Some Environmental Policy Implications of Recycling Paper Products in Western Europe

Yrjö Virtanen and Sten Nilsson

EXECUTIVE REPORT 22
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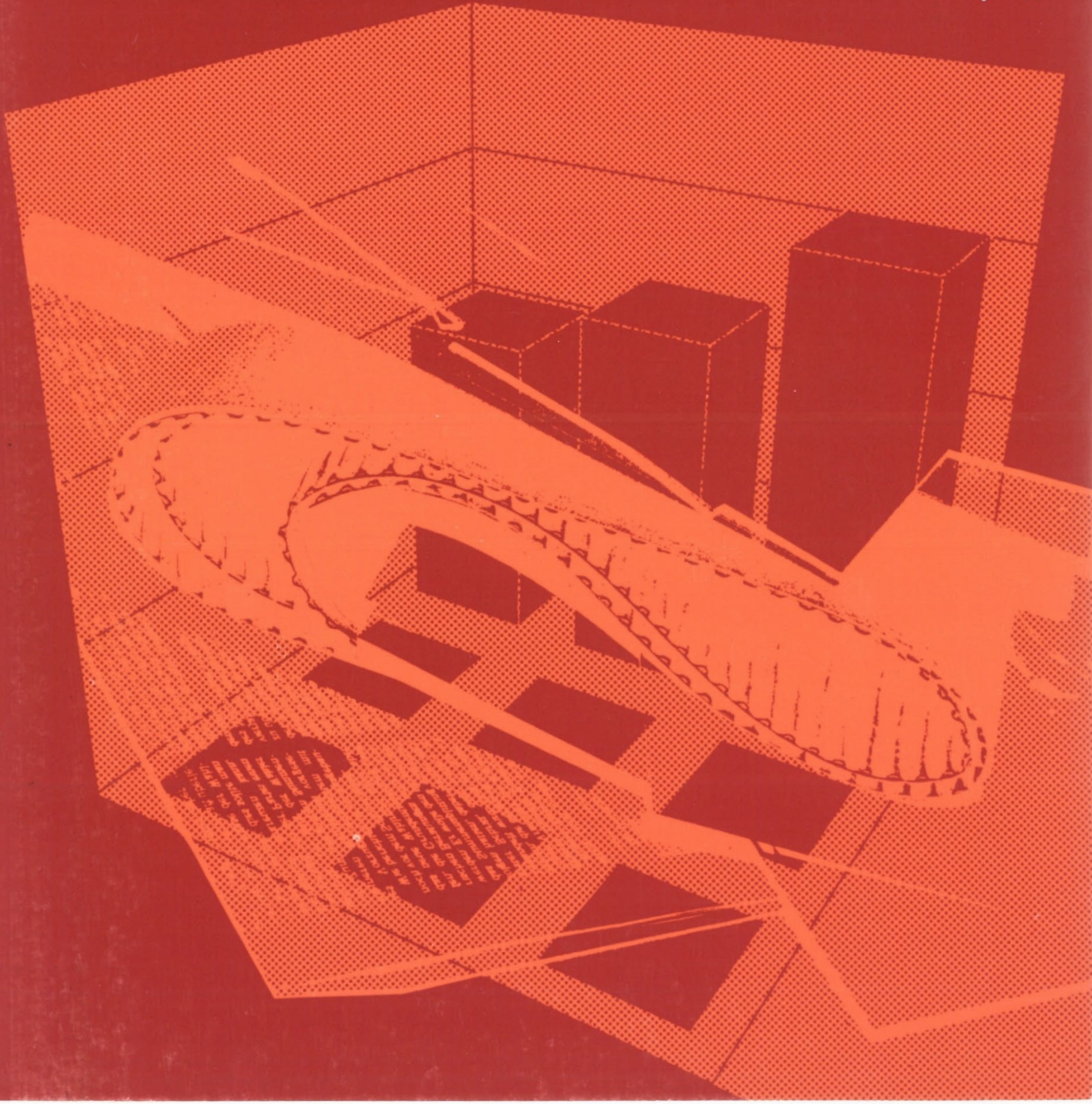

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Preface

We live in a wasteful society, and are becoming increasingly aware of this fact. Our concern for conservation of our natural resources and about the deleterious effects on the environment of disposal of waste products is increasingly reflected in proposed legislation aimed at reducing waste. The preferred technique is recycling of waste products.

While laudable in its objective, a narrow focus on recycling is also limited, and can result in unexpected effects that can at least partially offset the expected benefits. This is particularly true of paper for a least three basic reasons. First, paper is a major component, about 35%, of household waste volume. Second, unlike most waste, paper has a very high energy content. And third, unlike coal or oil, paper is a renewable resource, and in Europe is produced mostly from forests managed on sustainable principles.

This report summarizes a feasibility study of large-scale paper recycling in Europe (Virtanen and Nilsson, forthcoming) which investigated the entire production and disposal process using a "life-cycle" methodology and data base (Lübkert et al., 1991) developed at IIASA. In addition, the feasibility study has also used data and results produced by IIASA's *Forest Resources Project* (Nilsson *et al.*, 1992).

STEN NILSSON
Leader
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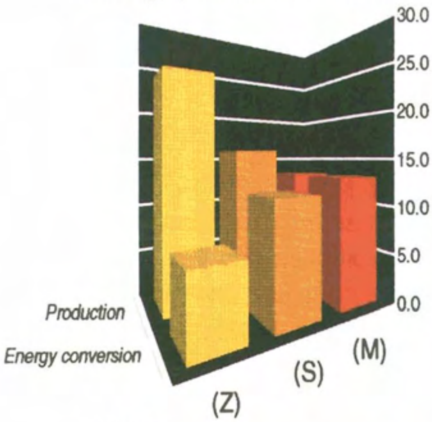
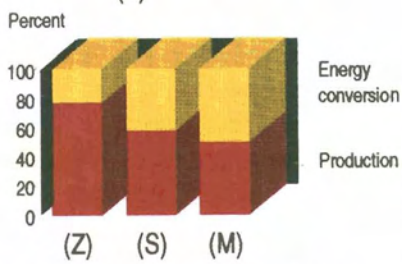
Summary

During the last few years waste generation, together with energy consumption and the connected emissions, deforestation, and global change, has become one of the major environmental issues on the political agenda. Public opinion and legislators have, in response to the debate on recycling, requested the introduction of mandatory recycling systems and certain minimal levels of recycling. Unfortunately, too narrow a focus on the recycling concept of paper products can have limitations in scope, and may, on implementation, generate unexpected effects that can at least partially offset the expected benefits. This is especially true for paper, which is a major component of municipal waste. Since paper has a high energy content and is a renewable resource, the issues involved in large-scale paper recycling systems can be very complex.

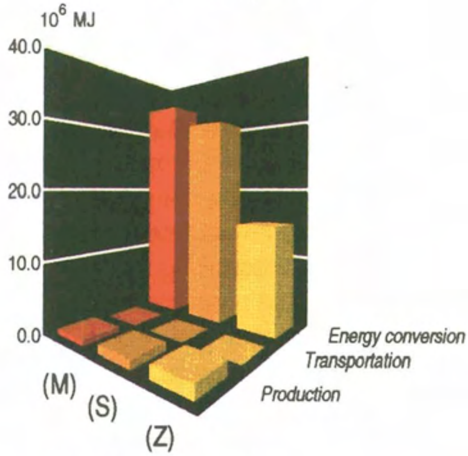
The objectives of IIASA's feasibility study on recycling paper products in Western Europe were to evaluate the applicability of a life-cycle approach to paper recycling, to provide new insights into the complexity of introducing large-scale recycling into existing production and distribution systems, and to broaden the debate with new arguments. In several respects, and up to certain levels, recycling paper seems to be beneficial. However — as often occurs in the case of complex systems with multiple interdependencies and feedback loops — simplified policy actions tend to produce counter-intuitive effects.

Energy production

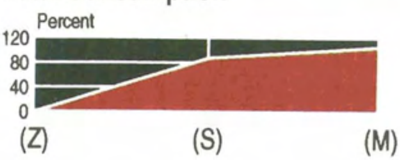




Non-renewable primary energy source consumption



Total consumption



In order to demonstrate more explicitly the consequences of alternative policies on paper recycling, we have chosen two extreme scenarios and one medium scenario as regards the extent of recycling: this means a maximum (M), a selective (S), and a zero (Z) recycling scenario. In the latter scenario old paper is used for energy recovery. The average furnish rate at which recycled fibers were used was 28% for Western Europe in 1986. The reuse rates (based on the furnish) in the selective (S) and maximum (M) scenarios were 35% and 56% respectively.

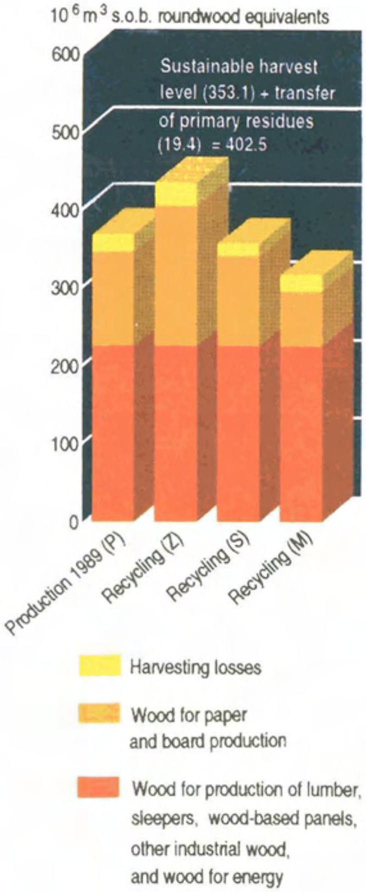
Among the major findings, we illustrate in two adjoining figures the differences between gross energy demand and the net non-renewable energy demand (i.e., fossil fuels consumed) for the different scenarios. The following trends can be identified:

- The gross energy demand is lowest for the maximum (M) and highest for the zero (Z) recycling scenario.
- The opposite is the case for the net fossil fuel demand.
- Thus the opposite is also true for emissions such as SO_2, NO_x, and net CO_2.

As illustrated in the third adjoining figure, the selective and maximum recycling scenarios show a forest utilization considerably below that estimated as a sustainable level for Western Europe. Under-utilization of forest resources may lead to unsatisfactory economic conditions for the necessary forest management, resulting in fewer vital forests and higher vulnerability to natural stress and air pollutants.

The conclusions of the feasibility study, while too preliminary to permit solid quantitative comparisons, indicate that the recycling of paper

Wood balance in Western Europe, 1989



in Western Europe has economic and environmental advantages. However, the renewable character and the high energy content of paper and wood seem to make energy recovery more attractive than recycling under some conditions. Therefore, a balanced mixture of recycling and energy recovery seems to be a suitable solution, since recycling minimizes the use of certain resources and emissions, while energy recovery minimizes the overall use of fossil fuels. The appropriate balance may vary from country to country in Western Europe.

There remain a number of important questions that must be investigated further before large-scale programs for the increased recycling of paper products are introduced. These questions are connected with the fact that the environmental impacts of recycling strongly depend on how far recycling is taken and how selective it is. Also, product performance may be influenced by the percentage of recycled fibers used and thus have impacts on the environmental profile (e.g., increased transportation). Both the degree and the selectiveness of recycling will heavily influence the degree of energy recovery from wood which is appropriate and the possible intensity of forest management. The latter is crucial for the vitality of European forests and for limiting their vulnerability to natural stress and air pollutants.

Background and Objectives

We live in a throw-away society, and much of what we throw into Europe's growing rubbish mountain is paper: paper comprises about 35% of total household waste volume (although a significant fraction of this paper cannot be recycled).

The sheer volume of solid waste, in particular, complicated by limited waste-management resources, has led to changes in consumer behavior, to the introduction of legislation intended to reduce waste volume, and to great improvements in technology in industry. For example, during the past 20 years, despite increased production, the total waste water discharge from paper and pulp production in some Western European countries has been halved, and the total biological oxygen demand (BOD) load reduced to one-third its former value (National Board of Waters and Environment, Finland).

Driven by the anxieties of environmentally concerned citizens, many communities and countries have introduced legislation designed to reduce waste very quickly. For example, the British target is a 50% overall recovery of recyclable household waste by the year 2000 (UK Environmental Protection Act), the German target is 80% by July 1995 (German Dual System regulations), and the EC target is 60% by the year 1996 (Draft Directive on Packaging). In the Netherlands, industry has undertaken to reuse at least 60% of material, so that by 1995 packaging currently going to landfill sites will be reduced by 60% (Environmental News, 1991).

Targets for materials recovery are set, in particular, to provide substitutes for primary materials in the manufacture of goods. But recovery of materials as substitutes for fuels in energy production is presently often excluded from political recovery plans, even though the development of incineration technology and reduction of heavy-metal, chlorine, and other contaminants in wastes might be an essential future strategic alternative.

One of the main arguments behind the popularity of planning materials recovery from the starting point of "closed loop recycling" is the general belief in the overall reduction of environmental load through recycling. Obviously, recycling is a means of reducing waste streams and, accordingly, reducing the demands for waste-treatment capacity. But, on the other hand, recycling may also have the opposite effect of increasing demand for resources. The facilities and activities required for managing recycling, and the need to add material to compensate for quality degradation, all consume energy and materials.

Paper differs from other basic materials in Western Europe (and also in the rest of the world) in several fundamental ways. First, paper originates from a renewable source. Second, it possesses a high energy potential. Third, because of geo-climatical circumstances, the centers of consumption and raw material sources are far apart. Because of renewability, the application of the principle of sustainability to paper should be focused on managing the wood balances rather than overall minimization of the use of raw wood material. In addition, the energy potential of paper should be taken into account as an alternative to non-renewable energy sources. Utilizing the heat potential of waste paper represents both an essential way of saving non-renewable resources and minimizing solid wastes.

The objective of an efficient material production and recycling scheme should be to minimize the resource utilization and emissions of all streams of materials from "cradle" to "grave". When searching for such an optimal scheme, it is necessary to consider many different alternative arrangements for material management, because the advantage gained in one respect might easily be lost in another. One of the cornerstones of such considerations should be, rather than intuition, an objective and comprehensive impact inventory of the alternatives.

The objective of the IIASA feasibility study on recycling paper products in Western Europe was to demonstrate and evaluate the applicability of the life-cycle approach and methodology to the paper recycling problem and, from this starting point, become involved in and introduce new arguments into the debate on material management strategies and the concept of sustainability: to present reasons to question the arguments of the public debate about the recycling of paper products, rather than provide evidence verifying or disproving them.

At this stage, the preliminary nature of the data used for inventories and the lack of refinement in the model of the recycling system do not allow solid quantitative analyses, evaluations, or comparisons. An essential objective of a planned full-scale study at IIASA on the recycling of paper products in Western Europe is to collect new data and refine the model to such an extent that even quantitative evaluations will be relevant and justified.

Methodology

The methodology used in the IIASA feasibility study on recycling paper products in Western Europe is life-cycle analysis (LCA). The principle of life-cycle analysis implies that products, activities, or even entire economic sectors are analyzed from an end-use perspective. The life-cycle approach makes it possible to quantify the cumulative impacts that a product generates from the point where materials and energy for this product are extracted from nature, up to either a certain point in the product's life-cycle or, in the most complete case, the final disposal of the wastes, i.e., when they are returned to nature. The processes that the emissions and wastes undergo in nature should be included, but, at present, these processes are disregarded in the analyses because of their complexity.

Life-cycle analysis has its roots as far back as the early 1960s. At the World Energy Conference in 1963, Harold Smith published a report on the cumulative energy requirements for the production of chemical intermediates. In the late 1960s and early 1970s, several researchers undertook global modeling studies in which they attempted to predict how changes in population would affect the world's total mineral and energy resources (e.g., Meadows *et al.*, 1972; Mesarovic and Pestel, 1974). Around the period of major world oil crises in the mid- and late 1970s, the United States commissioned about a dozen major "fuel cycle" studies to estimate the costs and benefits of alternative energy systems. Later, similar studies were commissioned by both the US and British governments on a wide range of industrial systems. In 1985, the Commission of the European Communities introduced a "Liquid Food Container Directive" (CEC, 1985) which charged countries with monitoring the raw material and energy consumption, as well as the amounts, of the solid waste they generated. As concern about global air and water pollution problems increased, these emissions were then also routinely added to energy, raw material, and solid waste considerations.

In the traditional approach of environmental impact analyses, the industries or industrial sectors themselves are studied and their impacts are implicitly taken as representative of the products. Although in most cases the traditional approach gives a rough estimate of the product's impacts, it does not identify all sources of pollution associated with this product and, in many cases, may not even identify the largest or major sources of environmental degradation. For this reason, the traditional approach is not comprehensive enough to identify all possible strategies for reducing a product's environmental impacts.

Although life-cycle analyses identify the amounts of known pollutants from the production systems studied, they cannot, and should not, without further interpretation, be used to compare these production systems with regard to their environmental toxicity. One can readily compare different production systems with respect to the amounts of identical pollutants they generate, but one cannot deduce from life-cycle analyses whether or not one specific pollutant, or a group of pollutants, is more harmful to the environment than another.

Another potential weakness of life-cycle studies is the tremendous amount of data required. It is extremely difficult to document clearly and understandably all the data and assumptions that go into the final results of any life-cycle analysis. If different studies of the same products, however, come up with different final results, one should be able to trace these discrepancies back to the different assumptions made. This is only possible if all base data are accessible and well documented as regards their sources.

In the first place, *life-cycle analysis is an inventory method* and, as a result, generates a long list of substances that are either:

- *produced* by the system studied either as *useful products* or *wastes* discharged into the environment; or
- *consumed* by the system studied either in *material* or *energy* form.

In order to use these results for policy decisions, these lists of substances need to be interpreted and, in general, reduced to a limited number of factors. Some researchers consider this step to be part of the life-cycle analysis itself, whereas others refer to it as the *ecoprofile analysis*. This reduction can be done by:

- *using* one or several of the individual substances as *indicator(s)* of the overall impacts; or
- *aggregating* these lists *into limited numbers of substances*, such as
  - total material requirements;
  - total air emissions;
  - total water emissions;
  - total solid waste discharges; and
  - total environmental costs.

Both methods involve *value judgments*. In the first case, representative indicators have to be selected; these almost always depend on the goals set by the person studying the respective production system. For example, if the main objective is to reduce the amounts of solid waste generated, the representative indicator(s) will be different than if the goal is to limit the release of toxic substances into the environment. In the second case, data for different substances have to be added together into one, or several, still meaningful, numbers. This requires a value judgment on the comparability of these various substances and on their relative harm to the environment. Even environmental costs can be seen as a subjective issue, although they could also be approached, in part, from the techno-economical aspect of "reduction" costs.

Therefore, when discussing life-cycle analysis it is very important to differentiate between:

- *an inventory and quantification of the impacts; and*
- *interpretation of results in order to answer policy questions.*

Life-cycle analyses are used to quantify and compare stresses on the environment caused by alternative products or by different production systems and technologies making the same products. In the same way, the method can be used to compare the impacts of entire industries, economic sectors, and even total national economies. The information can then be used in ecoprofile analysis to help address a number of technical and political issues in several areas, such as the following.

Comprehensive environmental impact assessments

- What are the life-cycle impacts generated by a certain product and how do different products compare?

Environmental labels

- LCA can furnish a quantitative basis for awarding labels for environmentally benign products (eco-labels).

Assessment of industrial processes' efficiencies

- The information can be used to calculate energy and material usage efficiencies within a given economic sector or activity and identify possible areas of improving those efficiencies.

Evaluation of policy alternatives to minimize environmental impacts

- One can assess the impacts of possible alternative environmental regulations through the analysis of different scenarios in order to find the best regulation.

Comparison of environmental performance

- How do different countries compare in their environmental performance in certain economic sectors?

International negotiations on environmental policies

- LCA can be used to assess and compare the systems' efficiencies for different geographic regions or countries, in order to detect potentials for improvements.

Optimization of policies for the eco-restructuring of economies

- LCA provides a tool for evaluating alternative ways of restructuring a national energy system in an environmentally sound manner.

The IIASA feasibility study on recycling paper products in Western Europe, however, has been limited to demonstrating the general justification for and possibilities of LCA methodology only. The impact inventory is based on preliminary data and rather rough assumptions about the recycling system. Accomplishing a comprehensive assessment is a major task that requires resources far beyond those available for this study. Nevertheless, the inventory results from the study under discussion still offer a factual basis for introducing new arguments into the debate on recycling paper products.

Problems of Paper Recycling in Western Europe

A general problem with paper recycling in Western Europe is that production sites for pulp and paper and pulp and paper consumption sites do not coincide. Therefore, it becomes necessary to build up transportation networks between producers and consumers. A production facility relying mostly on recycled materials could, however, be placed near the major consumption centers instead of major sources of primary wood raw material. These considerations indicate one degree of freedom in the search for optimal production and recycling structures.

It is also important to include forestry in life-cycle studies. It is quite normal to start impact assessment by taking logs felled as the 'raw material'. The forestry cycle, however, has a significant influence on the CO_2 balance and, therefore, it is essential to include it in the system studied.

A scenario with large-scale paper recycling immediately includes the option of regional (and international) restructuring of the existing pulp and paper industry. Because of the large, new investments needed for reused pulp production, and also the large, existing investments in primary pulp production facilities, the change-over to large-scale paper recycling could be anticipated to take a long time and to encounter economic and political difficulties.

The restructuring aspect of the current industry has been omitted, however, in this study due to the complexity of the problem, even though it has potential significance for the overall environmental impact. Primary pulp production, for instance, could be expected to become, for the most part, separated from paper production. This would mean increased use of market pulp and, accordingly, increased energy consumption because of intermediate drying and diluting. In this IIASA feasibility study, the production structure is assumed to remain as it is now for the different scenarios produced. However, aspects of the changing production structure and locations will be among the topics which will be addressed in the planned full-scale study on recycling of paper products in Western Europe.

Large-scale paper recycling would also have a fundamental impact on European wood balances and, therefore, on the possibilities of practicing sound forestry in the region. About 80% of the raw wood material used at the end of the 1980s in Western Europe's pulp industry was in the form of pulp-logs (UN, 1991), the predominant part of which originated from forest thinnings. If increased recycling were to cause the raw wood demand to sink significantly under the biological harvest potential, maintaining silvicultural standards and the vitality of forest resources in Western Europe could be difficult. It can be argued, on the other hand, that the thinnings not used by the pulp industry could be used by the mechanical wood industry. This is, however, unlikely to occur due to the fact that the mechanical industry's paying capacity for pulp-logs is much lower in comparison with the pulp industry.

An interesting question related to paper recycling strategies is the economic potential of waste paper in paper and energy markets. For some national economies it could be more profitable to use waste paper for energy production than to use it as raw material for domestic paper production or export it. Depending on the proportion of wood fibers, the heat content of waste paper is 14–17 MJ/kg, which makes 1 ton equal to about 0.4 tons of oil. We cannot, at present, generalize the relative advantage of recovering waste paper for its energy versus its fiber value, since the most economical utilization of waste paper depends on which fuels it would replace and what kind of paper could be produced from it. Such calculations can be made in the planned full-scale study on recycling of paper. However, it should be pointed out that waste paper for energy would be a clean source of energy if some of the raw materials in the paper, board, and printing processes (chemicals and heavy metals) were replaced with other more benign materials. For some production processes and paper products this transition has already begun.

There are also technical limitations to large-scale recycling. Fibers degenerate each time they are reused, which limits the number of reuse cycles to between three and five. On the other hand, a sizable proportion (20–25%) of paper is used for purposes that make recycling impossible or infeasible. Papers belonging to this group are, typically, sanitary and food parchment papers, for hygienic reasons, and construction and archive papers from a life-span point of view. Another limitation to using recycled fibers is the mixture of brown and white, respectively chemical and mechanical, fibers in the collected wastepaper. In addition, different kinds of contaminants in the wastepaper mixture may not be easy to remove in the recycling process.

From an environmental point of view, the impact of recycling on greenhouse-gas emissions is an important issue to be considered. What are the consequences if wood balances (the yearly increment in relation to the yearly harvest of wood) become largely positive? How do the greenhouse-gas emissions (CO_2 and CH_4) from the natural cycle of the surplus wood compare with incineration emissions? These questions could not be studied in the current feasibility study but are to be evaluated in the planned full-scale study.

Another question which needs to be studied in more detail later is the disposal of the sludge from repulping. Non-fibrous materials need to be extracted from waste paper in order to avoid contamination in paper produced from the reused pulp. Thus, the sludge is contaminated with different paper additives and therefore may introduce problems on disposal in landfill sites or by incineration.

To identify the outer boundaries for paper recycling in Western Europe and its implications three different scenarios were selected under the conditions and limitations discussed above. The three scenarios have been intentionally selected to represent the two possible extremes of recycling of paper products, with a reasonable midway alternative to illustrate flexibility between the recycling strategies and their environmental impacts. These scenarios may not represent realistic future visions but they still serve the primary purpose of demonstrating the scope of sensitivity of the environmental impacts of different recycling strategies. The scenarios are as follows:

(M) maximum and equal share of recycled fiber for all paper and board qualities

(S) maximum selective use of recycled fiber, with easy-to-use waste paper grades and geographical availability as the selection criteria

(Z) no recycling and maximum energy recovery of the fibers.

In the **maximum recycling scenario (M)**, a certain percentage of the waste paper is assumed to be collected and used as raw material for recycled fiber forming an equal relative share of the furnish in all paper and board qualities. The collection percentage is assumed to be the highest possible (90% for most of the qualities). The assumed overall average furnish share for the reused pulp is 56% for all paper and board grades, compared with about 30% today. These estimates are based on rough balance calculations for Western Europe. Although such an average furnish share is not realistically possible today due to technological constraints, the objective of this scenario is to illustrate one of the extremes of paper recycling. The waste paper supply is assumed to be based on Western European domestic markets. Waste paper imports from other parts of the world are assumed to be minimal. Re-pulping technologies are assumed to be available, with de-inking, separation of non-fibrous materials, refining, and screening of the recycled fiber carried out to such an extent that the pulp matches the fiber property demands of each paper quality. The disposed part of the waste paper is assumed to be incinerated (26%) and landfilled (74%), the figures in brackets being the averages in Western Europe today.

In the **selective recycling scenario (S)**, the criteria for the waste paper grades and the respective paper qualities they are used for are the simplicity of fiber recovery and the availability of waste paper. Simplicity of recovery means that there are existing and feasible technologies for fiber recovery and that there would be no significant decrease in the quality of the papers caused by furnishing them with recycled fiber. The availability factor means that the waste paper could be collected inside a reasonably compact area, i.e., within a range of 150 to 200 km. Long-distance transportation of waste paper is assumed to be minimized. The disposed part of the waste paper is assumed to be incinerated and landfilled in the same proportion as the previous scenario (26% and 74% respectively). The overall recycling rate (based on the furnish) in this scenario is 35%, which is about 5% higher than today's rate of 30%.

The **zero recycling scenario (Z)** represents an alternative strategy with the maximal energy recovery of paper fibers. In general, energy use is the most important factor when considering environmental impacts. The use of paper waste for energy production reduces solid waste streams and saves fuel. It might also reduce overall direct emissions from energy production into the air and water, because of the relatively high emission protection level of incinerators, depending on the mixture of the substituted fuel. Energy production that is assumed to be substituted for incinerator output in this scenario is assumed to follow the current average profile for Western Europe. The disposal pattern for the zero recycling scenario is 100% incineration and 0% landfill, i.e., it is assumed that all the disposed waste paper is burned.

The data used for the inventories are basically the same for all scenarios. The majority of the data, the main sectors comprising basic production, transportation, energy conversion, and waste management, comes from IIASA's IDEA database (Lübkert *et al.*, 1991). These data were collected during the past two years from industrial and official statistical sources and, in practice, represent the current state-of-the-art in Western Europe. The rest of the data, needed to build up a description of the Western European paper product system, were obtained from the latest available OECD statistics (statistical year 1986), and processing data were obtained from individual industrial sources. Since the scenarios, however, partly involve assumptions that do not correspond to the present technology sphere, the data for those parts are estimates, but they are still realistic for the needs of the primary objectives of this feasibility study.

Impacts Studied

For each of the three scenarios the following environmental impact indicators were calculated.

Energy demands

- electric power
- heat.

Non-renewable fuel demands

- hard coal
- brown coal
- derived coal
- middle distillate
- light fuel oil
- heavy fuel oil
- natural gas.

Raw material demands

- common raw materials.

Consumption of primary energy sources

- coal seam
- crude oil
- hydro power
- nuclear fuel
- crude natural gas
- biomass of trees.

Air emissions

- CH_4
- SO_2
- NO_x
- CO
- CO_2

Water emissions

- total suspended solids (TSS)
- biological oxygen demand (BOD)
- chemical oxygen demand (COD)
- chlorinated organic compounds (AOX).

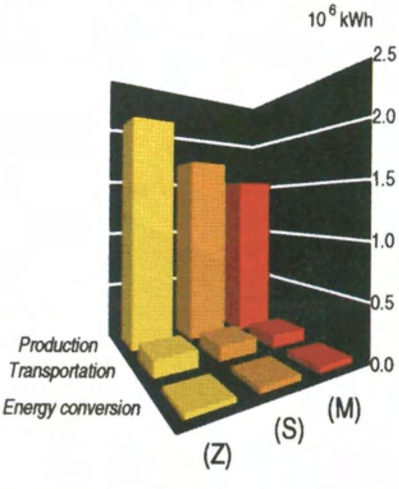
Solid wastes

- gross municipal wastes (output from the life-cycle)
- terminal municipal wastes (in landfills).

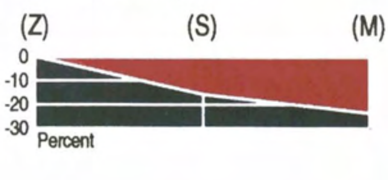
One criteria for selecting the impacts listed above was that they are the most commonly referenced factors in the political discussion on environmental impacts. On the other hand, they are also most consistently represented in the IDEA database (Lübkert *et al.*, 1991).

Scenario Results

Electric power consumption



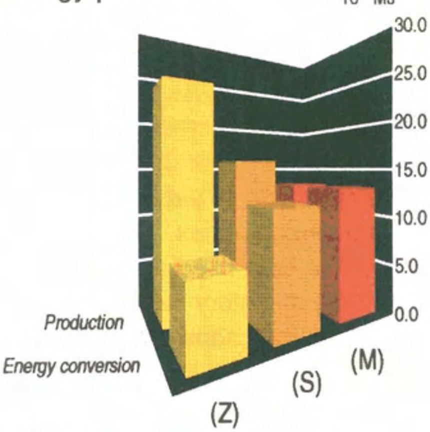
Total consumption

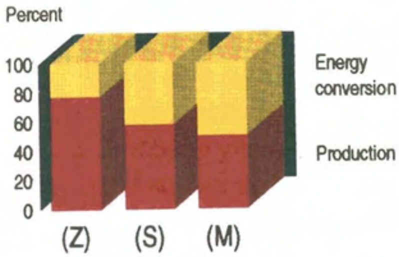


The following scenario results do not cover all of Western Europe but refer to Austria, Finland, France, Italy, the Netherlands, Sweden, the United Kingdom, and former West Germany. All the figures are given per kton of paper and board consumed in these countries. Due to the preliminary nature of the data used and the simplified approach, the inventory results must be interpreted with care; they show only the possible trends of environmental impacts with respect to recycling. In general, several of the environmental impact trends seem to be decreasing with increased recycling, but contraventional trends can also be seen.

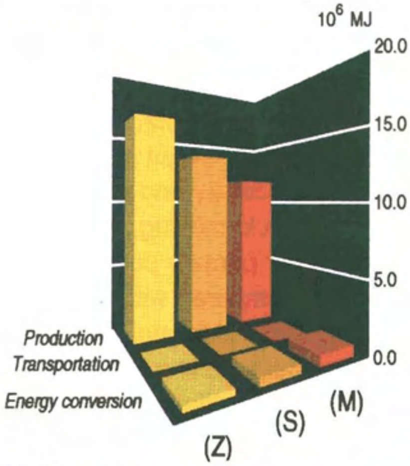
The trends for gross **electric power** and **heat** consumption are linearly descending with increased recycling. The overall demand for electric power, also for heat and steam, is about 25% less for the maximal recycling case compared with the zero recycling case. For the selective recycling scenario the consumption is about 15% less than in the zero recycling scenario. The descending direction of the energy requirement reflects the differences in specific energy requirements between primary and reuse pulping. The electricity and steam consumption for chemical pulp making, which is the dominant technology for primary pulp making, is relatively high compared with the re-pulping of waste paper. The additional energy consumption for primary pulp making is mostly covered by energy internally produced from burning black liquor and bark. The shift from wood-based energy in the production sector to fossil-fuel-based production in the energy conversion sector increases with increased recycling. In the zero recycling case about 80% of the total energy is based on wood, compared

Energy production



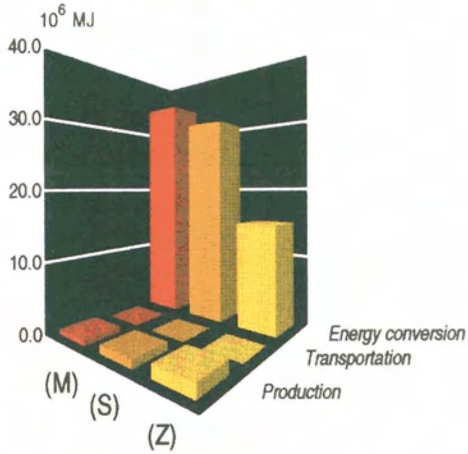


Heat and steam consumption

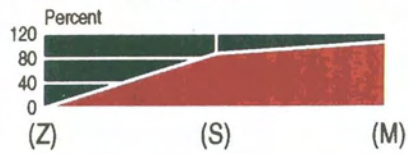


Total consumption

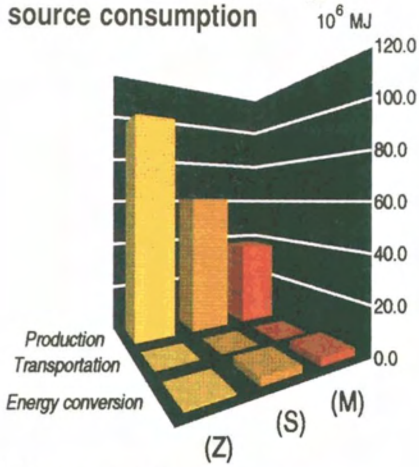
Non-renewable primary energy source consumption



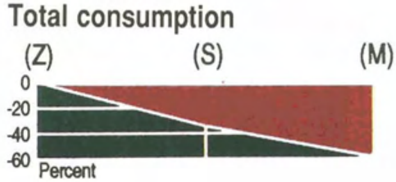
Total consumption



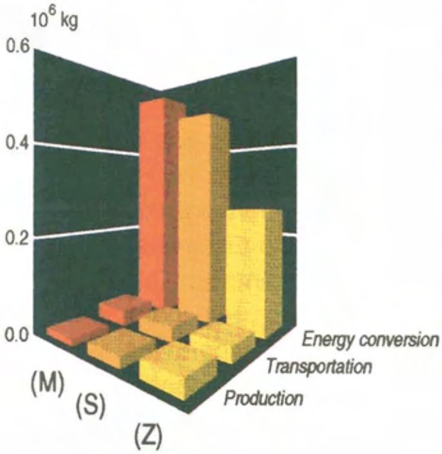
Renewable primary energy source consumption



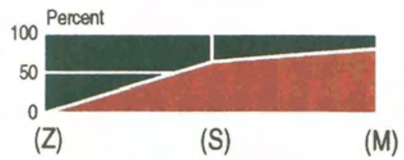
Total consumption



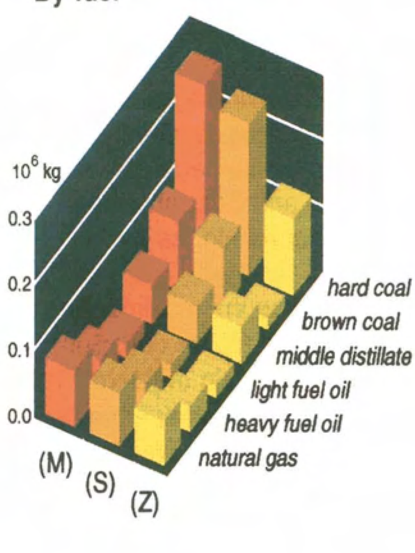
Fossil fuel consumption



Total emissions



By fuel

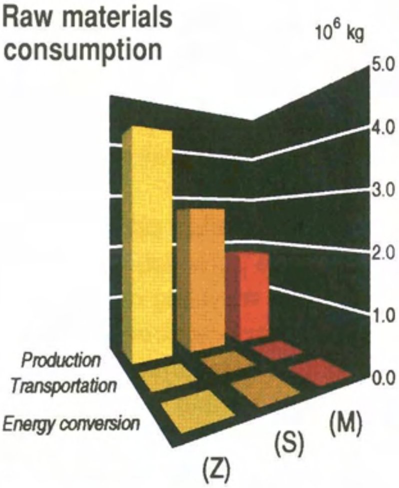


with only 45% in the maximal recycling scenario. The reduction trend in the total energy consumption is dominated by the production sector. Energy conversion and transportation have only marginal roles in the overall energy demand.

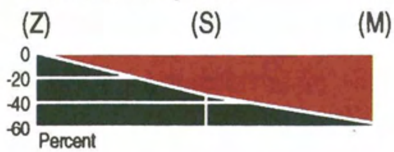
The demand for **non-renewable primary energy sources** (heat value potential) is about 100% larger in the maximal recycling case, while renewable resources are required about 60% less in this scenario in comparison with zero recycling. The reason for this is the substitution of bark and soda boiler steam and cogenerated electric power, which are renewable energies, by coal, natural gas, and other non-renewable fuel-based types of energy in the maximal recycling case. In the zero recycling case, on the other hand, most of the heat value potential of used paper is assumed to be utilized in the incinerators, which naturally lessens the demand for the rest of the actual energy conversion sector. In the maximal recycling case, a prominent part of the recoverable heat value of waste paper is assumed not to be utilized, i.e., tombed in landfills.

Because of increased demand for transportation and energy conversion with increased recycling, the overall **fossil fuel** (mass) inputs are about 75% greater in the maximal recycling case compared with the zero recycling case. The major relative growth can be seen in hard coal, brown coal, and diesel fuel for transportation. The prominent increase in coal fuels is due to the substitution of wood-based energy production (from residues), which decreases more than the overall energy demand decreases with recycling. Also, the assumption in the zero recycling scenario of a comprehensive incineration of waste paper has a

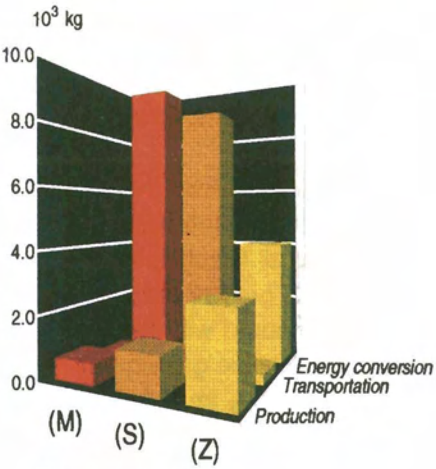
Raw materials consumption



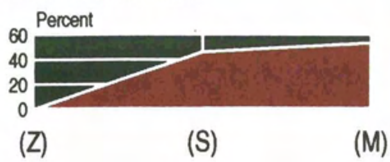
Total consumption



SO_2 emissions



Total emissions



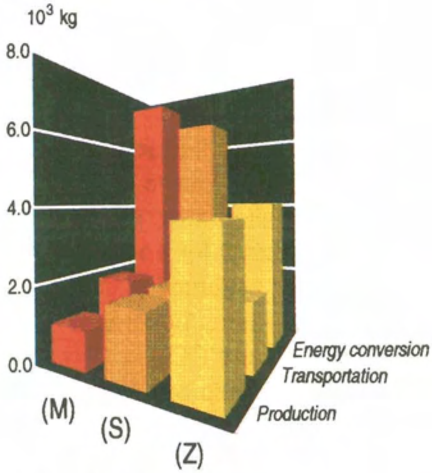
substantial influence on the relative figures of increased use of coal fuels. So the zero recycling case well illustrates the potential of trying to maximize renewable, wood-based energy and to minimize fossil fuel consumption. Based on the life-cycle model runs, the main factor which causes an increase in the transportation demand is the transportation of waste paper over considerable distances, e.g., from Central Europe to Scandinavia. On the other hand, the reduction in log transportation counterbalances the overall transportation demand so that the total growth in energy required for transportation is rather insignificant.

Consumption of other **raw materials** prominently decreases with recycling. The amounts of raw materials (except wood) needed for wood pulp making (limestone rock, salt rock, etc.) are reduced by about 60%, following the ratio of the primary fiber quantities. It should be noted, however, that the calculations do not trace all material streams classified as raw materials because of the absence of data in the IDEA database. This distorts the figures for some specific raw materials. For example, the raw materials needed for de-inking agents are not included in the resulting figures. On the other hand, the predominant volume of raw materials consists of water and CO_2, any other material has only a marginal role in the overall raw material consumption.

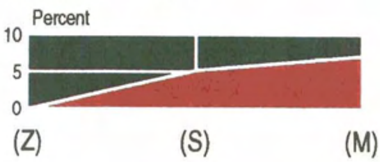
For the main **air emissions** the maximal recycling case gives significantly higher emissions of SO_2 (53%) and NO_x (7%) than in the zero recycling scenario. On the other hand, emissions of other gases are significantly smaller in the maximal recycling scenario; CH_4 (–50%), CO (–30%), and gross CO_2 emissions (–45%).

The growth in **SO_2 emissions** in the maximum recycling scenario is explained by an

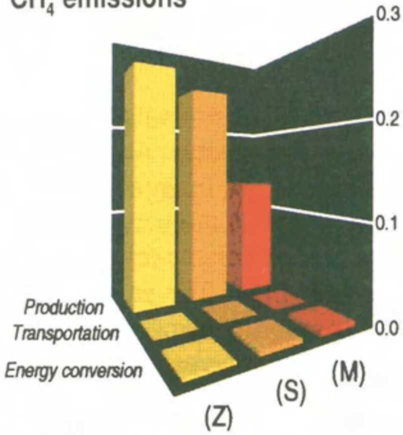
NO_x emissions



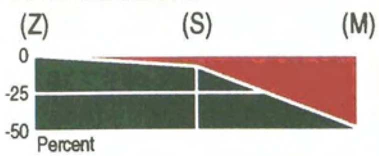
Total emissions



CH_4 emissions



Total emissions

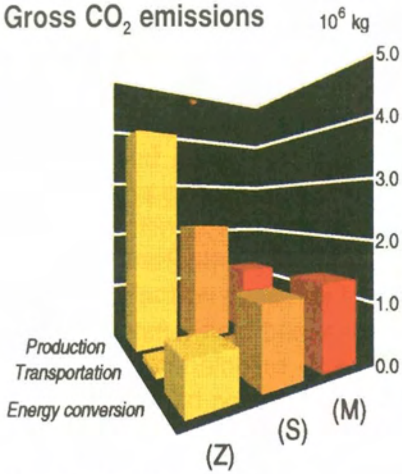


increase in hard and brown coal combustion that replaces the combustion of wood-based fuels (bark, black liquor, and waste paper). The average sulfur content of these fuels is higher than that of wood-based materials. Sulfur emissions from primary pulp-making processes, other than combustion, are less significant.

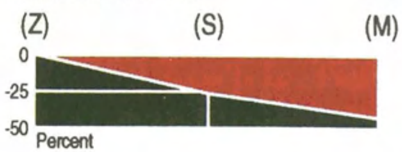
Also, the increase in **NO_x emissions** is due to the replacement of wood-based fuels. An increase in natural gas, and high-temperature combustion in general, is reflected in an increase in NO_x. Transportation has a noticeable role in NO_x emissions, but is less important as regards the general trend because there is no essential difference in total transportation requirements between different scenarios. This is perhaps surprising in view of the long distances involved in the assumed waste paper transportation from Central Europe to Scandinavia in the maximal recycling case. It should be noted, however, that the figures for transportation emissions only include direct emissions from vehicles. Thus, emissions given out during the production of electricity needed for electric trains is excluded from the transportation emissions figures. A logical explanation of the trends in transportation requirements lies, also, in the ratio of the specific demand for logs with respect to waste paper per final output. For a ton of chemically produced primary fiber, the mass of logs needed is roughly four times greater compared with the mass of waste paper required for reuse pulp. Thus, a decrease in the volume of logs transported compensates for the longer distances over which waste paper must be transported.

The main factor explaining the differences in the **CH_4 emissions** for different scenarios is the decomposition of harvesting wastes. Harvesting

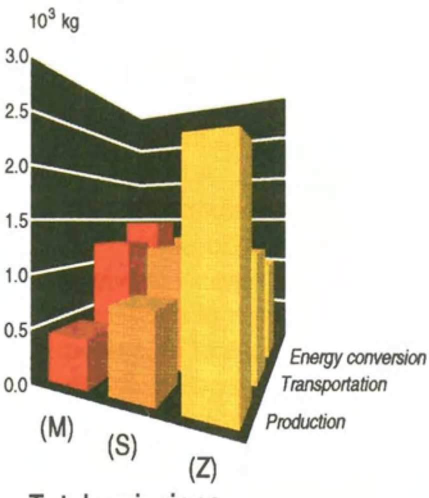
Gross CO_2 emissions



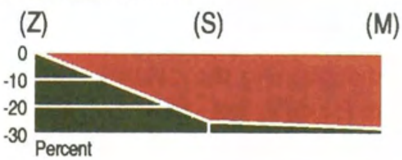
Total emissions



CO emissions



Total emissions

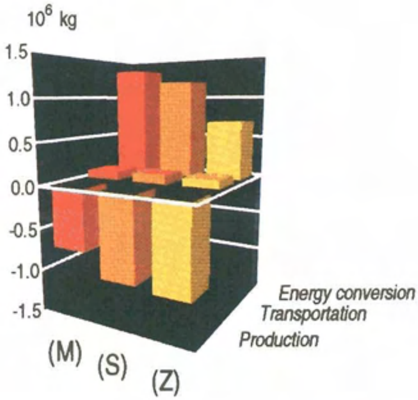


wastes represent about 35% of the total biomass of trees. This represents roughly the same amount of organic matter as the cellulose fibers in 65% of the biomass taken out as logs to the pulp mills. In each scenario, all harvesting wastes are assumed to be left in the forests where they decompose in four to five years into CH_4 and CO_2. An alternative would be to collect the waste and burn it for energy production. Under the former assumption, decomposition of harvesting wastes becomes the predominant factor in CH_4 and CO_2 emissions — the more primary pulp required the greater the harvesting wastes and, eventually, decomposition gases. The estimate is rough because the natural decay in unmanaged forest has been taken into account in a simplified manner and data available on the carbon cycle are limited. An interesting and important aspect related to this is how the life-cycle of the forests, and thus different silvicultural practices, influences more precisely emissions of the gases. This could not be studied in this feasibility study, but will be considered in the planned full-scale study.

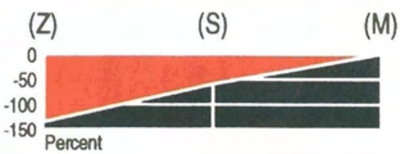
The reduction of **gross CO_2 emissions** depends on the transfer from carbon-rich (wood-based) to less carbon-rich fuels (natural gas, hydro power, nuclear power) in the overall energy production of the total cradle-to-grave system between the scenarios. The same explanation can be given for the similar CO emission trend, even though harvesting with small, two-stroke chain saw engines makes a noticeable contribution to it.

However, when the formation of wood biomass (forest growth) is included in the considerations, the CO_2 trend may be reversed. The calculated **net CO_2 emissions** are negative for the production sector in all scenarios

Net CO_2 emissions



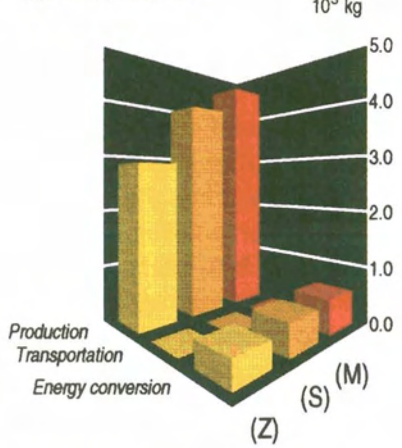
Total emissions



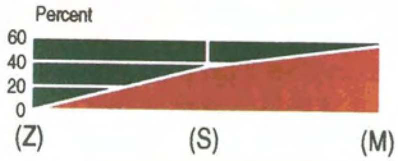
(meaning that a fixation of carbon takes place). For the zero recycling case the overall net emissions are −150% of the maximal recycling case. This can be explained by the carbon balance of paper production and consumption. Out of the total amount of carbon fixed in the wood biomass, 35% is returned into the atmosphere through the decomposition of harvesting wastes. Roughly 50% of the carbon decomposes into methane. Of the rest of the biomass travelling to pulp mills in the form of logs, roughly 50% ends up in paper after chemical pulping. The other half is burned in bark and black liquor boilers to form carbon dioxide. About 20% of the carbon in paper ends up in archives or is exported out of Europe. About 25% of European waste paper is burned and the rest tombed in landfill sites where eventually about half of it decomposes into CH_4 and another half into CO_2.

The reason why the zero recycling case appears to have less overall CO_2 emissions is obvious under the assumptions described above about the carbon balance. In the selective, and even the maximal, recycling case, the landfilled part of the waste paper releases, in a slow 'burning' process, its heat potential and carbon into the environment. In the zero recycling scenario the burning takes place in boilers and the released heat is used as a substitute for heat produced, to a large extent, with fossil fuels. Thus the total CO_2 emissions are reduced by the amount corresponding to the substituted fossil fuels. In spite of the apparent simplicity in the current carbon balance, however, there are a number of open questions left to be studied, such as the paper streams leaving Europe, the role of archive or other long-term papers, and, eventually, the life-cycle of forests and a sustainable utilization of forest resources.

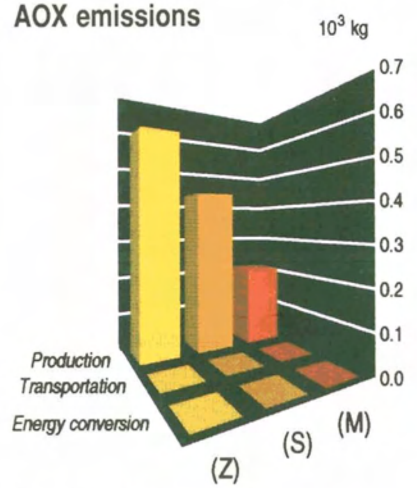
TSS emissions



Total emissions

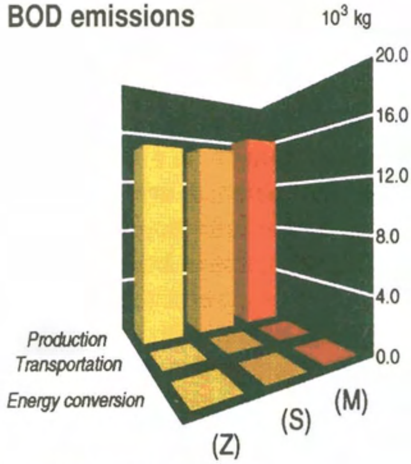


AOX emissions

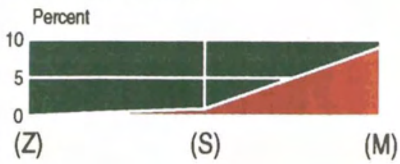


Total emissions

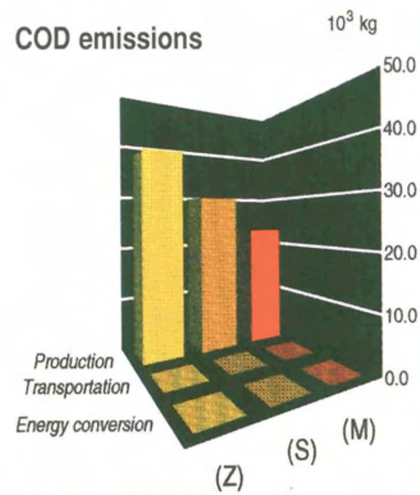
BOD emissions



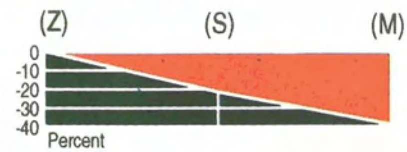
Total emissions



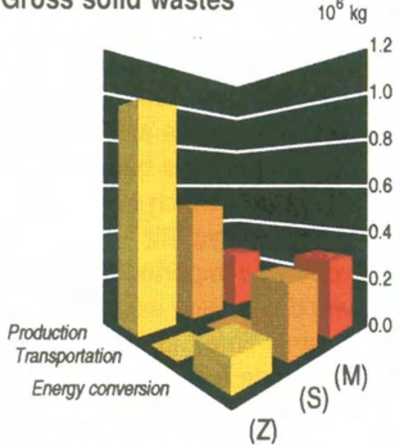
COD emissions



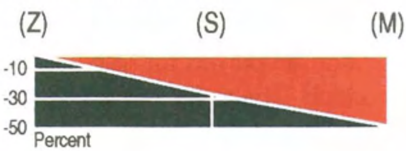
Total emissions



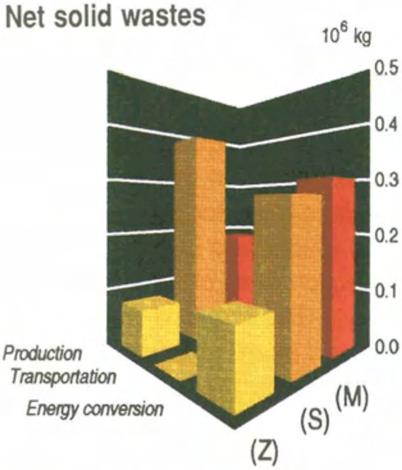
Gross solid wastes



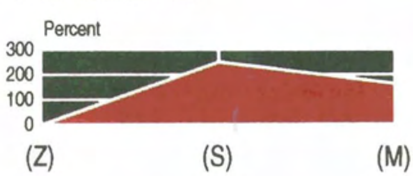
Total emissions



Net solid wastes



Total emissions



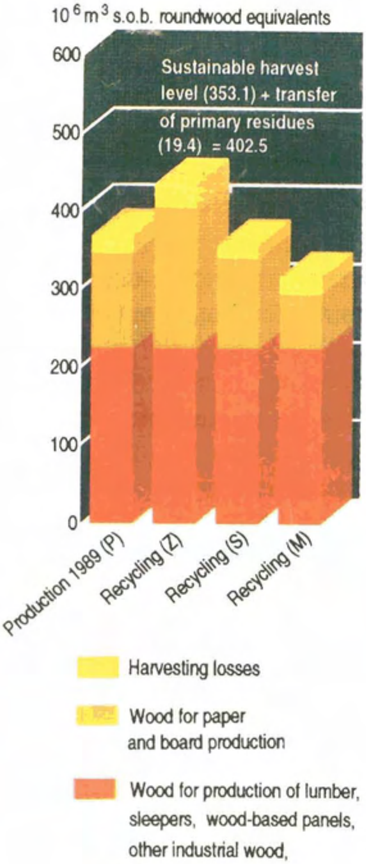
For **water emissions** a similar fluctuation in trends can be seen to that of air emissions. Total suspended solids (TSS) are about 70% and the BOD about 10% greater in the maximal recycling case compared with the zero recycling case. On the other hand, COD and AOX emissions are significantly smaller. However, there are no acceptable explanations for all fluctuations and therefore one should be careful not to draw any further conclusions from this. The water emission data needs to be updated to give more reliable results; for instance, the AOX emissions from reused pulp production should be investigated in the future, as should the state and the performance of the waste water purifiers.

The amount of gross municipal waste (the waste generated by consumption and manufacturing processes which is assumed to be further processed) naturally decreases rapidly with increased recycling. However, if the terminal amounts (waste which is assumed not to be further processed, i.e., tombed in landfills) are considered the trend is reversed. The maximal recycling scenario produces about 50% less gross solid waste than the zero recycling scenario, although the amount of solid industrial waste is increased. The total net wastes (terminal wastes) in the maximal recycling scenario are twice that of the zero recycling case. The growth in industrial net waste volume with increased recycling is explained by an increase in coal-based energy production, which implies increased coal-mining wastes, to which the ashes from the coal boilers also contribute.

Wood Balances

The scenario results concerning wood consumption for Central Europe and

Wood balance in Western Europe, 1989



Scandinavia have been widened to encompass a wood balance for all of Western Europe (except Turkey and Yugoslavia). The wood balance is carried out for the year 1989; the most recent year for which complete statistics are available. Wood consumption is based on the production of final products which occurred in the region in 1989. To achieve this production in 1989, wood was imported to the region, but in reality wood was also exported from the region at the same time. In the actual wood balance, we have made a self-sufficiency calculation for the region, which means that the production of final products is assumed to be supplied entirely with wood from the region. Country-specific conversion factors for wood consumption have been employed for each individual forest product. These factors are from the mid-1980s (UN, 1986) and must be regarded as high estimates for wood consumption. In the figure opposite, the wood balance is presented. The figure may require some clarification. Let us take information for "Production 1989" as a basis for this clarification (the left bar of the figure). The wood consumption, expressed in million m^3 solid over bark (s.o.b.), is presented for two major product aggregations (paper and board production and production of all other forest products, respectively). The required wood supply for the paper and board produced in Western Europe in 1989 was 116.3 million m^3 s.o.b. The corresponding figure for the production of all other products was 228.4 million m^3 s.o.b. In the production of wood for industrial manufacturing we get harvesting losses of 23.4 million m^3 s.o.b. In total, wood consumption would be 368.1 million m^3 s.o.b. It should be pointed out that at the 1989 production level in Western Europe, raw material (wood and fibers) was both imported and exported to and from the region. In the wood balance calculation we have made the assumption that the wood and fibers required for the actual production in 1989 of industrial products were produced domestically.

The bars in the figure for the different recycling scenarios are presented in a corresponding way to the information in the "Production 1989" bar. From the results of the recycling scenarios it can be seen, as expected, that the selective recycling scenario has about 18% less total wood consumption than the zero recycling scenario. The corresponding figure for the maximal recycling scenario is about 27% less.

The long-term (next 100 years) sustainable biological harvest potential for exploitable and closed forests in the region (sustainable development of growing stock and flows from the stock), based on information from Nilsson *et al.* (1992), is estimated to be 353.1 million m^3 s.o.b. The transfer of primary residues (chips, sawdust, etc.) between industries should be added to the sustainable harvest level to get a complete wood balance. There are also residues from secondary processing available: residues from pulp mills and residues from recycled wood products (wooden packages, used furniture, etc.). These latter kinds of residues have been excluded from the actual wood balance. The transfer of primary residues constitutes 49.4 million m^3 s.o.b. (stemming from the long-term sustainable harvest level). Thus, the total possible long-term sustainable wood supply is 402.5 million m^3 s.o.b., which is illustrated by the top line in the figure. It should also be pointed out that the estimated sustainable harvest levels presented by Nilsson *et al.* (1992, p. 163) are said to be conservative. It is also important to point out that the region's actual roundwood production in 1989 was only 308.9 million m^3 s.o.b. (FAO, 1991), indicating that the forest resources were under-utilized from a sustainability point of view.

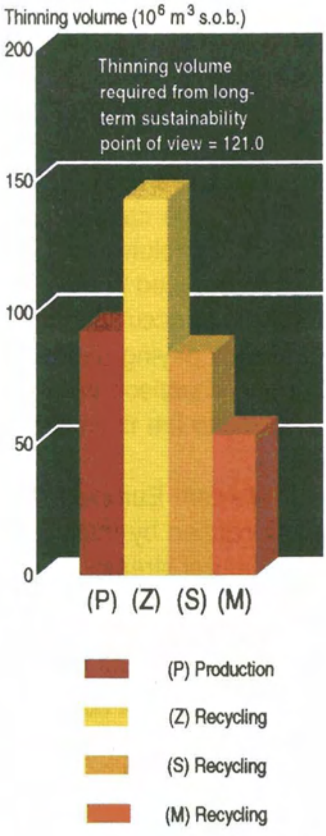
From the available results, it can be seen that wood consumption corresponding to the production of final forest products in 1989 was well within the long-term sustainable limits of the harvest (about –35 million m^3 s.o.b.). If there were no recycling, wood consumption would exceed the sustainable harvest level by about +33 million m^3 s.o.b. With the increased recycling (selective and maximum recycling) scenarios wood consumption would be well within the sustainability limits (–45 and –87 million m^3 s.o.b., respectively). From the figure it can also be seen that the results for wood consumption for "Production 1989" and the scenario "Selective recycling" are quite similar. The latter scenario includes a consideration of the geographical and economic availability of waste paper. It indicates that industry today is already close to the recycling rate estimated to be feasible from practical and economic points of view.

In carrying out the detailed calculations underlying the wood balance figure, it was established that no straight, linear relationship exists between increased paper recycling and decreased wood consumption. An increased recycling rate may result in an increased usage of more wood-consuming technologies (like chemical pulping instead of mechanical pulping) for the production of primary fibers. Such a shift depends on the availability and appropriateness of different waste paper qualities for paper production and the market conditions for different end-use products. We have not been able to analyze these effects to their full extent in this aggregated study. It will be a topic for further investigation in the planned full-scale study.

A change in the occurrence of recycling will have impacts on roundwood prices and silviculture and forest management. We have not been able to analyze the effects on roundwood prices in this study. Adams and Haynes (1991) have illustrated that an increase in the long-term recycling rate in the US as a whole (from 29% to 39%) will decrease the long-term stumpage price in the south of the US by some 20%. Wiseman (1990) has also pointed out that the stumpage price will be affected by an increased recycling rate. The increase in the recycling rate (based on the furnish) between the selective recycling and maximum recycling scenarios in this study means an increase in average waste fiber use from 35% to 56% in the pulp mixture. Therefore, at a greatly increased recycling rate, strong effects on the stumpage prices can be expected in Western Europe too.

One problem that exists with increased recycling and decreased stumpage prices is the lower possibility of maintaining silvicultural standards and the vitality of the forest resources in Western Europe. To achieve long-term sustainable development of the forest resources and vital forests in Western Europe, Nilsson *et al.* (1992) have estimated that there would be an average yearly requirement of thinnings of roughly 121 million m^3 s.o.b. in the region. About 80% of the raw material used at the end of the 1980s in Western Europe's pulp industry was in the form of pulp-logs (UN, 1991), of which the predominant part originates from thinnings. The remaining volume of fiber used in the pulp industry came from the residues of primary processing. By combining the above information, a rough balance for the thinning volume can be established (see figure opposite).

Pulp-log balance



In this figure, the thinning volume required to achieve sustainable development of the forest resources (according to Nilsson *et al.*, 1992) is compared with the pulp-log requirements for the 1989 production of paper and board and with the different recycling scenarios in Western Europe. It is assumed in this balance that the thinning volume is constituted entirely of pulp-logs. In reality, some of the output from the thinnings is also in the form of saw-logs. From this comparison, it can be seen that, even at a domestic production level in Western Europe equivalent to the total number of pulp-logs required for the actual production of pulp and paper and board products in 1989, there is a gap between pulp-log consumption and the required thinning volume of 28 million m^3 s.o.b. (due to unprofitable thinning operations). This gap will increase to 36 million m^3 s.o.b. in the selective recycling scenario and 67 million m^3 s.o.b. in the maximum recycling scenario. In the latter case, this means that more than 50% of the required thinnings may not be carried out. It can be argued that the thinning volume not used by the pulp industry can be used in the board industry. This is unlikely to occur due to the fact that the board industry's paying capacity for pulp-log is much lower in comparison with the pulp industry, which will make the thinnings even more unprofitable.

The forest resources of Western Europe are already under severe stress caused by the deposition of air pollutants, natural stress factors, and silviculturally induced stress such as the lack of silvicultural measures (Nilsson *et al.*, 1992; Kuusela, 1988). In the case of further induced stress in the exploitable forests caused by insufficient utilization, there is a high risk of further decreased vitality and increased degeneration of the resources.

Policy Implications

Judging the environmental friendliness of products using simple arguments such as the rate of recycled fiber may lead to errors of judgment. The reasons for this are many, most of them, however, relate back to the generic nature of the overall environmental impacts of products. There are relations between different economic sectors involved whose implications cannot be directly foreseen because of their complexity. For example, reducing primary fiber consumption in paper production implies a reduced energy production from bark, lignin, and waste paper. However, since the overall energy demand is not reduced by the same proportion, substitute energy production is needed. In our example, the current average Western European mixture of fuels was assumed to be used for this purpose. Thus, paradoxical as it may seem, increased recycling leads to an increase in SO_2 emissions, and also a significant increase in the consumption of non-renewable energy sources.

The results of the static calculations for the conditions prevailing at the end of the 1980s and for increased recycling rates are summarized in the table on page 32.

From this table it can be seen that an increased rate of recycling has a positive impact on some environmental parameters and a negative impact on others. The overall task for the policy makers is to weigh the pros and cons of these factors into a consistent total valuation before policies on increased recycling of paper products are implemented on a large scale.

Energy use emerges as the most important sector as regards the environmental impacts of recycling. The possible use of waste paper for energy production adds a credit which should be

Energy Consumption	
Electric power	Decreased
Heat and steam	Decreased
Fossil fuels	Increased
Non-renewable primary energy sources	Increased
Renewable primary energy sources	Decreased
Emissions — Air	
SO_2	Increased
NO_x	Increased
CH_4	Decreased
Gross CO_2	Decreased
CO	Decreased
Net CO_2	Increased (or decreased fixation)
Emissions — Water	
TSS	Increased
BOD	Increased
COD	Decreased
AOX	Decreased
Materials	
Raw materials for pulp and paper production (other than wood)	Decreased
Wood consumption	Decreased
Waste Production	
Gross solid waste	Decreased
Net solid waste	Increased
Forest Management	
Intensity	Decreased

compared with large-scale fiber recycling and with the energy input necessary for collection, sorting and re-pulping. The interactions between different economic sectors may also introduce problems if the potential heat value of household waste decreases. By not making a distinction between non-renewable and renewable energy sources in the policy discussions on recycling of paper, there is a risk that policy makers and consumers will get a distorted view of the impacts. In fact, as the calculations show, recycling would add to the consumption of non-renewable energy sources under present conditions.

An important policy question which requires more consideration is the production of energy by burning waste paper. In the existing proposed regulations in Western Europe on packaging and recycling paper the burning alternative has been considered, but has been ruled out in most cases. The results of this study indicate that burning waste paper for energy production may be a good alternative from both environmental and economic points of view. This is especially true if some of the chemicals and heavy metals used in the pulp, paper making, conversion, and printing processes today were replaced with other materials. In that case, waste paper could be classified as a clean fuel. Energy recovery of waste paper could be regarded more like energy from coal, bark, or peat, rather than as energy recovery from household waste which is much more complex in content.

Special concern in the policy discussion on a suitable rate of recycling must be directed toward forest resources and forest management. Based on the calculations for 1989 in Western Europe it can be concluded that a dramatically increased recycling rate (the maximal recycling scenario) will probably generate the following effects:

- A decrease in total wood consumption of about 25% in the region.

- A decrease in the stumpage prices (in Western Europe and, indirectly, in other regions), resulting in less intensive forest management.
- A particularly decreased thinning intensity: it is estimated that about 50% of the thinning requirements may not be carried out.
- A revision, due to the above, in the forest policies in several countries toward less intensive policies than those presently in effect.
- Decreased stumpage prices creating the risk of a decreased afforestation rate in Western Europe and also, indirectly, in other countries.
- A strong decrease in disposal possibilities for sawmill chips. The market for sawmill chips seems to decrease by more than 40% in the case of maximal recycling in Western Europe, in comparison with the figures for "Production 1989". The income from chips is, in most cases, crucial to the survival of the sawmills. Such a development may lead to a decrease in the transfer of financial resources to forestry operations, which may result in less silviculture and fewer vital forests.

The above conclusions are based on the conditions in 1989. If we look into the future, the picture becomes more complicated. Nilsson *et al.* (1992) estimate that, if no radical measures are taken against the current emissions of air pollutants in Europe, the long-term sustainable wood supply in the region will be around only 355 million m^3 s.o.b. (including transfer of primary residues), instead of the 402.5 million m^3 s.o.b. discussed earlier. The consumption of paper and board in the region is also estimated to increase by between 2 and

2.5% per year during the next 10 years (Jaakko Pöyry, 1992). These developments will tighten the wood balance and may change the above conclusions concerning the effects of recycling on forest management. The long-term development and effects of recycling of paper products is a central component of the planned full-scale study for Western Europe.

In earlier sections, it has been illustrated that the zero recycling scenario seems to generate the largest net fixation of carbon for the scenarios studied. However, the carbon balances produced have not been able to illustrate the dynamics of carbon fixation over time by forest growth. It is intended that these dynamics will be analyzed in the planned full-scale recycling study. As illustrated by the wood balances, the wood supply/demand balance will, at a strongly increased recycling rate, require that policy makers implement policies which stimulate wood consumption for energy production in Western Europe. Otherwise, there will be limited possibilities of carrying out satisfactory silvicultural measures (thinnings) in the future in order to create vital forests.

When planning the collection and recycling of waste paper it is necessary to consider the different qualities of paper. High-grade waste paper can be recirculated and used for many different lower qualities, but low-grade waste paper can be used for only a few less-demanding purposes. Paper cannot be recirculated without additional primary fibers because a certain quality degradation will occur at each reuse cycle. Source separation of waste paper into different qualities should make the usage of recycled fibers in the paper production process more economical and also make it possible to better allocate the waste paper qualities most suitable for energy production. However, the distribution of the availability of different waste paper grades for different recycling schemes is, for the moment, not sufficiently known and documented for a generally acceptable evaluation of the environmental impacts of recycling of paper. There are also large unquantified variations in energy demand and waste sludge generated by reused pulp production from different grades of waste paper.

In addition, there are several policy questions that we have not been able to analyze in this study but which are important for further considerations. Wiseman (1990) has pointed out that an increased recycling rate will also decrease the prices of final industrial forest products in the long-term due to decreased stumpage prices. This may lead to a relatively higher consumption of paper products in the future due to their substitution for other products (like plastics) at decreased prices. A quite different scenario is also possible. There is a high probability that the proposed regulations in Western Europe may cause large practical and economic problems when they are implemented. This may lead to the replacement (substitution) of paper and board products by other products. Furthermore, there may be a risk that this replacement will take the form of more environmentally harmful products.

We have pointed out earlier that the current sites for the production of pulp for paper and the paper consumption sites do not coincide. An increased recycling rate will probably result in a relocation of the pulp and paper industry (the market for waste paper) to the sites where paper is consumed. Such relocation will incur considerable investment costs, and will have specific environmental impacts which we have not been able to analyze in this feasibility study.

An increased recycling rate may also change the trade patterns of paper and board products in Western Europe (in addition to the changes caused by the relocation of industry). The net importing countries may be forced to import a higher amount of paper and board products with high degrees of primary fiber in order to obtain the necessary high-quality fibers for recycling. A changed trade pattern may also have environmental impacts.

When considering the use of paper products it should be noted that they represent one of the most-used, renewable material and energy sources in the world. Well-thought out schemes for the recycling and energy recovery of used fibers and efficient forest-management programs are important factors in attaining a sustainable development condition for the environment and the forest resources in Western Europe.

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