The size of the resulting model explodes, the cumulative effects of errors and the unreliability of the gathered data begin to weaken its results, and the complexity of analyses combined with butterfly effects make it too unwieldy for practical use.

2.1. Product-based system boundaries

One material flow modelling approach limits the system to the linear flow of one product. In its simplest form such a system depicts a product's partial life cycle flow from the cradle to the customer's gate. Such models are generally considered a good tool for the identification of problem areas on the life cycle of a particular product at which an environmental improvement could be made. Industries and firms have been able to use LCI's of this kind successfully in their environmental planning to select suppliers, improve production methods, eliminate logistical problems and other unnecessary waste.

The applicability of product-based flow models to national planning is limited, and their results may lead to incorrect policies. In principle they can be used when the flows of different products of the industry are not appreciably mixed at any location and are independent of each other. For example, separate LCI's of newsprint, and magazine and fine paper grades are usable tools for national planning in those countries where the papers are either imported or are manufactured at different production units and are deposited after use to landfills. The cradles and the graves of the life cycles are well defined, the systems are separable in principle, and national policy can be used to steer each system independently of the others.

The use of product-based system boundaries is not good practice when the material flows are mixed and pooled. This is the case when different paper grades are made by the same production units, and when used papers are pooled in the collection and recycling system of old papers. The life cycle of a product in such a case can not be determined exactly, because it depends on the complete system of which it is a part. For example, the life cycle of newsprint depends on the amounts, furnishes and reuses of recovered old papers. Some collected old newspapers may be shipped to become raw-material of hygiene and technical papers, or board, some may be exported, and a part may be de-inked for reuse either in newsprint or magazine paper manufacture. The proportion which is used for what depends on very many factors, ranging from the demand of the various end products, to the prices of recovered papers relative to virgin materials, to the extent and accuracy of the sorting of the recovered papers.

The application of only a linear part of a product's life cycle as a basis of national policy may lead to suboptimization and even outright errors. One such analysis computes the linear life cycles of old paper to pulp and wood to pulp and shows that making newsprint of old newspapers consumes less energy than the manufacture of virgin paper (Tiedemann 1993). It is also clear that collecting old newspapers for recycling will reduce the amount of community waste which is placed into landfills. Together, these findings point out that both energy and landfill capacity will be saved with a maximal recovery and reuse policy. Yet, some analyses of larger systems show that such a policy would increase the total amount of solid waste (Pento 1994), would be detrimental to the environment in several respects (Virtanen and Nilsson 1993), and might not even provide the best energy solution (Kärnä et al. 1995).

Product-based LCI's may also be too unspecific for national planning. They calculate loads for a functional unit (SETAC 1993, 13) which, as an example, could be defined as a ton of newsprint at a publisher's gate. This form of calculation does not provide a national decision maker with sufficient information about the quantities and directions of flows which are to be managed by policy, neither about the actors who would be in the position to make the changes required by a policy. A modelling technique at the level of the industry or a nation would be preferable to the policy maker.

2.2. *Industry-based system boundaries*

LCI's have been adapted for national and regional environmental planning by calculating effluent, material, and energy inventories for a functional unit of an "average material flow". In this approach, all production and consumption units which handle the same or similar products are aggregated into one, and one or more of aggregates are bounded to form an industry. Virtanen and Nilsson (1993), in their ground breaking study analysed printing paper recycling in Europe by considering average flows of papers, and by counting the effluents, energy, and carbon balances affiliated with them. Similar calculations for the average life cycles of one or more products have been presented by Ebeling et al. (1993), Kärnä et al. (1994, 1995), Byström et al. (1994), and Clift et al. (1994).

The use of average data of the type effluent/ton of product, energy/ton, and material/ton confronts the user with a formidable problem of data collection and definition. For example, there can be tenfold differences in the effluent production/ton of product of different mills, and the definition of an average mill may be difficult because of this. Data of all production units which belong to an aggregate may not be available, and the data obtained may thus be skewed. On the other hand, the absolute errors of average figures might be smaller than those of independent mills, which are more affected by different conditions, capacity utilization rates and other factors.

First objective in setting the system boundaries for national planning is that either the total model, or one of its classifications must conform to the geographical area of the country. This separates domestic consumption and production from those of other nations, and facilitates analyses of environmental data together with other factors relevant for policy making, such as imports and exports, and domestic production. It is also good practice to set the boundaries of the subsystem of the industry in such a way that the material flows in and out of the system are as linear as possible, without recycling loops going out and coming back in. Figure 1 gives one example of an industry-based national system, that of printing papers in Germany. The incoming flows of material in this system are from nature to gate without return, and the outgoing flows are either to nature or one way linear to other production processes. For example, any old papers which flow to the manufacture of hygiene or technical papers or different types of board, or which are exported do not come back to the main recycling loop.

Industry-based LCI methods can be designed to model complicated material flow systems, which have recycling loops, multitudes of material sources and sinks, several types of production units, which combine materials to products and disassemble products to materials, as well as multiple consumption units. Recent advances in LCI modelling techniques and programs, especially in the one developed by Kärnä et al. (1995) provide the user with tools with which to prepare such extensive models using average data.

3. *Industry-based life cycle inventories as tools in national material flow planning*

The process of making industry-based LCI's for national planning is straightforward: define the functional unit to be measured and the boundaries of the system, analyze the material flows, construct the corresponding LCI-model, and calculate the inventory of materials, energy and effluents which is generated by the specified flows. The inventories make for a powerful tool of analysis and planning, especially when augmented with sensitivity analyses and sub-inventories for different parts of the model.

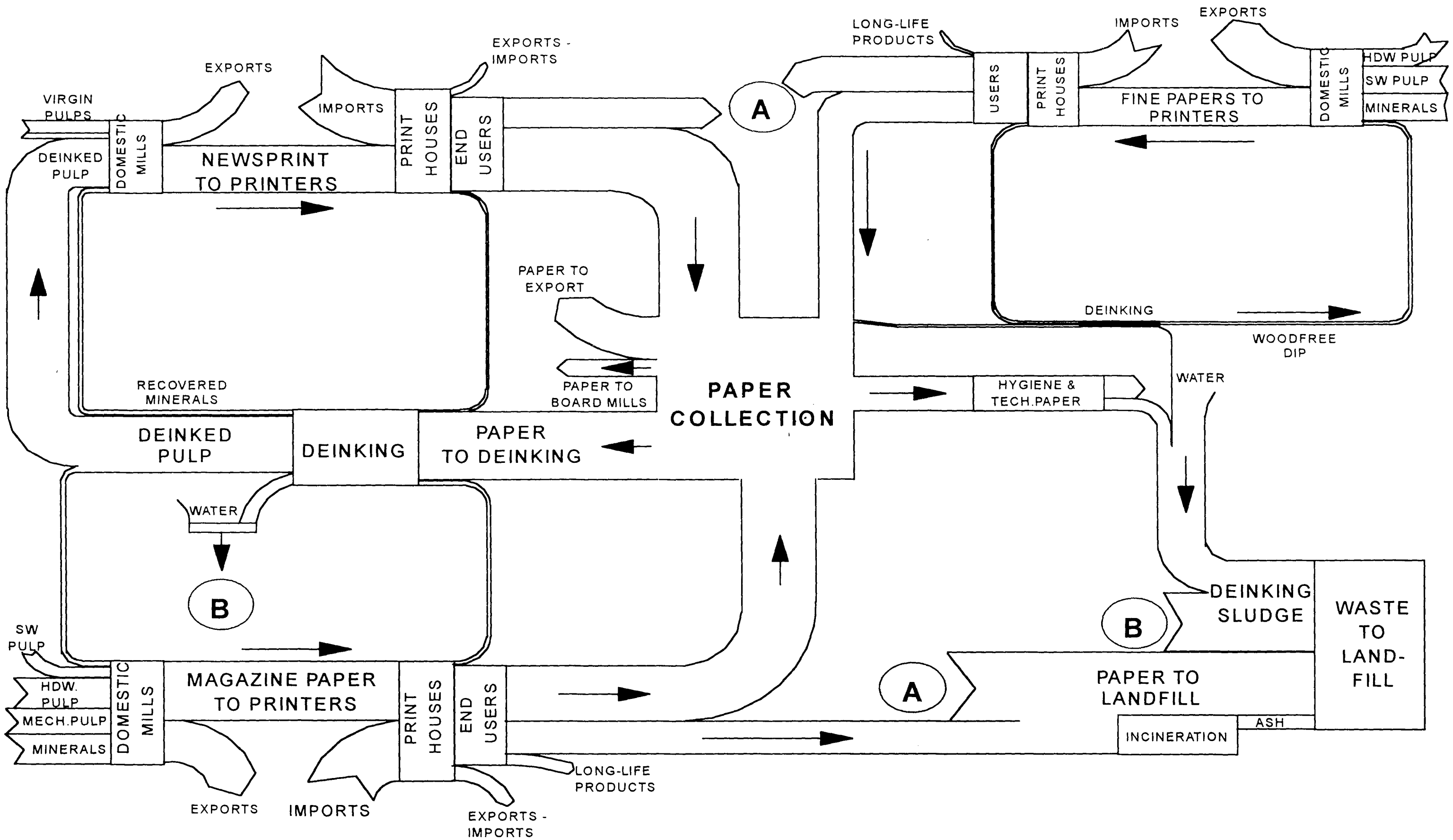

Figure 1. ***Material flows of printing papers in Germany in 1993 (Pento, 1994).***

The static nature of industry-based LCI-models considerably reduces their value as a tool in national environmental planning. A static LCI counts environmental loads and energy and material uses on the basis of the material flows, which existed in the industrial structure of the past, not those of the future. Static LCI's enable the user to analyze the amounts of loads and the locations where they occur, but they do not facilitate the making of structured analyses of the effects of different policy alternatives, which could be considered feasible ex ante.

The basic problem of a static LCI is in its incapability of accounting for the combined effects of system changes. An LCI is constructed by taking the effluent/energy/material figures of a mill operating in the industry in the past, and by assuming that the same mill operating in exactly the same way will have the same figures in the future. The effects of changes in the system make this assumption invalid. The yield of a de-inking plant makes for a good example. Consider a fictitious "average" German newsprint mill in 1994, when printing paper recovery rate was around 50 %. The mill used 100 % de-inked pulp, and had a raw-material composition of 60 % newsprint, 40 % magazine papers, and no mixed quality old papers. It could reuse most of the fillers in this raw-material into its paper, and had a yield of over 85 %. Consider then a policy which raises the recovery rates to 70 %, and where the recovered papers are used de-inked into newsprint manufacture. The yields of the same "average" mill will be drastically lower because of these changes. The composition of the raw-material will have to change because the increased recovery rate will produce more magazine papers and mixed qualities for the "average" mill. This will reduce the yield drastically in two ways. First, the yield of the mixed qualities is lower than that of the other used paper grades. Secondly, the proportion of fillers in the old papers will be so much higher, that the mill can use only a part of them into its newsprint, and has to put the remainder into waste.

Such effects of dynamic system changes on the material flows and their generation of effluents, and use of materials and energy must be a consideration to the national decision maker, who is interested in the total effects of a policy. A static LCI is not the best possible provider of the necessary information.

Second, current LCI-techniques do not provide for a policy's effect analysis. This can create huge unnecessary costs, when policies are put into effect using the society or an industry as an experiment ground. A good example of this is the German Verpackungsverordnung of 1991, and the results which it created. The ordinance decreed ever-increasing recovery rates and reuse rates for all packaging materials, without giving any consideration to the placement of the collected material. As a result, millions of tons of unwanted material were collected, and the finances of the national organizing body, the Duales System Deutschland (DSD), were repeatedly insufficient to secure proper end treatment for the collected material. The total cost of this experiment is not known to us, but the mere subsidies to the DSD range in many thousands of millions of DM. It is likely that a prior analysis of the material flows would have prevented these problems by pointing out the magnitude of the problem, and by indicating more suitable recovery rates and end-treatments of the collected material. (Buchner, 1993)

Another drawback of a static industry-level LCI lies in its incapability to incorporate in its analysis dynamic changes which are expected to take place in the system in the future planning period. There will obviously be changes in consumption patterns and amounts, industry will modernize their capital equipment, new technologies will be introduced, and collection and recovery systems may change. Such changes will affect all parts of the system: material flows, yields, energy consumption, and the production of effluents and waste. An LCI, whose average figures are based on some functional unit, made with the production equipments and technologies which existed in the industry at some time in the past will overestimate all environmental loads from effluent production to energy consumption. The history of industries shows consistent improvements, which are in most cases expected to continue in the future. An example in point is that of the amount of AOX in the waste waters of an old kraft pulp mill using active chlorine, compared with those of modified, or new mills who use no chlorine in bleaching.

The effects of changes could be built by constructing several static LCI-models using today's averages, and BATNEEC (best available technology not entailing excessive costs) of today and tomorrow. Even then, the dynamics of the actual change which are expected to take place in the system will not be shown by these LCI's, even though that these are of the liveliest interest to the policy maker. One of the most important tools in national policy is to advance such system changes which have environmental characteristics: new technologies, better capital equipment, improved collection and sorting methods, etc.

In summary, the environmental data of a static LCI is very useful as a basis of national environmental policy for it points out the amounts of effluents, energy and materials used and produced by the system. But it is deficient in the sense that it will not provide the planner the possibility of simulating the effects on the system by some environmental policy. For example, several communities in the U.S. have raised the recovery rates of old papers by law, and have found out that these laws have backfired in the form of glutted markets and illegal dumps. Such occurrences can be better avoided by making dynamic forward-looking analyses of alternative policies.

4. *The needs of national environmental planning*

National environmental planning must have several characteristics if it is to be successful. The first need is that there must exist a clearly defined object of policy. An object like a product or the environment is impracticable when the policy has to be put into action. Therefore, an object like an industry is preferred, because the firms of the industry have the tools and the organizations to make changes, and they can be either commanded or induced to take actions toward the desired goals (Soininvaara, 1993).

Any method of the national environmental planning must also be able to forecast the effects of what different policy alternatives might cause. A complete forecast of the future is not needed, but trajectories of the effects of different policies, as well as their sensitivity in reaching the specified goals.

A good method also analyses complete systems, as much as that is possible. In any case, separate analyses of interdependent subsystems is fraught with the risk of producing indeterminate results, and as a result, suboptimal policies. For example, a linear life cycle analysis of printing papers shows that their recovery and recycling will reduce the amount of solid waste produced, while a comprehensive analysis of the material flows of the printing paper industry show clearly, that this is not the case. The total solid waste produced actually increases when paper recovery rates are raised substantially (Pento 1994, Pento 1994a).

There is also a need that as many of the relevant decision factors as possible should be included the same analysis frame. A list of such factors includes the following:

- environmental considerations: use of raw-materials and energy, and output of effluents and waste
- economic factors: size of investments and operating costs, and the effects on different markets
- results on employment: amounts and types
- technical feasibility
- effects on international trade: amounts of import and export

Joining these factors into one analysis framework facilitates their commensurability when planning different policy alternatives. There are other factors as well which in theory could be included in the model but in practise the model would grow so much as to become too unwieldy to use.

5. *Joined time projection models in planning national environmental policy*

The Joined Time Projection (JTP) technique facilitates the dynamic analysis of the material flows of an industrial system, in which many factors change simultaneously over time (Pento 1994). This construction technique joins together a series of models, which each describe the material flows of a system in a given time period, such as a year. The models of different periods may be temporally connected with stock equations or like, or may be semi-independent, in which case there are only some or no intertemporal links between them. The technique is a type of quantitative scenario analysis, in which future projections are made of the parameters which largely define the annual material flows. Some of the parameters can be policy variables.

A Joined Time Projection model of the flow system of Figure 1 has been constructed to analyze the effects of paper recovery policies in Germany, specifically policies of compulsory recovery rates and fibre reuse to de-inking and incineration. The construction of the model proceeds from the base material flows of 1993. Projections up to the year 2000 can be made by specifying parameters to arrive at wanted scenarios. Consumption projections of paper grades determine the volumes of the system. Capacities of paper machines and de-inking facilities are projected, and serve as a basis in determining the amounts of imports and exports of papers and used papers, as well as a limiter to domestic reuse of collected papers. Technology projections are also made of yield changes and improvements in the processes which handle the flows. Finally, the most important projections are those of policies which are studied, such as used paper recovery rates

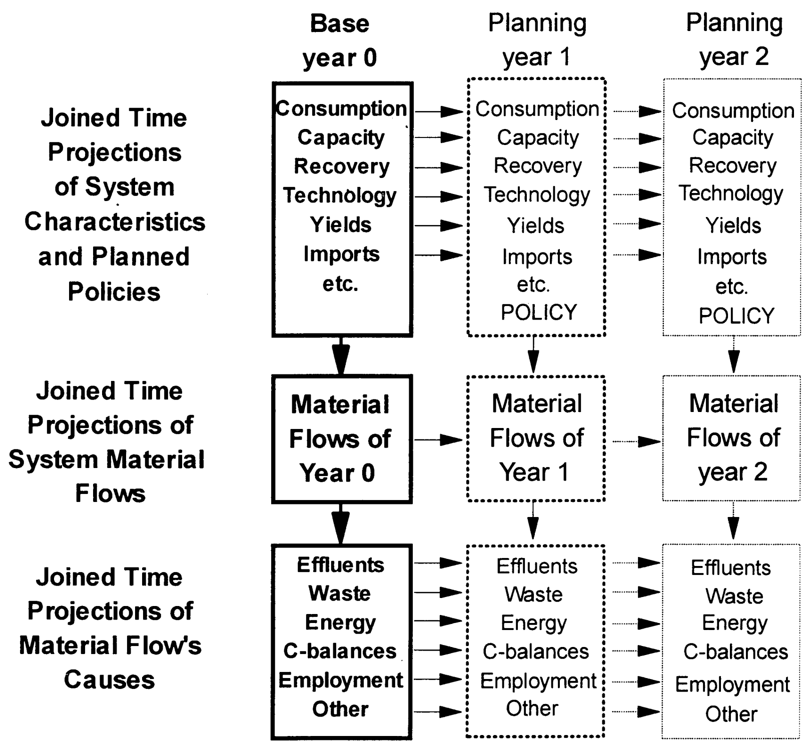

Figure 2. The structure of a joined time projection model.

The annual material flows are determined on the basis of the set parameters. The flows in turn are used as an input to calculations of their causes, such as the use of materials and energy, the effluents and waste produced, carbon balances, employment, imports and exports. A dynamic analysis is facilitated by setting the models side by side for a study of the changes over time.

A set of projected parameters commonly produces problems in the sense that the material flows in the annual models do not balance, do not make any sense, or create unwanted results. For example, a policy of a very rapid increase in used paper recovery and forced de-inking[3] may create unwanted large temporary stocks of material, because de-inking and at newsprint mill capacities are a limiting bottleneck. Sometimes disturbances are caused by market projections, for example in the case when projected domestic use of chemical pulp exceeds capacity and leads to massive increases in imports.

Two types of Joined Time Projection techniques are currently under development. The simpler approach constructs industry-level LCI models for a number of years into the future with the scenario technique, and joins their causes for a time projection. The material flow management modelling first analyses the development of the characteristics which define the material flows, builds separate models to simulate the flows for each year in the planning horizon. The estimates of the environmental, economic, commercial, and other causes which are generated by the flows are iterated and made after the flows are known, and are joined into a dynamic framework. These two development directions are already converging, and it is expected that JTP-techniques of the future will be material flow based LCI simulations, in which the environmental data is more or less automatically picked from an inventory.

5.1 *The advantages and problems of the Joined Time Projection model*

The main advantage of the Joined Time Projection technique is that it allows the user to make detailed and quantified projections and scenarios of the future. The JTP model facilitates greatly dynamic scenario analyses partly because of the model's capability to look forward in time. The time perspective can be very wide, and continually dynamic, in the calculations if that is demanded. Figure 3 shows waste production in Germany between 1993 and 2000 in two alternative scenarios. Scenario 1 assumes that no policy actions will be taken concerning the recovery rates or incineration of papers, but that the development will continue in a laissez-faire situation. Scenario 2 assumes three policy changes. Paper recovery rates are increased by decree to 70 % by the year 2000. The mineral content of all papers is slowly reduced to correspond to a minimal thermal value of 17 GJ/t. A substantial amount of lowest grade waste papers are incinerated, together with the increasing amount of de-inking sludge. The results of these policies onto the total amount of waste generated by type is visible in Figures 3A and 3B.

[3] Policy forced de-inking = prohibition of incineration and exports of used papers.

Figure 3. Total waste produced by the paper recycling system in Germany in 1993-2000, thousands of tons.

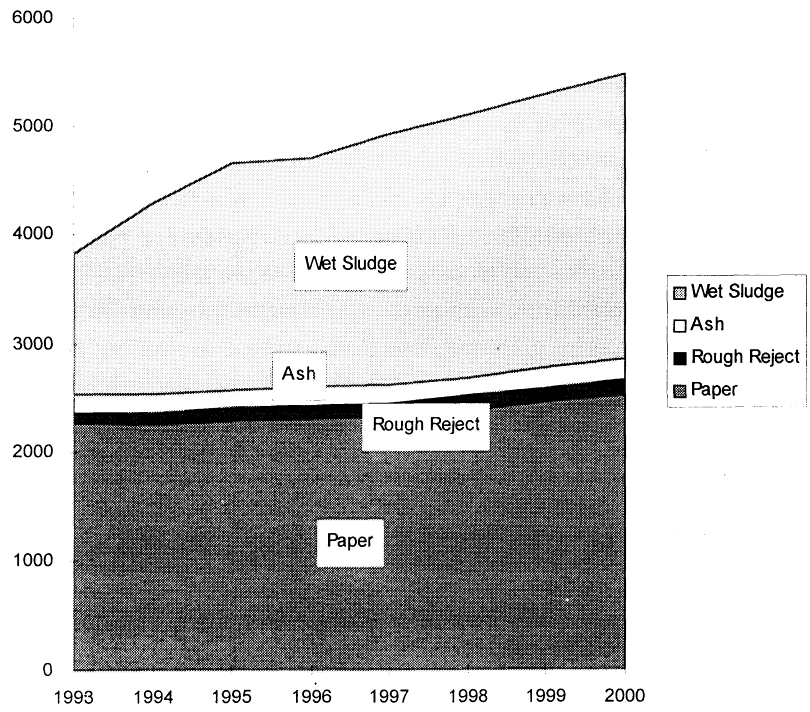

Figure 3A. No policy actions, "laissez-faire".

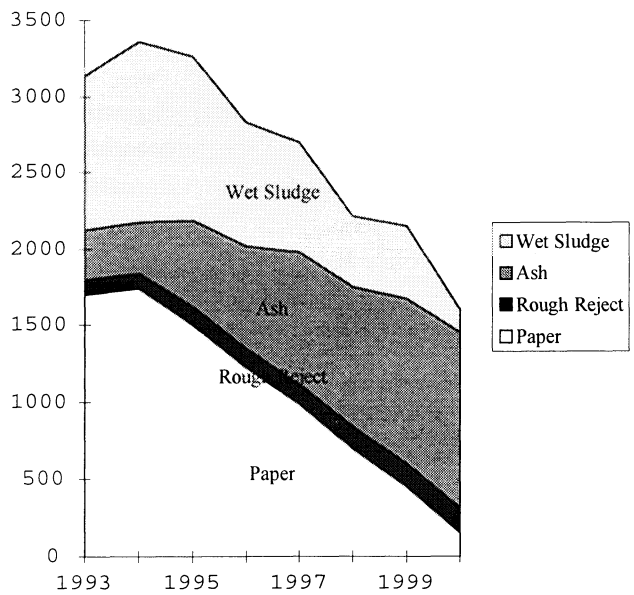

Figure 3B. Minimal thermal value of 17 GJ/t for papers, and increasing incineration of low quality paper with de-inking sludge.

The Joined Time Projection model's holistic method allows to analyse the relations of the research object with other related systems. The JTP model considers complete industrial not only one average product (like an LCA does).

The model also makes it possible to see clearly if, when, and where a particular policy will create disturbances and bottlenecks in material flows and markets. It makes possible to do analyses on techniques, technologies and capacity changes.

A major problem in JTP modelling is the lack of data, and the application of available data, especially that which pertains to environmental factors. A projection may show that material flows will be balanced when the furnishes of newsprint mills contain on the average 74 % of de-inked pulp. The availability effluent data for this kind of average is unavailable, and has to be estimated with rather subjective methods. On the other hand, the effects of possible errors in the estimates of the parameters and functions are minimized by a differential analysis over time, in which the actual figures are not of interest but rather the changes in the measured variables.

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ARTICLE II

LES FLUX MATERIELS DES PAPIERS D'IMPRESSION EN FRANCE PENDANT LA PERIODE 1993-2000

By

Gronow, Tito

Papier, Carton et Cellulose, Nov. & Dec. 1996, 76-80, 101-106. Reproduced with kind Permission from Papier, Carton et Cellulose.

PLANIFICATION

Les flux matériels des papiers d'impression

Tito Gronow, de l'Université de Jiväskylä, en Finlande, nous propose une étude sur les flux matériels des papiers d'impression, en France, de 1993 à l'an 2000, et plus particulièrement du rôle joué par la récupération du papier sur ces flux.

Il y a de plus en plus de demande en faveur de la récupération de papier en Europe depuis les années 1980. Ce développement a lieu aussi en France. Plusieurs facteurs affectent ce développement, dont les plus importants sont la prise de conscience écologiste qui va en croissant, les facteurs politiques législatifs, les redevances des décharges publiques et le prix du papier récupéré.

Les différences entre les pays, même en Europe, sont grandes. Le degré de récupération du papier au début des années 1990 en France était relativement faible. Seulement 34% du papier a été récupéré, toutes classes de papier incluses, carton exclu. (Pulp &Paper VII-1993).

L'Allemagne est le "primus motor" de la récupération et du recyclage en Europe. Les motifs pour l'Allemagne sont la dépendance vis-à-vis des fournisseurs étrangers, les problèmes avec les décharges publiques et un mouvement écologiste très puissant.

On note une évolution semblable vers une plus grande récupération et un plus grand recyclage dans la plupart des pays de l'Union européenne. Il est fort vraisemblable que le degré de récupération du papier sera accru par voie de législation dans plusieurs pays industrialisés, en France aussi. La France a signé une convention avec l'Allemagne pour standardiser les systèmes de recyclage des déchets d'emballage. (Byström, 1994). La convention, en entrant en vigueur, va accroître de manière significative le recyclage des déchets en général et, par là même, le recyclage du papier.

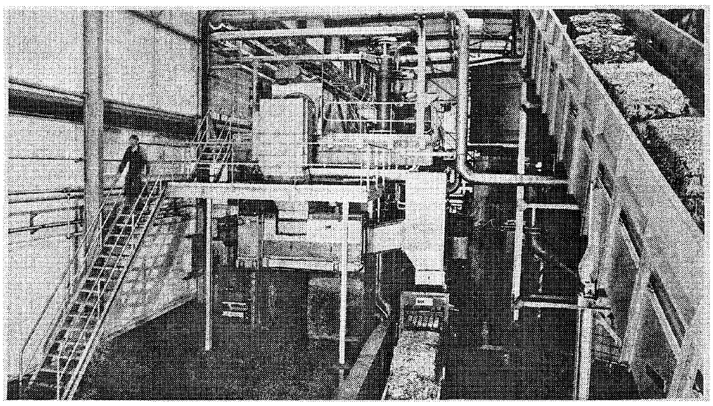
Grâce à l'intégration européenne, les lois européennes pourront éventuellement faire progresser la récupération de papier. Dans les usines de papier en France, il y a actuellement beaucoup de capacité libre pour le désencrage du papier.

DÉBOUCHÉS DU PAPIER RÉCUPÉRÉ

L'augmentation du degré de récupération par le biais d'une nouvelle loi ou d'une autre façon implique toujours des débouchés nouveaux pour le papier récupéré, s'il n'y a pas de demande pour celui-ci sur le marché. On pense généralement qu'il est meilleur pour l'environnement de recycler le papier, et même que le recyclage du papier est l'alternative la moins chère. Les responsables des décisions devraient d'abord étudier toutes les alternatives pour les débouchés du papier récupéré, les coûts, et les frais secondaires, la capacité actuelle, (Boerner, 1994), les possibilités d'augmentation de la capacité et les conséquences de ces décisions, pour éviter une situation comme celle qui prévaut par exemple en Allemagne.

Les décisions des autorités allemandes en 1991 d'augmenter le degré de récupération des déchets d'emballage (Verpackungsverordrung, 1991) ont été mises en œuvre sans que l'on ait prévu de (nouveaux) débouchés pour les déchets. Le résultat, c'est qu'une partie des déchets a fini dans des décharges sauvages et que les coûts du système de recyclage ont augmenté énormément (Berliner Tagesblatt 1994, Buchner 1993, Economist 1994). A la suite de cela, les exigences ont été rabaissées.

En 1988, il y a eu 5.000.000 de tonnes de déchets ménagers provenant du papier et du carton. Le pourcentage recyclé était faible, ce qui veut dire que la majeure partie a fini dans les décharges publiques ou a été incinérée (Etat de l'Environnement 1989). La récupération de papier couvrait 73% de la population au début des années 1990.



Concernant la récupération des vieux papiers, les différences entre les pays sont grandes.

❑ Le recyclage et le désencrage

Le désencrage du papier en vue de le transformer en une pâte secondaire et l'utilisation de celle-ci dans les différents types de papier est évidemment un débouché important, mais qui peut exiger des investissements. L'opinion générale est souvent favorable au désencrage et à la pâte secondaire (peut-être sans que l'on sache qu'il y a des alternatives). On pense souvent que le désencrage est la meilleure alternative pour la nature. Le désencrage n'en est pas moins un processus industriel comme n'importe quel autre. Tout en épargnant certaines ressources, le désencrage en consomme certaines autres (Boerner, 1994).

Il faut considérer les différents points de vue techniques et économiques du désencrage. Une machinerie et l'énergie suffisantes sont aussi des conditions nécessaires. Des compromis techniques entre le prix, la qualité et la production des différentes classes de papier sont possibles. (Howart, 1977, 1994).

La structure et les caractéristiques techniques du papier produit à partir de pâte désencrée sont différentes de celles du papier produit à partir de pâte vierge. Le degré de rendement des différents types de papier diffère beaucoup.

L'assortiment des différents types de papier joue un rôle important. Dans les usines anciennes, il est possible de produire seulement une qualité inférieure à partir de papier récupéré, alors que dans les nouvelles usines il est possible de produire du papier de la même qualité.

En France, il y a beaucoup de capacité de désencrage. La capacité de désencrage pour les papiers d'impression était de 1.262.000 tonnes en 1993. A cause du prix élevé du papier récupéré à cette époque, seulement 20%-25% de la capacité était utilisée. Il y a donc une capacité existante abondante qu'on peut utiliser au besoin, par exemple si le degré de récupération est favorisé par une loi ou quand le prix baisse. Dans les nouvelles usines françaises, on peut produire du papier journal à partir de pâte désencrée à 100%.

DÉCHARGES	ANNÉE	NOMBRE TOTAL	CAPACITÉ TOTALE (EN 1000 T)
Autriche	1990	160	3216
Danemark	1985		50241
Finlande	1990	750	25000
France	1990	484	16000
Allemagne	1987	10400	
Italie	1991	1463	33681
Pologne	1990	13813	79298
Espagne	1990	94	9376
Suède	1990	282	7500
Suisse	1990	60	20000

(Europe's Environment Statistic Compendium)

Tableau 1: les décharges

❑ Les décharges publiques

Les décharges publiques comme débouchés des déchets posent un problème, car les existantes commencent à être saturées, en France comme dans les autres pays européens. Il est difficile de créer de nouvelles décharges publiques à cause de l'évolution des mentalités et des changements dans la législation. A cause des normes strictes des nouvelles lois sur l'environnement, il revient cher de créer de nouvelles décharges publiques.

Le syndrome N.I.M.B.Y. (Not-In-My-Back-Yard) donne aussi du souci aux Français. Les gens ne veulent pas avoir des décharges publiques près de chez eux et essaient d'en empêcher la création par des plaintes et des recours et avec l'aide de groupes de pression. Par peur de perdre des voix, les politiciens évitent souvent de promouvoir des projets auxquels la population locale est opposée (Carlson, 1990).

Les tarifs des décharges publiques augmentent en même temps que les problèmes des débouchés des déchets solides. Le traitement des déchets doit changer en France, parce qu'il y a relativement peu de capacité de décharges publiques en France en comparaison avec les autres pays européens, comme le montre le tableau 1.

En 1990, le nombre des décharges publiques était de 484 en France, avec une capacité totale de 16.000.000 tonnes. Dans de nombreux autres pays européens, on place ou on peut placer en théorie plus de déchets dans les décharges publiques.

❑ Importations et exportations

La majeure partie du papier récupéré dans le monde est importée ou exportée. La France a augmenté ses exportations pendant les années 1980, en même temps que le taux de récupération croissait. Elle a même doublé ses exportations de 1985 à 1990 (Payne, 1992). Les exportations ont diminué après 1991 et les importations de papier récupéré ont au contraire augmenté pendant les années 1990. Les investissements dans les installations de désencrage et l'augmentation de la capacité de désencrage ont probablement contribué à accélérer les importations de papier récupéré.

❑ L'incinération

Les autres alternatives aux débouchés du papier récupéré permettant un gain d'énergie sont les installations d'incinération des centrales d'énergie, et l'incinération dans les usines de papier. Le papier d'impression est souvent incinéré avec d'autres déchets ménagers. En France, environ 40% des ordures ménagères sont incinérées, ce qui représente la valeur européenne moyenne. Ce n'est pas beaucoup en comparaison avec le Danemark ou la Suisse, où 80% des déchets ménagers sont incinérés (statistiques OCDE). C'est pourtant en France qu'il y a le plus grand nombre d'installations d'incinération en Europe: 306 en 1990, avec capacité totale de 8.700.000 tonnes. 68% de l'énergie produite par l'incinération peut être exploitée. (Europe's Environment: Statistic Compendium).

L'accroissement du pourcentage d'incinération est tributaire du prix du papier récupéré, de la volonté politique, de la capacité industrielle d'incinération et des possibilités d'augmenter celle-ci.

Malgré le nombre élevé des installations d'incinération en France, en comparaison avec ▶▶▶

▸▸▸

les autres pays européens, il est caractéristique pour la France que les deux tiers des usines d'incinération d'ordures ménagères soient de petite taille et que la majorité d'entre elles soient menacées de fermeture à court terme à cause d'une directive de l'UE.
Actuellement, il y a au niveau national des projets visant à augmenter la capacité d'incinération des déchets ménagers avec récupération d'énergie (Lancesseur, 1995). Un accroissement de la capacité rendait également possible une augmentation de l'incinération du papier en France.
L'accroissement du taux d'incinération des déchets ménagers peut quand même se révéler difficile, parce que le prix des équipements d'épuration augmente tout le temps à cause des normes de plus en plus strictes sur les rejets atmosphériques.
Les scientifiques ne sont par exemple pas tous d'accord sur la part des métaux lourds dans les rejets atmosphériques.

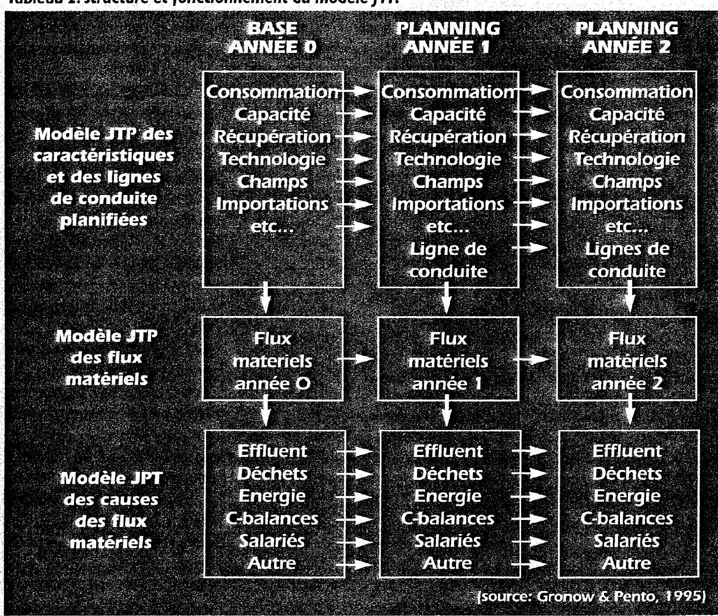
LES MODÈLES DES FLUX MATÉRIELS

La jeune science des modèles des flux matériels est en train de se développer, bien qu'elle n'en soit encore qu'à ses balbutiements pour ce qui est des modèles de planification régionaux ou nationaux. Plusieurs approches ont été proposées, dont la majorité sont basées sur des analyses des flux matériels. On a aussi présenté plusieurs modèles qui s'efforcent de calculer des flux matériels nationaux et leurs effets sur l'environnement.

❑ L'analyse du cycle de vie traditionnelle

L'analyse du cycle de vie (ACV) basée sur un produit de valeur moyenne a été étudiée et utilisée par plusieurs chercheurs. Ils s'efforcent souvent de calculer les cycles de vie du berceau à la tombe. Les modèles de l'écobilan calculent les flux, l'énergie et le chargement matériel pour un cycle de vie de valeur moyenne d'un produit de valeur moyenne dans un temps donné.
Premièrement, les écobilans statistiques s'attachent à un seul produit à la fois, de valeur moyenne. Les ACV traditionnelles ne peuvent ainsi pas analyser plusieurs systèmes dynamiques et indépendants. Le dynamisme perpétuel des systèmes vastes met en question l'utilisation d'un modèle fixé sur un seul produit, parce que la méthode présuppose que le produit n'influence pas le système dont il fait partie ou n'est pas influencé par lui.
Deuxièmement, il y a un problème méthodologique de fond dans les modèles traditionnels d'ACV quand le produit analysé est une partie du système de recyclage dans lequel il est difficile de définir le point terminal du cycle de vie d'un produit. Comme il y a plusieurs points terminaux et que l'ACV devrait être stochastique, il est impossible de faire des calculs exacts des flux et de l'énergie. L'ACV traditionnelle demande en principe un cycle de vie linéaire. Si une relation linéaire ne peut pas être mise en évidence, les résultats d'une ACV traditionnelle ne sont pas définis.
Les ACV traditionnelles analysent les données historiques des processus déjà existants, ce qui met souvent en question l'utilisation de leurs résultats dans le travail de planification, surtout dans les secteurs à développement technologique rapide.
Les groupes de recherche essaient de développer plusieurs modèles pour surmonter les problèmes des modèles traditionnels de l'ACV et pour que ceux-ci puissent être utilisés dans le travail de planification nationale sur l'environnement, maintenant que le recyclage est en train de devenir une partie de plus en plus importante de ce travail. Comme solution aux problèmes de l'ACV, la recherche semble s'orienter vers des systèmes industriels globaux où la consommation de l'énergie et des matières premières, les flux de sortie et les déchets ne sont pas fixés pour un produit, mais sont étudiés au niveau industriel ou national.

Tableau 2: structure et fonctionnement du modèle JTP.



❑ Le modèle JTP

Le modèle JTP (Joined Time Projection) est un modèle dynamique qui offre de nouvelles possibilités surtout pour la planification écologique à long terme au plan national ou industriel. Avec le modèle JTP, on peut étudier de grands ensembles, des industries entières. La structure du modèle combine plusieurs unités semi-indépendentes dont chacune figure les flux matériels du système pendant une certaine période de temps, par exemple un an. Le type de technique est une analyse de scénario quantitative où les calculs sur l'avenir sont basés sur des paramètres qui définissent des variables annuelles. Certains paramètres peuvent être des variables de ligne de conduite. L'analyse dynamique est facili-

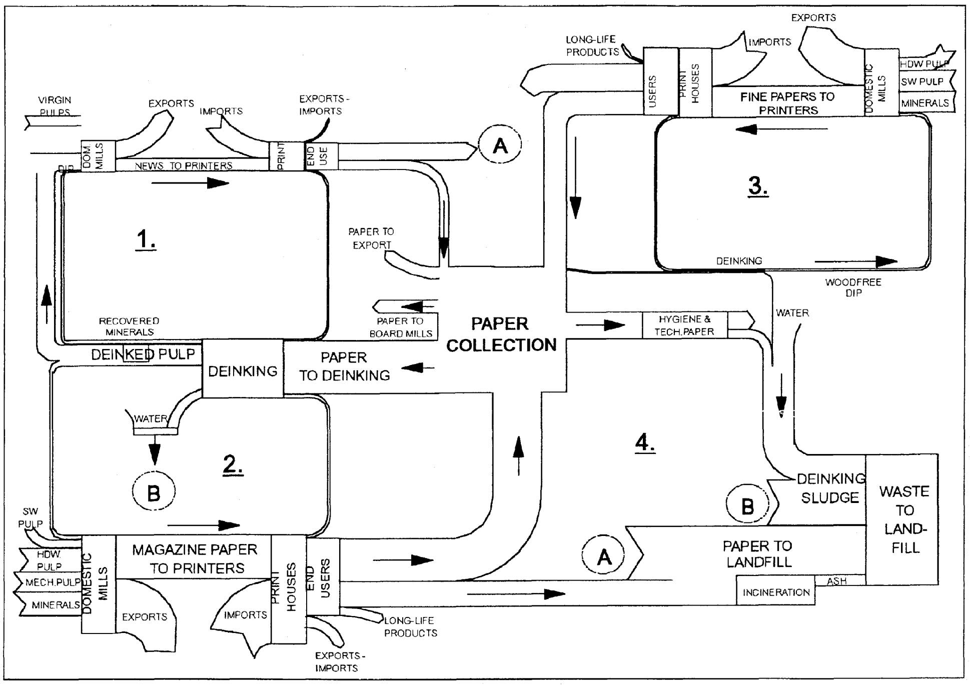


Figure 3: analyse des flux des papiers d'impression par le modèle JPT dans un système national.

tée si l'on met les unités annuelles l'une à côté de l'autre. De cette façon, il est facile de comparer et de voir les différences dans le temps. Le **tableau 2** expose la structure et le fonctionnement du modèle JTP. Le plus grand problème du modèle JTP est l'acquisition des données. Le manque de statistiques et de différences dans les statistiques oblige de temps en temps à faire des estimations subjectives.

Le risque de faire des estimations potentiellement fausses n'a toutefois qu'un effet sur le résultat. Il a été minimisé par une analyse différentielle où ce ne sont pas les chiffres séparés qui sont pris en compte dans l'analyse, mais le développement des variables dans le temps.

❑ L'approche industrielle

Une des meilleures propriétés du modèle JTP est son approche souple vis-à-vis de l'objet de planification ou l'objet de recherche. Le modèle JTP facilite les analyses des flux matériels des systèmes industriels qui comportent plusieurs variables changeant en même temps. Dans les modèles des flux matériels, la complexité des produits, la relation avec les autres produits et, surtout, le point terminal du cycle de vie posent un problème pour la recherche. Si une quantité importante de papier est recyclée, autrement dit si le papier est récupéré, assorti, désencré et retransformé en papier, le mélange des fibres et la réutilisation des fibres secondaires constituent un problème difficile pour les modèles traditionnels des flux matériels où la consommation d'énergie et de matières premières, les flux de sortie et la production des déchets ne sont pas fixés sur un seul produit (de valeur moyenne).

Dans le cas des papiers d'impression français, il y a aussi plusieurs produits qui s'influencent l'un l'autre. Le papier journal, le papier pour magazines, les papiers fins et les papiers hygiéniques et techniques forment une totalité. Chaque classe de papier influence les autres. L'influence des papiers hygiéniques et techniques cependant est à sens unique. Les différentes classes de papiers forment des sous-systèmes semi-indépendants. Les sous-systèmes et les flux matériels ont plusieurs points de contact, comme le désencrage, où les différentes classes se mélangent. Les sous-systèmes communiquent l'un avec l'autre et forment des systèmes très vastes concernant toute une industrie. Dans la totalité d'un sous-système de plusieurs produits, il y a plusieurs objets de placement final.

Le modèle JTP est une approche globale de toute une industrie ou de tout un système national. La **figure 3** montre comment le modèle JTP analyse les flux des papiers d'impression dans un système national. Les différents sous-systèmes ont des points de contact continuels au niveau de la collecte, du désencrage, des décharges publiques et de l'incinération.

Les flux des fibres de papiers d'impression français forment quatre sous-systèmes: le papier journal (1); le papier pour magazines (2); les papiers fins (3); les papiers hygiéniques et techniques (4).

Le Modèle JTP examine d'abord les sous-systèmes séparément, puis sont examinées et recherchées des relations de l'un à l'autre pour former ▸▸▸

une grande totalité quand il est possible de faire des calculs. Le Modèle JTP a été utilisé avec succès pour analyser des systèmes complexes comme les flux de papiers an Allemagne (Pento, 1994).

Le travail de planification au niveau national demande un modèle qui examine de grands ensembles. Une analyse séparée d'un sous-système qui est dépendant d'une totalité peut facilement conduire à des résultats erronés. Par exemple, une analyse séparée linéaire du cycle de vie des papiers d'impression montre que la collecte et le recyclage réduisent la formation de déchets solides, alors qu'une analyse globale concernant les flux de papier de l'industrie toute entière montre nettement que le résultat est l'inverse. En effet, dans une étude à vaste échelle, la quantité relative de déchets solides augmente quand le recyclage augmente (Pento, 1994, 1994 a).

❑ La perspective temporelle

Les modèles traditionnels exigent que l'on connaisse le cycle de vie du produit du berceau à la tombe, pour pouvoir être fonctionnels. La pluralité des points terminaux constitue un problème, comme déjà mentionné. Il y a un autre grave problème: la perspective temporelle, autrement dit le dynamisme des modèles.

De même que les produits et leurs flux matériels sont dépendants de la totalité où ils se trouvent à un moment donné, ils sont également dépendants du temps. Les cycles de vie peuvent être des processus très longs. Il est impossible de décomposer ces processus en termes déterministes. Lors de la collecte du papier, les classes différentes sont mélangées. Une partie des fibres et des minéraux sont en circulation pendant plusieurs années. Quand le papier récupéré est désencré, une partie de la pâte désencrée peut être utilisée en tant que matière première dans la fabrication du nouveau papier, qui sera à son tour désencrée etc., à l'infini. A cause de ce processus continuel, les papiers d'impression provenant d'Europe continentale contiennent beaucoup de fibres et de minéraux qui ont été recyclés, non seulement une fois, mais plusieurs fois.

C'est surtout dans le travail de planification qu'il est très important de pouvoir évaluer ce qui se passera à l'avenir. Le Modèle JTP, qui est dynamique, tient compte de la perspective temporelle. Il peut être utilisé pour construire des scénarios sur plusieurs années.

L'avantage de ce modèle est qu'il offre des moyens de faire des analyses et scénarios sur l'avenir, des analyses qui sont détaillées et quantifiées.

Un modèle de travail de planification écologique au niveau national doit être capable d'évaluer l'avenir et les effets des décisions prises sur les lignes de conduite. On n'a pas besoin d'une estimation complète du futur, mais la connaissance des lignes de conduite présidant aux décisions est importante, tout comme il importe de savoir s'il est possible de réaliser les objectifs recherchés par les décisions prises. Ainsi, il est possible d'éviter les problèmes similaires à ceux qui avaient gêné au début la Verpackungsverordnung en Allemagne, problèmes dont l'origine était le fait que les hommes responsables n'avaient pas tenu compte des effets des décisions de la ligne de conduite.

❑ Les besoins du travail de planification écologique

La planification écologique au niveau national prend rarement comme direction de travail le développement durable ou les solutions les moins chères. En outre, les personnes responsables des décisions et les chercheurs veulent avoir les meilleurs instruments de travail pour la planification écologique nationale. Les besoins profonds de la planification écologique nationale ainsi que la manière dont ils sont mis en œuvre sont bien sûr une bonne mesure d'estimation. La planification écologique au niveau national doit remplir plusieurs conditions préalables pour qu'elle puisse être couronnée de succès.

Soininvaara constate qu'il faut d'abord avoir un objectif de ligne de conduite bien défini. Le produit ou l'environnement ne peut néanmoins pas constituer l'objectif de la ligne de conduite. Il est difficile ou impossible de la maîtriser en mettant en œuvre la ligne de conduite.

Ainsi, il est plus raisonnable de choisir une industrie comme objet d'une ligne de conduite, car les entreprises ont souvent les moyens et l'organisation nécessaires à la réalisation des changements. Il est possible de conduire et d'orienter les industries ou les entreprises pour qu'elles prennent les mesures nécessaires à la réalisation des résultats voulus. (Soininvaara, 1993).

Weaver et al. font remarquer que la majorité des approches analytiques commencent l'analyse avec des instruments de ligne de conduite déjà arrêtés, puis présentent les effets probables sur l'environnement, et, dans certains cas, les effets sur le commerce et l'industrie.

Une analyse de ce type, bien qu'elle soit utile, est limité, car elle est dépendante d'un facteur, c'est-à-dire de l'instrument qui est défini extérieurement. Ainsi, il n'est pas possible d'estimer le rôle du choix de la ligne de conduite dans le résultat obtenu (Weaver et al, 1995).

Dans la méthodologie du modèle utilisé par Weaver (Ayers et al, 1989), on élimine le problème en définissant d'abord les objectifs, et ensuite seulement les choix de ligne de conduite qui conviennent aux objectifs.

Dans le Modèle JTP, les problèmes évoqués par Soininvaara et Weaver sont éliminés. Les objectifs, tels que l'alternative la moins chère ou l'alternative la plus écologique, et les décisions fonctionnent en interaction continuelle. Le modèle décrit les flux matériels de telle sorte que les chercheurs peuvent accentuer l'aspect qu'ils préfèrent: objectifs ou lignes de conduite.

Le point de départ du Modèle JTP est la planification au niveau national ou industriel et les besoins réels de celle-ci, pour qu'elle puisse répondre aux questions posées par les décideurs. Les facteurs qui influencent les décisions sont inclus dans le cadre analytique du Modèle JTP. Les facteurs inclus peuvent être notamment les suivants :

- facteurs environnementaux: consommation de matières premières et d'énergie
- facteurs économiques: importance des investissements, coûts des activités et effets sur les marchés
- main-d'œuvre : quantité et qualité
- possibilités techniques
- effets du commerce extérieur: valeur et importance des importations et des exportations.

En utilisant le modèle, il est facile de voir où et quand les décisions concernant la ligne de conduite choisie provoquent des perturbations ou des engorgements dans les flux matériels et dans les marchés. Le modèle permet d'analyser les changements techniques, technologiques et de capacité.

●●● (À suivre)

(*) Dans notre prochain numéro Tito Gronow nous propose trois types de scénarios réalisés à l'aide du modèle Joined Time Projection sur l'évolution des flux du papier d'impression de 1993 à 2000.

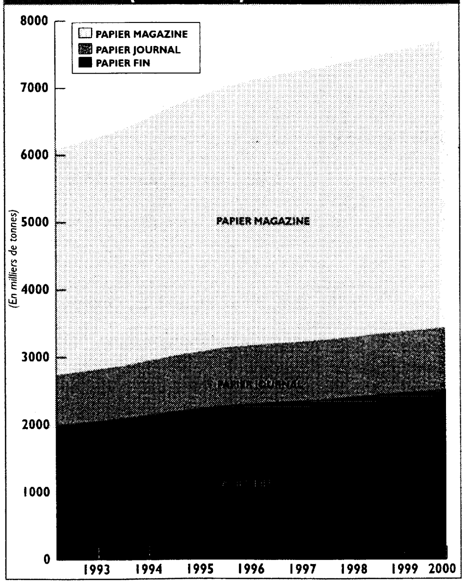
PLANIFICATION

Les flux matériels des papiers d'impression (2)

Après avoir expliqué le fonctionnement du modèle JTP de planification dans notre précédent numéro, Tito Gronow, dans cette seconde partie, examine les prévisions élaborées à l'aide de ce modèle.

Le développement et les changements des flux matériels du papier d'impression de 1993 à 2000 en France seront analysés à l'aide du modèle Joined Time Projection en comparant les exigences et les conditions préalables de trois scénarios différents. Les calculs sont basés sur une prévision de demande constante pour les trois scénarios. La quantité de fibre utilisée pour le carton est aussi censée rester la même dans les trois scénarios.

DEMANDE DE PAPIER (PRÉVISIONS) - SCÉNARIO A



- Scénario A : laissez-faire
Le pourcentage de récupération du papier d'impression n'est pas accru par voie de législation ou de décision politique et il n'est pas influencé de façon notable par les forces du marché. Les flux matériels se développent sur la base de la législation du moment, en tenant compte des lois de l'offre et de la demande. La part en pourcentage des importations augmente très lentement dans ce scénario.

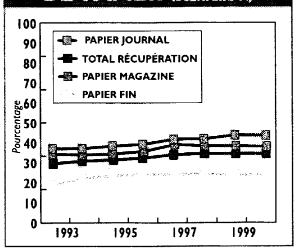
- Scénario B: récupération active
Le degré de récupération du papier d'impression s'élève à 47% et la fibre est principalement utilisée dans le désencrage. La pâte de désencrage est utilisée pour le papier journal, mais aussi le magazine. La possibilité d'influencer le degré de récupération par voie législative a été facilitée par la croissance de la prise de conscience écologique et des problèmes causés par les décharges saturées.

- Scénario C: degré élevé de récupération
Ce scénario correspond à une augmentation du degré de récupération à 60% en l'an 2000, qui est le niveau atteint par les pays concurrents de la France, l'Allemagne par exemple. Des efforts sont faits pour utiliser la quantité additionnelle récupérée dans la fabrication du papier journal, ce qui demande une augmentation de la capacité de désencrage et de la fabrication du papier journal en France.

ANALYSE DU SCÉNARIO A

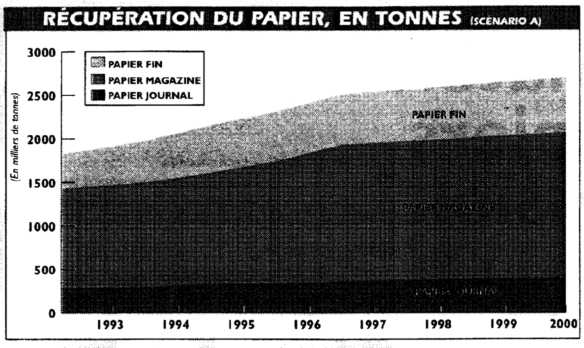
- La demande
Les prévisions concernant la demande sont fixées au même niveau dans les trois scénarios. Les prévisions de demande proviennent de plusieurs sources différentes, qui ont traditionnellement été exactes. Les autres calculs sont tirés surtout des prévisions présentées au tableau 1. La fiabilité des autres calculs est dépendante en grande partie des chiffres présentés dans le tableau 1. La croissance annuelle est estimée à 3,4% pour le papier fin, à 3,6% pour le papier pour magazines et à 3,0% pour le papier journal.

TAUX DE RÉCUPÉRATION DE PAPIER (SCÉNARIO A)



- Le degré de récupération
Le pourcentage total de récupération en France s'élève de 1993 à 2000 à seulement 5%. La récupération de papier augmente néanmoins d'un peu plus de 6%, passant de 38% à 44%. En tonnes, cela veut dire que la collecte totale passe de 1 826 tonnes à 2 701 tonnes, soit 48%. Malgré le fait que le degré de collecte du papier journal augmente plus rapidement que celui des autres classes de papier, cette augmentation en tonnes est moindre que celle des autre

RÉCUPÉRATION DU PAPIER, EN TONNES (SCENARIO A)



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classes de papier à cause d'une demande moindre pour le papier journal, demande qui n'augmente pas à la même vitesse que celle des autres classes de papier.

- Le rôle des importations

La part de marché du papier importé dans le scénario A augmente très lentement, en moyenne de 2,66% jusqu'en l'an 2000.

L'augmentation la plus forte concerne le papier fin. Pour le papier magazine, l'importation atteint le maximum de 60% en 1995, après quoi commence une lente diminution. Le pourcentage des importations de pâte est censé rester au niveau de 1993.

- Importations en tonnes

En maintenant constante la part de marché de la pâte importée, et quand la demande augmente, la quantité absolue importée des différentes classes de pâte augmente proportionnellement aux prévisions de demande. Les classes de papiers sont aussi proportionnelles aux prévisions de demande et d'importations les concernant.

- Les matières premières du papier produit dans le pays

On peut dire que la tendance générale en ce qui concerne le papier journal est à une baisse de l'utilisation de fibre recyclée comme matière première par l'industrie du papier produit dans le pays. Le vieux papier récupéré devient cher, et la plupart des fabricants peuvent aussi utiliser de la fibre vierge.

L'année 1994 est une exception à cette règle car, entre autres choses, les importations de papier sont proportionnellement plus élevées cette année-là. Cela peut être le résultat du prix raisonnable du papier récupéré début 1994. On a aussi importé moins de papier récupéré en 1994 que pendant les autres années. Pendant cette période, l'utilisation de fibre récupérée dans le papier pour magazine augmente et passe de 2% à 5%, suite à l'augmentation de la demande de papier pour magazine.

- Les débouchés du papier recyclé

Les débouchés du papier récupéré dans le scénario A et la quantité de papier qui y est placée augmentent en proportion de la demande. La majeure partie de la pâte désencrée est utilisée dans la fabrication de papier journal, et la pâte utilisée pour la fabrication du papier fin est pour la plupart de la pâte sans bois, dans laquelle le papier récupéré nécessaire et le désencrage de celui-ci sont différents des autres classes de papier.

- La composition des déchets

Le flux matériel annuel en direction des décharges inclut les suspensions denses du désencrage, les cendres, les effluents du désencrage et du papier.

Environ la moitié des déchets est du papier et l'autre moitié est constituée principalement de suspensions denses du désencrage.

- La production en France

Comme la part des exportations est supposée être constante, les quantités de production en France suivent la demande. La production de papier fin et de papier pour magazine est, elle, inférieure à la demande.

C'est pendant les années 1999 et 2000 que la différence est la plus grande. Pour ce qui est du papier journal, la tendance est très nettement le contraire. La production de papier journal est supérieure à la demande nationale française, car les exportations augmentent et la demande sur les marchés internationaux est importante, surtout pendant les années 1994/1997.

Vers la fin de la période, la différence entre la demande et la production diminue. En l'an 2000, la production est déjà un peu plus grande que la production française. Les excédents et les déficits de la production sont équilibrés avant tout par le commerce extérieur.

- Les exportations

Les exportations de papier pour magazines augmentent de 452.000 tonnes pour la période 1993/2000, en même temps que les exportations de papier journal et de papier fin restent plutôt constantes. Pendant les années 1994/1997, le taux d'exportation du papier journal augmente aussi à cause de la conjoncture favorable des marchés internationaux.

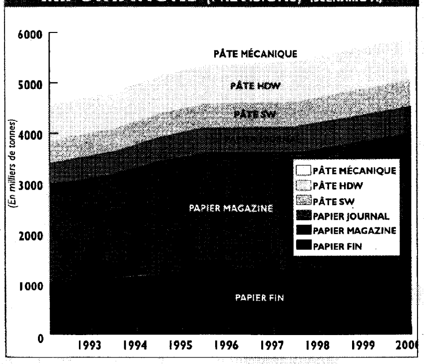
La part de papier récupéré dans les exportations augmente aussi de 83.000 tonnes entre 1993 et 2000.

SCÉNARIO B

- Le degré de récupération

Dans le scénario B, le degré de récupération de toutes les catégories de papier est supposé augmenter pour l'année de base, de 1993 à 2000, de 17 points, soit jusqu'à 47%. C'est la récupération du papier pour magazine qui augmente le plus, de 23,5 points.

IMPORTATIONS (PRÉVISIONS) (SCÉNARIO A)



En tonnes, l'accroissement de la récupération de papier pour magazine représente 1.320.000 t (115 % par rapport à 1993). Ainsi, le degré de récupération du papier pour magazine atteint le même niveau que celui du papier journal.

Autrement dit, près de 60% du papier journal et du papier magazine est recyclé. Des différences entre les scénarios A et B peuvent être observées seulement à partir de 1997.

- Le rôle des importations

La part de marché des importations augmente dans la même mesure que dans le scénario A, en moyenne 2,66 % par an entre 1993 et 2000. Le degré de récupération plus élevé a toutefois un léger effet sur la diminution des minerais importés.

- Importations en tonnes

Le scénario B suit les mêmes lignes que le scénario A, mais les importations de pâte mécanique diminuent après 1996. Les importations des types de papier varient en relation des prévisions d'importations et d'exportations comme dans le scénario A.

- Les matières premières du papier produit dans le pays

Dans le cas du papier journal, on peut considérer comme une tendance générale un lent accroissement de l'utilisation du papier récupéré comme matière brute de l'industrie papetière française, car la récupération du papier journal se trouve intensifiée.

Les années 1995/1996 forment une exception à la tendance générale, notamment parce que le prix du papier récupéré est très élevé. Les producteurs de papier utilisent beaucoup de fibre vierge.

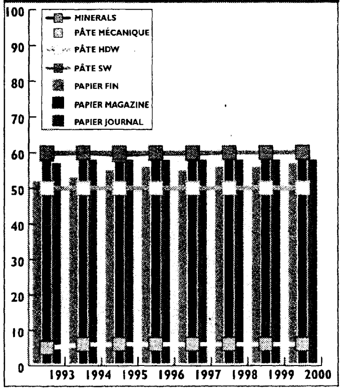
- Les débouchés du papier recyclé

Grâce au désencrage, il naît près de 1.000.000 tonnes de déchets de moins que dans le scénario A, en partie parce que les exportations de papier récupéré augmentent notablement. Une partie des déchets aboutit à l'étranger. Une part de plus en plus grande des fibres recyclées est réutilisée dans le papier journal.

- La composition des déchets

C'est dans le scénario B que sont produits le moins de déchets, 250.000 tonnes de moins que dans le scénario A et 345.000 tonnes de moins que dans le scénario C. C'est surtout la part de papier qui diminue en comparaison avec le scénario A, en même temps qu'augmentent les suspensions denses du désencrage.

TAUX IMPORTATIONS (PROJECTION)
(SCÉNARIO A)



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- La production en France
Les quantités de production sont les mêmes dans les scénarios A et B. Le degré de récupération plus élevé résulte à partir de 1997 en une utilisation plus grande des fibres récupérées.
C'est en l'an 2000 que la différence est la plus grande, 600.000 tonnes. L'utilisation de pâte mécanique diminue en même temps que la quantité des fibres augmente.

- Les exportations
Il n'y a pas de changements dans les exportations par rapport au scénario A, sauf que les exportations de papier récupéré augmentent fortement (403.000 tonnes) entre 1993 et 2000.

SCENARIO C

- Le degré de récupération
Dans le scénario C, le degré de récupération est supposé augmenter, de l'année de base 1993 jusqu'en 2000, d'une façon considérablement plus rapide que dans les scénarios A et B. Le degré de récupération du papier journal et du papier pour magazine approche les 70 % et le degré de récupération total s'élève à 55 %.
La part du papier pour magazine augmente beaucoup plus fortement que celle des autres classes de papiers. Le pourcentage de papier pour magazine augmente entre 1993 et 2000 de 150%, soit 1.711.000 tonnes. Le degré de récupération n'augmente pas aussi rapidement que celui des autres classes de papier car, dans la pratique, il est plus difficile de récupérer du papier fin.

- Le rôle des importations
Dans le scénario C, la part de marché du papier fin et du papier pour magazine augmente de façon modeste, dans la même mesure que dans le scénarios A et B, mais les importations de papier journal diminuent de façon significative (30 %) tandis que le degré de récupération augmente fortement. L'accroissement du degré de récupération a éventuellement un léger effet sur la diminution des minerais importés. La part de marché des importations de pâte est supposée être au même niveau qu'en 1993.

- Importations en tonnes
Le degré très élevé de la récupération a un effet net sur la diminution des importations de papier journal, qui passent de 425.000 à 275.000 tonnes pendant la période 1993/2000, car dans le scénario on part de l'hypothèse que le papier récupéré est désencré et que les fibres sont utilisées en premier lieu dans le papier journal. On note une diminution de la pâte mécanique qui se fait sentir plus tôt et plus fortement que dans le scénario B.

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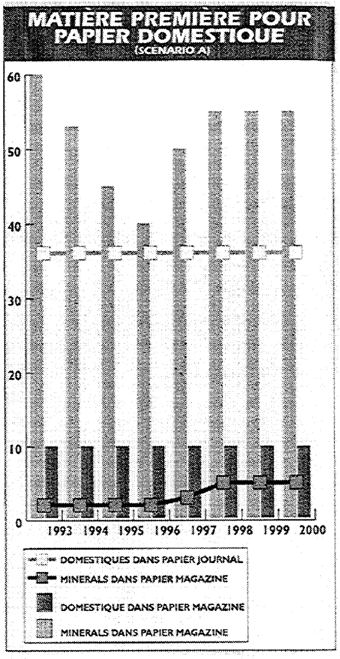
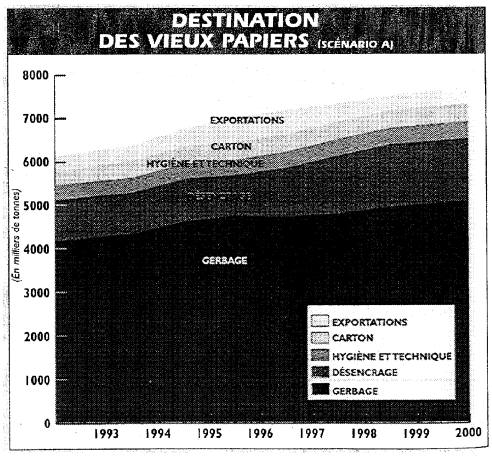
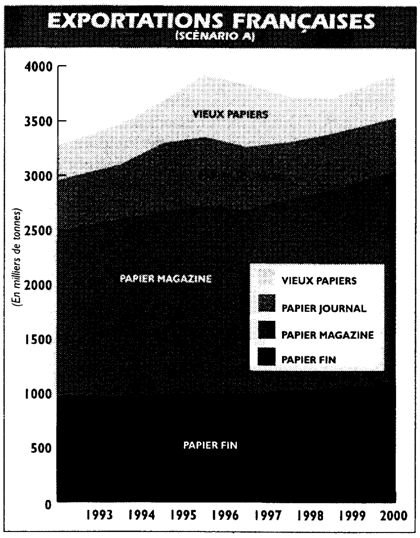
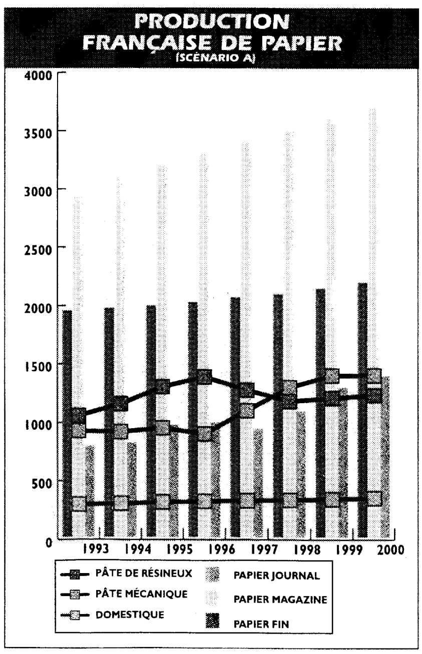
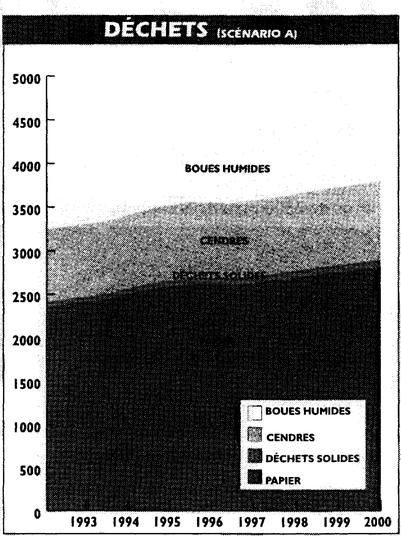





EXPORTATIONS FRANÇAISES
(SCÉNARIO A)
(En milliers de tonnes)
4000
3500
3000
2500
2000
1500
1000
500
0
VIEUX PAPIERS
PAPIER MAGAZINE
PAPIER FIN
VIEUX PAPIERS
PAPIER JOURNAL
PAPIER MAGAZINE
PAPIER FIN
1993 1994 1995 1996 1997 1998 1999 2000


PRODUCTION FRANÇAISE DE PAPIER
(SCÉNARIO A)
4000
3500
3000
2500
2000
1500
1000
500
0
1993 1994 1995 1996 1997 1998 1999 2000
PÂTE DE RÉSINEUX
PÂTE MÉCANIQUE
DOMESTIQUE
PAPIER JOURNAL
PAPIER MAGAZINE
PAPIER FIN



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- Les matières premières du papier produit dans le pays

Dans le scénario C, on décèle une tendance très nette: la part des fibres augmente considérablement dans le papier journal et dans le papier pour magazine quand le degré de récupération augmente fortement. Bien qu'il y ait beaucoup de capacité de désencrage dans l'immédiat, toute la capacité arrive à saturation en 1997, après quoi il faut construire de nouvelles installations pour satisfaire la demande.

- Les débouchés du papier recyclé

Les exportations de papier recyclé diminuent en comparaison avec le scénario B, car le papier récupéré finit systématiquement dans la production de papier journal, soit en 1994, 574.000 tonnes de plus que dans le scénario B. Dans le papier pour magazine, on utilise aussi de plus en plus de fibres récupérées, même si ce n'est pas autant que dans le papier journal.

- La composition des déchets

Le scénario C produit le plus de déchets en général, mais le moins de déchets de papier, soit 1.000.000 tonnes de moins que dans le scénario A. Au lieu de papier, ce sont des suspensions denses de désencrage qui sont produites, pour lesquelles il est difficile de trouver des débouchés. La quantité de suspensions denses de désencrage augmente de façon considérable, il y en a 1.670.000 tonnes de plus qu'en 1993, l'année de départ.

- La production en France

Dans le scénario C, il est produit nettement plus de papier journal (520.000 tonnes en 2000) que dans les scénario A et B. En ce qui concerne le papier fin et le papier pour magazine, il n'y a pas de différence. L'utilisation de la fibre recyclée augmente énormément, de 2,1 millions de tonnes, mais en revanche l'utilisation de la pâte mécanique diminue parallèlement.

- Les exportations

Les exportations de papier journal augmentent nettement, passant de 473.000 tonnes à 744.000 tonnes de 1993 à l'an 2000. Les exportations de papier recyclé sont moindres que dans le scénario A; et nettement moindres que dans le scénario B. En effet, les exportations de papier recyclé sont moins importantes en 2000 qu'en 1993.

■ CONCLUSION

En principe, les trois scénario évoqués peuvent être mis en œuvre en France mais en pratique, le scénario C, surtout, demanderait des investissements et des changements structurels d'une ampleur telle qu'il ne peut être raisonnablement supportable avant l'an 2000. Les scénarios peuvent être utilisés comme outil de planification écologique de l'industrie papetière. Tous ces scénarios montrent les orientations qui s'ensuivent, et ce qui se passe si telle ou telle ligne de conduite est choisie. ❑

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ARTICLE III

EFFLUENT GENERATION FROM PAPER PRODUCTION AND CONSUMPTION IN FRANCE

By

Gronow, Tito

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Effluent generation from paper production and consumption in France

T. GRONOW

SUMMARY

Life cycle inventory calculations are made here to determinate the quantity of emissions caused by the production of several paper grades in France. The life cycle of each paper grade is first analysed from cradle to mill gate. Then all grades are compared, and their emissions are combined with the results for France of the FAO's pulp, paper and paperboard capacity survey for 1992-97 (1) to investigate how the quantity of emissions develops during the period.

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MOTS-CLÉS :
LCA - life cycle inventory - life cycle assessment - air pollution - emission - carbon dioxide - water emissions - coated paper - uncoated paper.

INVENTORY

Models for paper and board production in France were constructed using the KCL - ECO life cycle inventory software program developed at KCL, The Finnish Pulp and Paper Research Institute. KCL-ECO's basic database contains data from the paper industry and related fields. It is used by mills to calculate life cycle inventories for their paper products from cradle to mill gate and even from cradle to grave. In other articles, where the structure of the model has been presented, it has been used for life cycle assessment (LCA) connected mostly with the Finnish and German pulp and paper (P&P) industries. (2)

The functional unit chosen for the inventories is 1 000 kg of paper end-product at the mill gate. The following paper grades are analysed:
- Newsprint (abbreviated as News)
- Coated wood-free printing and writing paper (WF c.)
- Coated wood-containing printing and writing paper (LWC)
- Uncoated wood-free printing and writing paper (WF unc.)
- Uncoated wood-containing printing and writing paper (SC)
- Household and sanitary paper (Tissue)

Emissions are calculated from all elements of the life cycle from cradle to mill gate. Inventories begin from tree growth and harvest to transport and industrial processes such as production of cellulose, production of chemicals, de-inking of collected paper, electrical power and heat production and paper production. Figure 1 shows the life cycle of newsprint with de-inked pulp (dip) content of 60 per cent. The life cycle looks some what different for other paper grades: for example, the chemicals differ and the paper can be produced in either an integrated mill or a dedicated mill.

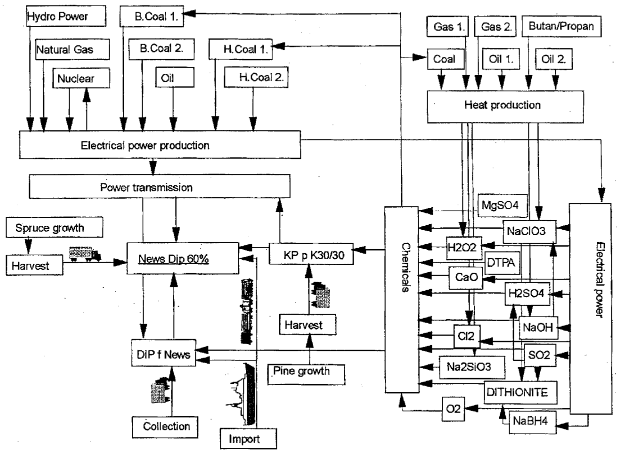

Fig. 1 : Life cycle of newsprint, dip 60 %

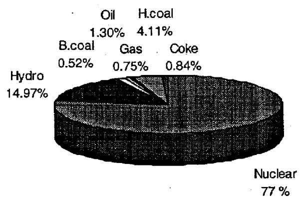

Fig. 2 : Fuel breakdown in France

Assumptions

It is necessary to make estimates concerning an "average mill" for the model. The furnish of paper is assumed to be the same throughout the research period, and the following formulas have been used:

Newsprint contains 33 per cent spruce/PGW (CSF 100 ml), 60 per cent de-inked pulp from outside and 7 per cent pine kraft pulp *Kp p K30/30* from outside.

Both wood-containing paper and wood-free paper are divided into coated and uncoated grades. Coated wood-containing paper contains 35% PGW CSF45, 19% pine kraft from outside *Kp p K18/11,* 42% fillers and 4% sizers and binders. Uncoated wood-containing paper contains 53% spruce/PGW(CSF 45 ml), 18% pine kraft pulp *Kp p K18/11* from outside and 29% fillers.

Coated wood-free paper contains 20% pine kraft pulp (Con30) *Kp p K30/30,* 29% birch kraft pulp (Con21) *Kp b K21/14* and 51% fillers. Uncoated woodfree paper contains 20% pine kraft pulp (Con30) *Kp p K30/30,* 48% birch kraft pulp (Con21) *Kp b K21/14* and 32% fillers.

Household and sanitary paper contains 20% bleached birch kraft pulp *Kp b K21/14,* 40% bleached pine kraft pulp *Kp p K 30/30* and 40% de-inked pulp.

Cellulose assumed to be used in SC and LWC paper of the model is *Kp p K18/11.* Cellulose used in wood-free paper is partly *Kappa 30* and partly *Kappa 21.*

Both uncoated and coated wood-free paper is produced in an integrated mill: i.e. part of the pulp is not imported, unlike with other grades, which means lower emissions for transport. The grade or the composition of cellulose chosen here is commonly used in paper production but can vary from mill to mill.

Production of the materials needed in the process (energy and chemical) has been included in the inventory, as have the emissions due to the transport of wood, pulp and paper. The imports and exports of pulp have been taken from Eurostat customs statistics. (3)

Energy production is based on the average fuel breakdown in France in 1993, (4) shown in Figure 2. Exports and imports of electricity have not been considered in the inventory. The heating energy data concern heat production connected with industrial output of basic organic chemicals for 1993. (5)

The input, specific consumption and output figures used for the mills in the inventory are based on average level available technology and are the same throughout the period. The furnishes of end-products are also assumed to be the same.

Results

The results are discussed in terms of main air and water emissions. The bases used for the selection of variables include (6):

- measurability of all units in the system
- effect on global environmental phenomena
- inclusion in criteria for granting environmental labels.

EMISSIONS AT DIFFERENT STAGES OF THE LIFE CYCLE

Air emissions

Most fossil $C0_2$ and $S0_2$ emissions from fossil fuel combustion stem from energy production. They are relatively low in France because around three-quarters of French electricy is generated in nuclear plants, which do not result produce as many emissions as thermal power plants. The sources of $C0_2$ emissionsl are shown in Figure 3. Emissions are calculated for 1 000 kg of paper produced in France. For example, when 1 000 kg of newsprint is produced, the entire process or life cycle generates 884.99 kg of $C0_2$ emissions and 3.19 kg of NOx emissions.

Production of uncoated wood-free and uncoated wood-containing paper grades demand more extemal energy than production of coated paper grades. Consequently $C0_2$ emissions connected with extemal energy use

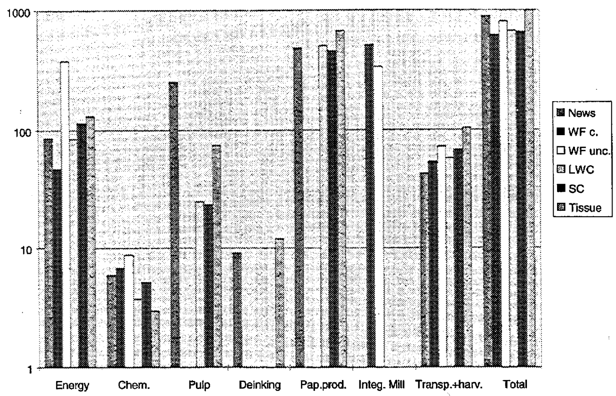

Fig. 3 : CO_2 emissions during different stages of LCA

	Energy	Chem.	Pulp	Dip	Pap.prod.	Integ. M.	Transp+harv	Total
News	85.87	5.91	252	9.1	490		42.11	884.99
WF c.	47.05	6.84				520	53.07	626.96
WF unc.	381.55	8.72				340	72.09	802.37
LWC	82.92	3.75	24.7		510		56.87	678.24
SC	114.61	5.19	23.4		460		67.35	670.55
Tissue	130.01	2.99	74	12	672		103.96	994.97

All CO_2 emissions refer to CO_2 from fossil sourses.

are higher for the uncoated grades, while CO_2 emissions connected with chemicals are higher for coated grades.

NOx emissions during the life cycle originate mostly in the production of cellulose and in transport, which has to be taken into account when comparing emissions connected with different paper grades, especially if de-inked pulp is used, as it results in somewhat lower NOx and AOX emissions. Even the VOC emissions generated by harvesting are a little lower if de-inked pulp is used. Different cellulose grades also affect comparison of emissions. More generally, inventories for paper grades using deinked pulp are not fully comparable with inventories for paper grades manufactured by virgin fibre.

It is extremely difficult, if not impossibly, to calculate what percentage of the effluent generation of paper that is (possibly several times) first produced, collected and deinked should be allocated to recycled paper. All recycled products carry a sort of ecological rucksack containing a share of the effluent generation of the original product. In LCA inventories the share of the effluent generation caused by the original product(s) and allocated to the recycled product can range from 0 to 100 per cent. If 0 per cent is chosen, the analysis is open to accusations that recycled pulp is assumed to drop more or less from heaven and that the part of the effluent generation that follows the de-inked pulp is ignored, with the result that the quantity of effluent generation that the LCA indicates, is too low. Conversely, if 100 per cent is chosen, it can be very difficult to avoid double calculation, i.e. the quantity of effluent generation indicated can be considerably higher than in reality. Yet all fixed percentages between 0 and 100 are very subjective. In the case of recycled paper it is usually impossible to say, for example, how many times de-inked pulp has been recycled, or even what original paper grades are included in the de-inked pulp and paper. In the inventories in this article, 0 per cent is chosen because it facilitates the calculations and because the focus of the comparisons is the virgin pulp based paper grades.

Water emissions

AOX emissions originate from bleached chemical pulp production. BOD and COD emissions originate from bleached chemical pulp production and from de-inking. Figure 4 shows COD emissions (in kilograms) for 1000 kg of paper produced. Emissions were calculated for all the stages of the LCA, but they arise exclusively from production processes (Fig. 4).

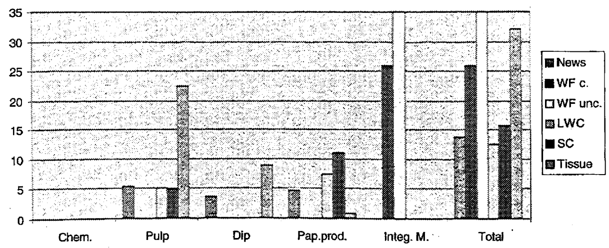

Fig. 4 : COD emissions

	Chem.	Pulp	Dip	Pap.prod.	Integ. M.	Total
News	0.000214	5.4	3.64	4.8		13.84
WF c.					26	26
WF unc.					35	35
LWC		5.13		7.4		12.53
SC		4.86		11		15.86
Tissue		22.4	8.8	0.82		32.02

DEVELOPMENT OF EMISSIONS, 1992-97

Emissions have been calculated per tonne of paper produced and are then correlated with the FAO results for France for 1992-97. The FAO's projection makes it possible to follow how emissions develop. As noted earlier, technology does not change in the inventories. The data are to be considered more relative than absolute. If improved technology aspect were considered, the emissions might be somewhat lower. However the calculations give the main directions of the development of the French P&P industry's emissions between 1992 and 1997. As an example, Figure 5 shows, per tonnes of coated wood free paper, the levels of emissions year by year. Calculations for all paper grades have been similarly carried out (Fig. 5) .

Total change in emissions

Emissions of the French P&P industry increased during the period studied, in line with increased paper consumption. Table 1 summarises year by year calculations for all the major paper grades and shows the increases in emissions, in tonnes, from 1992 to 1997.

The increases in emissions are quite large. An environmental assessment of the inventories presented here would require separate research. However, in view of, inter alia, the 1988 Toronto target of reducing global CO_2 emissions by 20 per cent of before 2005 and the 1990 EC agreement to stabilise CO_2 emissions by 2000 (7) the inventories indicate that new technology and strategies are needed if the French P&P industry is to help France meet the environmental commitments.

Table : 1

Unit: 1 000 tonnes

Change 1992-1997	CO2	NOX	SO2	VOC	AOX	BOD	COD
News 60% dip	106,199	0,383	0,781	0,018	0,029	0,128	1,661
WF unc.	168,497	0,949	0,814	0,076	0,294	0,357	7,35
WF coated	166,145	0,848	0,845	0,07	0,292	0,345	6,89
Coated woodcontaining	101,736	0,464	0,741	0,036	0,011	0,154	1,88
Uncoated woodcontaining	26,822	0,129	0,188	0,011	0,003	0,053	0,634
Tissue 40%	119,396	0,637	0,870	0,045	0,111	0,194	3,842

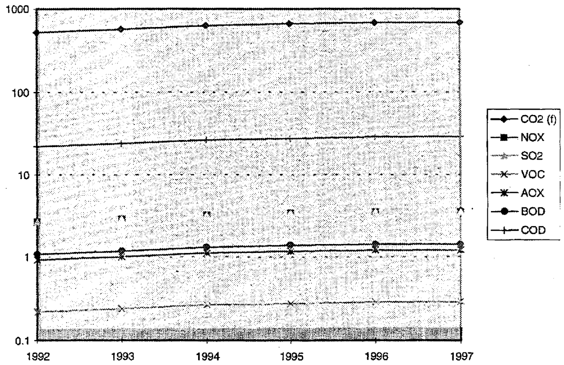

Fig. 5 : Wood-free coated

Unit: tonnes

WF coated	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Total production	830,000	910,000	1010,000	1055,000	1095,000	1095,000
Emissions to air						
CO2	520,380	570,537	633,234	661,447	686,526	686,526
NOX	2,655	2,911	3,231	3,375	3,503	3,503
SO2	2,648	2,903	3,222	3,365	3,493	3,493
VOC	0,218	0,239	0,266	0,277	0,288	0,288
Emissions to water						
AOX	0,913	1,001	1,111	1,161	1,205	1,205
BOD	1,079	1,183	1,313	1,372	1,424	1,424
COD	21,580	23,660	26,260	27,430	28,470	28,470

COMPARING EMISSIONS WITH CHEMICAL VS. MECHANICAL PULP PROCESSES

Discussions have been opened from time to time about the relative environmentfriendliness of paper based on chemical pulp or on mechanical pulp. Advocates of chemical pulp paper pointed out the positive net energy balance of this process, while proponents of mechanical pulping cite its high yields.

A crude analysis of the emission structures of both processes can be conducted by assuming that wood-free and wood-containing papers are substitutes. This clearly is not the case; LWC, which forms the largest part of coated wood-containing paper, is not suitable for the art printing uses of coated wood-free paper. Similarly, uncoated wood-containing paper is largely SC, which cannot be used in the copying and printing applications of uncoated wood-free paper. Hence the substitution is not realistic, given current technology, at least not on a large scale, so the data and comments in this section should be understood to be only indicative of a direction in which the development of paper should be taken for the optimisation of environmental effects.

Scenarios

In theory it is possible to lower emissions by substituting, using one paper grade for another. In following scenario, coated wood-free paper is substituted for 25 per cent of coated wood-containing paper. Production of coated wood-containing paper for which mechanical pulping is used is reduced by 25% from 1 055 to 791.25 thousand tonnes and production coated wood-free paper (using chemical pulping) is increased from 1 095 to 1 368.25 thousand tonnes. Table 2 indicates the total change in emissions.

As the table shows, the environmental effect of substitution would not be unambiguous. CO_2 and SO_2 emissions would be reduced, but the others would be higher.

To produce more radical changes in emissions, coated grades partly replaced by uncoated grades and vice versa. According to the FAO' s projections, the French paper industry will produce 1 515 thousand tonnes of uncoated and 1 095 thousand tonnes of coated wood-free paper in 1997. If the proportions were to be changed, i.e. 1 515 thousand tonnes of the more expensive coated wood-free paper and 1 095 thousand tons of uncoated wood-free paper, total emissions for the two paper grades would be considerably lower. Table 3 shows the real emissions due to production of uncoated and coated wood-free paper, and then the hypothetical emissions if the proportion were changed. The last column indicates how many thousand tonnes lower the emissions would be if the proportions were changed. The scenario is entirely hypothetical - such a change, could not actually be made, with current technology, but it is valuable from a theoritical point of view.

A more realistic scenario would be to change the proportions less radically. Table 4 shows the change in emissions that would result if the share of uncoated wood-free paper were reduced by 200 thousand tonnes from 1 515 to 1 315 thousand tonnes and the share of coated wood-free paper increased by 200 thousand tons from 1 095 to 1 295 thousand tonnes.

Table : 2

Unit: 1 000 tonnes

1997	**LWC**	**WVc**	**Change**
Amount produced	791.25	1368.75	
Emissions to air			
CO2	1402.07	1394.82	-7.26
NOX	6.76	6.82	0.06
SO2	8.71	8.28	-0.43
VOC	0.54	0.55	0.01
Emission to water			
AOX	1.28	1.57	0.28
BOD	2.50	2.59	0.08
COD	41.69	45.50	3.81

Table : 3

Unit: 1 000 tonnes

1997	**total 1**	**total 2**	**Change**
Amount produced	2 610	2 610	0
Emissions to air			
CO2	1902.11	1828.44	73.67
NOX	10.35	9.79	0.55
SO2	9.36	9.07	0.28
VOC	0.83	0.79	0.04
Emission to water			
AOX	3.33	3.20	0.13
BOD	3.99	3.83	0.17
COD	81.50	77.72	3.78

Table : 4

Unit: 1 000 tonnes

1997	**total 1**	**total 3**	**Change**
Amount produced	2 610	2 610	0
Emissions to air			
CO2 (f)	1902.11	1867.03	35.08
NOX	10.35	10.09	0.26
SO2	9.37	9.23	0.14
VOC	0.83	0.82	0.02
Emission to water			
AOX	3.33	3.27	0.06
BOD	4	3.92	0.08
COD	81.50	79.70	1.8

Uncoated wood-containing paper and coated wood-containing paper can in fact substitute for one another to a certain degree. In the next scenario the share of coated wood-containing paper has been lowered by 350 thousand tonnes from I 055 to 705 thousand tonnes while the share of uncoated wood-containing paper is increased by 350 thousand tonnes from 335 to 685 thousand tonnes. Table 5 shows, the environmental effect would not be unambiguous: some emissions would be higher and some lower.

Table : 5

Unit: 1 000 tonnes

1997	**total 4**	**total 5**	**Change**
Amount produced	1390	1390	0
Emissions to air			
CO2 (f)	940.18	937.49	2.69
NOX	4.35	4.40	-0.05
SO2	6.78	6.70	0.09
VOC	0.35	0.36	-0.01
Emission to water			
AOX	0.10	0.10	0.001
BOD	1.53	1.63	-0.10
COD	18.53	19.70	-1.17

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ARTICLE IV

EFFLUENTS OF ALTERNATIVE ENERGY SOURCES IN SWEDISH PAPER PRODUCTION

By

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EFFLUENTS OF ALTERNATIVE ENERGY SOURCES IN SWEDISH PAPER PRODUCTION

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INTRODUCTION

The Swedish Parliament decreed, after a popular referendum in 1980, that nuclear power would be phased out under a time-frame that takes into account the national need for electrical power in order to maintain employment and welfare. The Parliament also decreed that the last nuclear reactor in Sweden would be shut down by the year 2010 at the latest.[1] According to a recent press release of the Swedish Ministry of Trade, negotiations are underway to close down the first reactor in the phasing out scheme by July 1, 1998 and the second reactor by July 1, 2001[2].

The phasing out of nuclear power in Sweden is an issue of current interest which has been strongly debated domestically and internationally. Both macroeconomic and environmental arguments have been used in the debate for and against nuclear power. This paper focuses on the environmental consequences of different energy alternatives, stating and comparing several types of emissions and waste which are generated in the production of electrical power. The effluents are calculated using the Swedish pulp and paper industry as a case example. The pulp and paper (P&P) industry has been chosen for this paper due to its great importance to the country and the existence of tools to measure the industry and its effluents. The choice of the P&P industry also allows the researcher to focus on the environmental consequences of different energy alternatives.

INVENTORY

Life Cycle Inventory calculations are made here to determine the quantity of emissions which are caused by the production of main paper grades in Sweden. The life cycle of current (1993) paper production is first analysed from cradle to mill gate using present day energy composition. Next, a scenario is built, in which the share of nuclear energy is reduced to zero. This corresponds with the result of the Swedish election in 1980 in which the majority of Swedes decided to discontinue the use of nuclear power. Scenarios in which nuclear energy is substituted by coal and gas are constructed. Emissions of different energy alternatives are compared across scenarios.

LCI models for paper production in Sweden were constructed using the KCL-ECO life cycle inventory software programme. KCL, the Finnish Pulp and Paper Research Institute, has developed and advanced software tools for building LCIs. The KCL-ECO programme consists of modules such as pulp and paper mills, transport, harvest, power plants and chemical factories as well as waste sites, printing houses, etc. Modules are based on KCL's database which contains data from the paper industry and related fields. The modules can also be modified by the user and new modules can be created. The KCL study group has made extensive models of the P & P industry with this software[3]. This paper extends the groups work by an analysis of different energy alternatives.

The functional units chosen for the inventories are the Swedish paper production capacities for 1993[4]. Life cycle inventories are calculated for paper end-products at the mill gate. The following paper grades were analysed:

- Newsprint (2307 thousand metric tons)
- Coated woodfree printing and writing paper (532 thousand metric tons)
- Coated wood containing printing and writing paper (284 thousand metric tons)
- Uncoated woodfree printing and writing paper (925 thousand metric tons)
- Uncoated wood containing printing and writing paper (518 thousand metric tons)
- Household and sanitary paper (319 thousand metric tons)

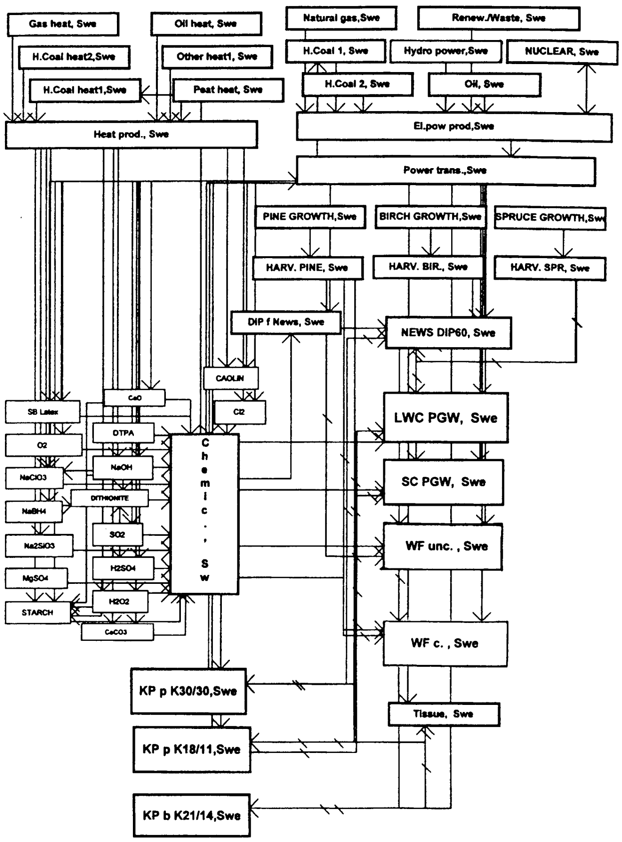

Figure 1.

Emissions are calculated from all elements of the life cycle from cradle to mill gate. The KCL-ECO model would make it possible to calculate inventories from cradle to grave but because the focus of the research is on energy input issues the rest of the life cycle after the mill gate is unnecessary. Inventories begin from tree growth and harvest to transports and industrial processes such as production of cellulose, production of chemicals, de-inking of collected paper, electrical power and heat production, and finally production of paper. Figure 1. shows the life cycle of paper production of main paper grades in Sweden.

MODEL SPECIFICATIONS

The fuel input, specific consumptions, and effluent and waste output figures used for the energy plants and P&P mills in the inventory are based on the average level of present-day technology. No efficiency improvements and changes in technology are assumed for the modelling principle. It is assumed that the furnishing of paper end-products is also unchanged.

Production of the materials needed in the P&P processes (energy and chemical) have been included in the inventory, as have the emissions due to the transport of wood, pulp and paper. Because the focus of the paper is on different energy sources, the rest of the life cycle is assumed to be the same. Production level and production capacity in 2010 is higher than in 1993 and the P&P industry's effluent generation and emissions will consequently also be higher, but this does not have much effect on research results. The focus of the research is namely on effluent generation depending on alternative energy scenarios in which the proportion of paper grades remains constant.

Energy production in the LCA model follows the average fuel breakdown of electricity in Sweden in 1993[5], as shown in Figure 2. Exports and imports of electricity have not been considered in the inventory. The main focus is on electricity alternatives but heating energy is also calculated in the inventories. Data concerning heating energy production represents average heating energy in Sweden in 1993[6].

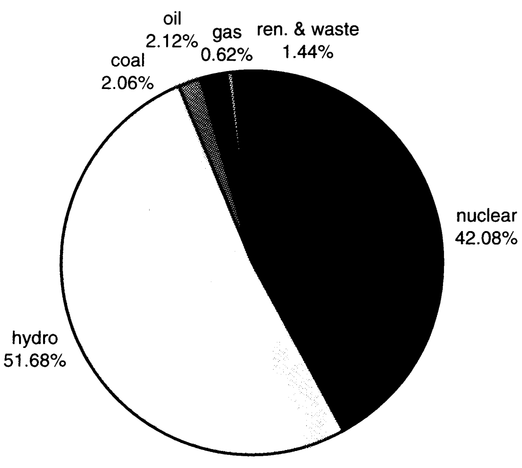

Figure 2.

RESULTS

The results are discussed in terms of air emissions and solid waste. The basis used for the selection of variables includes[7]:

- measurability of all units in the system
- effect on global environmental phenomena
- inclusion in criteria for granting environmental labels

The results are calculated for four different energy scenarios for 1993 and 2010: 1. The current energy fuel structure continues with a share of nuclear power of 42.08%, 2. Nuclear energy is replaced by coal energy with high cleaning technology (reduction of particles by 99% and SO2, wet method, used chemicals Ca/S 1.05, reduction by 80%), 3. Nuclear energy is replaced by coal energy with low cleaning technology with reduction of particles by 90%, 4. Nuclear energy is replaced by natural gas. All the alternatives demand investments, but are feasible development routes.

The scenarios are currently the only realistic alternatives in Sweden. Millions of crowns have been directed for research of alternative energy forms but researchers "have not been able to point to alternative techniques for generation of electricity which are commercially competitive with hydropower, nuclear power or electricity generation based on fossil fuels."[8]

Because of the assumptions and average values in the input data, the results should not be seen as absolute but rather as relative. Validity of the results would be higher if the inventories were calculated for specific plants with exact input data. Despite this it might be very difficult to obtain data from individual plants and the research work involved needed would be a huge amount.

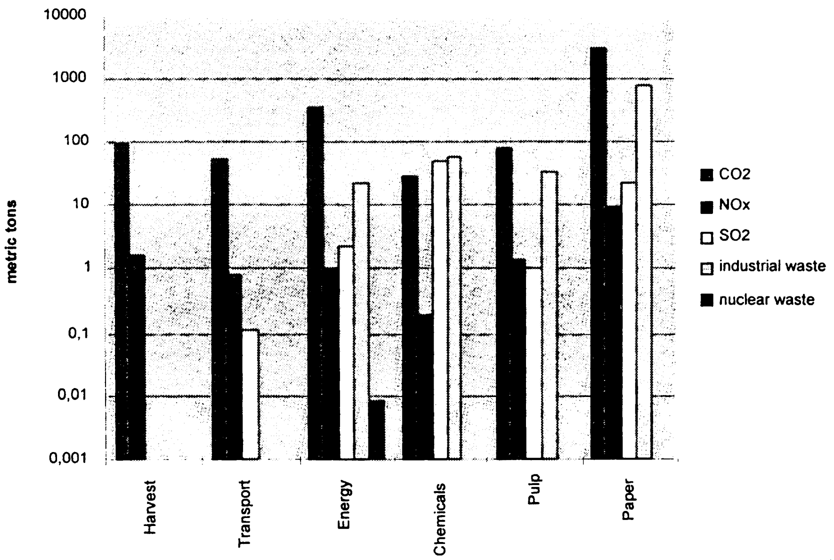

Figure 3.

EMISSIONS AT DIFFERENT STAGES OF THE LIFE CYCLE

Air emissions

Life cycle analysis (LCA) allows one to calculate energy intensity as well as emissions during different stages of the life cycle. Currently Most fossil CO2 and SO2 emissions originate from pulp and paper production but energy production is also an important source. The source of CO2 emissions are displayed in Figure 3. Emissions are calculated for main paper grades of the Swedish P&P industry. For example, the entire process or life cycle, from cradle to mill gate, of main paper grades in Sweden generates yearly 3739,489 thousand tons CO2 emissions and 14,717 thousand tons NOx emissions, etc.

Table 1. Emissions and Waste Production – Units % thousand tons

Thousand tons	Harvet	Transport	Energy	Chemicals	Pulp	Paper	Total
CO2	90.69	52.79	365.65	30.25	80.96	3119.16	3739.49
NOx	1.57	0.81	1.02	0.20	1.39	9.73	14.72
SO2		0.11	2.22	0.36	0.98	22.62	26.29
industrial waste			21.76	55.47	33.35	780.49	891.07
nuclear waste			0.0089				0.0089

The share of energy as an emission source increases considerably if nuclear power is replaced by coal energy (with highly effective filters), or by gas energy. Table 1 shows the share of energy during the entire life cycle in the different scenarios.

Table 2

% % %	Nuclear	Coal 1	Gas
CO2	9.78	35.55	24.08
NOx	6.90	20.96	20.96
SO2	2.87	15.35	8.09
industrial waste	2.44	11.70	1.91
nuclear waste	100	0	0

EFFLUENTS AND WASTE IN DIFFERENT FUTURE SCENARIOS

The production of the main paper grades in Sweden causes annually 8.9 x 10^3 kg of nuclear waste out of a total production of nuclear waste (250 x 103 kg in early 90's[9]). The CO2 and SO2 emissions are relatively low for the moment compared to other industry sectors because of the high percentage of hydro-power and nuclear energy. These have much less air emissions than energy based on fossil fuel power. There are great differences in generated emissions regarding different scenarios (see Table 3). All air emissions increase considerably, except for SO2 emissions in the gas scenario, if nuclear energy is replaced by coal or gas energy.

Table 3

	Nuclear	2010 Coal 1	2010 Coal 2	2010 Gas
CO2	3739.49	5249.15	5249.15	4443.88
NOx	14.72	17.34	21.96	17.34
SO2	26.29	28.44	37.41	26.19
Waste, ind	891.00	984.54	979.86	886.22
Nuclear waste	0.0089	0	0	0

CONCLUSION

An environmental assessment of the inventories presented here requires a separate analysis. However, it can be stated that the basic question is whether it is better to have nuclear waste or increased air and particularly CO2 emissions. The problem is illustrated in Figure 4.

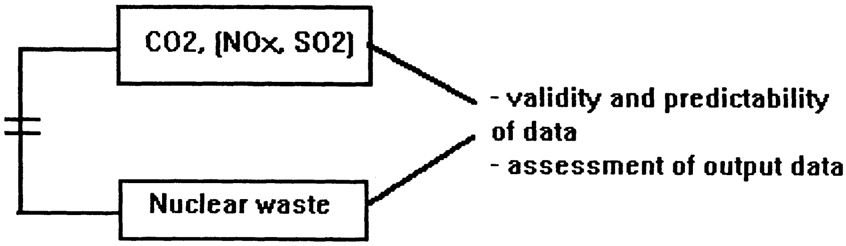

Figure 4

As already mentioned, the output data depends on average values which would create a validity problem if exact results were needed. It is also possible that the scenario that will actually be chosen is a mixture of scenarios presented here or even a totally different scenario.

It is difficult, even naive, to say whether it is environmentally preferable to maintain the production of nuclear waste at the current level or to have up to 40% increased CO2 emissions. The figures can not be compared easily. The issue of nuclear power as well as emissions often includes social values, such as fear of nuclear catastrophes or of global warming, which cannot be measured numerically.

It has to be mentioned, however, that Sweden has signed the Rio Convention which aims for a global reduction of CO2 emissions. In fact in 1992 the Swedish Parliament adopted a target of stabilising CO2 emissions at the 1990 level by 2000. Even if it does not appear to be possible to reach the emission target by 2000[10], the Energy Commission of the Swedish Ministry of Industry continuously "emphasises that Sweden should be active in encouraging the work on international climate policy...to reduce the greenhouse effect, or global warming[11]." In the light of life cycle, inventories, new technology and/or strategies appear to be needed if Sweden wants to follow the direction of the framework of the climate change convention, especially if one of the alternative energy scenarios is chosen.

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