Ecological comparison of office papers in view of the fibrous raw material

On behalf of the “Initiative Pro Recyclingpapier“

(“Initiative for Sustainable Use of Paper“)

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List of abbreviations

AOX	Absorbable organic bound halogens
BOD-5	Biological oxygen demand for degrading organic materials within 5 days
BREF	Best Available Technique Reference Manual
CED	Cumulated energy demand
CHP	Combined heat and power plant
CHPC	Combined heat and power cycle
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CORE	Crude oil resource equivalent
DIP	Deinking pulp
DM	Dry matter
ECF	Bleached without the use of elementary chlorine (elementary chlorine-free)
IFEU	Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research, Heidelberg)
IPR	„Initiative Pro Recyclingpapier“ (“Initiative for Sustainable Use of Paper”)
LCA	Life-cycle analysis
NO_x	Nitrogen oxide
PM10	Particulate matter with particle diameter smaller than 10 µm
PO_4	Phosphate
POCP	Photochemical Ozone Creation Potential
SO_2	Sulphur dioxide
TCF	Total chlorine-free
UBA	Umweltbundesamt (German Federal Environmental Agency), Dessau
WfD	Waste for disposal
WfR	Waste for recovery

Units and dimensions used

µm	Micrometre, 10^{-6}m
l	Litre
m³	Cubic metre, 1000 litres
mg	Milligram
g	Gram
kg	Kilogram, 1000 g
t	Tonne, 1000 kg
kJ	Kilojoule, 1000 Joules
MJ	Megajoule, 1,000,000 Joules
W	Watt
MWh	Megawatt hours, 1,000 kWh (Kilowatt hours)
a	Year

Executive summary

Germany is the largest manufacturer and consumer of graphic papers in Europe. In the uncoated printing and office paper sector, 1.5 million tonnes are produced annually, a good 20 percent of which, about 300,000 tonnes, is made from recycled paper. [1]

The Institute for Energy and Environmental Research (IFEU) in Heidelberg has analysed the production of virgin fibre and recycled paper on behalf of the IPR. The main result was that for all of the indicators taken into consideration, the balance result of recycled paper has clear benefits.

The Federal Environmental Agency recommends recycled paper

In August 2000, the Federal Environmental Agency (UBA) published a background information paper called “Life-cycle Analysis for Graphic Papers“. This was based on the life-cycle analysis (LCA) for graphic papers that a project group had carried out under the overall control of the IFEU.

In its background information paper, the UBA emphasizes as a central result that “it is significantly more environmentally friendly to produce graphic papers from recovered paper than to use virgin fibre from the raw material of wood“.

New basic data required

The stated life-cycle analysis is now a good ten tears old. The “Initiative Pro Recyclingpapier“ commissioned the IFEU to carry out a study to update the basic data. Primarily, what was wanted was a comparison and ecologic evaluation of virgin fibre and recycled paper for copying and office use. In this, important steps during the process were taken into consideration, from the obtaining of raw material, initially in the forest or in waste paper processing, down to the finished paper produced in Germany. Unlike the UBA life-cycle analysis, no consideration was given to other graphic papers or the removal of used paper.

Model assumptions

In this current work, the production of virgin fibre paper and recycled paper are considered separately. It ends with the finished office paper at the gate of the paper factory. In addition, there is no consideration given to the prior energy or chemical chains or the transportation required along the process chain (see Figure 1).

For improved comparability, only paper production in Germany is considered. The secondary researched fibre paper researched – identified as “Secondary D“ in the figures – is produced from deinking pulp, and primary fibre papers from bleached sulphate pulp. The market pulp used here in Germany comes principally from countries such as Sweden and Finland, followed by countries overseas such as Brazil. These regions are summarized in the figures by the terms “Primary North“ and “Primary South“.

[1] Verband Deutscher Papierfabriken e.V. (German Pulp and Paper Association), “Papierkompass 2006“ (Paper Compass 2006), Bonn, 2006

In this, selected scenarios depict average situations, so that the position of individual factories may lie above or below the results described. The data used reflects current facts, as far as these have been able to be researched using sources that are publicly accessible.

The comparison is based on the production of 1000 kg office paper.

Indicators investigated for the environmental evaluation

Different indicators were used in order to be able to estimate the ecological effects of paper production. These reflect the impact on air, soil, water and (energy) resources.

Depiction of the results

The results of the study are shown as stacked bar charts. A differentiation is made in this between different sectors of paper generation. In addition to the main processes, the individual sectors also contain relevant prior chains such as energy provision, the provision of process materials, as well as the transportation of raw materials and process materials (wood, waste paper, caustic soda solution, etc.). A differentiation is made between the provision of wood or waste paper, the production of pulp/DIP, the transportation of pulp and the production of paper.

Overview of the results

- The energy requirement for pulp production from wood is significantly higher than that for waste paper processing.
- The production of recycled paper comes off significantly better in a comparison of the indicators of fossil resource requirements, global warming (greenhouse effect) and acidification – in spite of significant use of production residues (waste liquor, bark) in virgin fibre paper production.
- The increased sulphur content of the waste liquor additionally leads to a clear increase in the acidification results in primary paper manufacture in obtaining energy for virgin fibre production.
- The long transportation routes for primary fibres from the south have a particularly serious effect on fossil resource requirements and the greenhouse effect.
- The significantly higher requirement for process water for producing virgin fibre paper can be traced back to differences in the production of pulp and DIP: boiling the wood to extract fibres is a more water-intensive procedure than the recycling procedure.

Tables 1 and 2 show the emissions saved resulting from recycled paper production, using different examples. The production of a 500-sheet pack of recycled paper alone saves so many fossil resources compared to virgin fibre paper made from pulp originating from the south that – using the fossil part of the German energy grid – the energy could light a 100 W bulb for 44 hours.

Compared to virgin fibre paper from northern pulp, one tonne of recycled paper saves the same quantity of CO_2 that an average car would emit driving about 1,000 km.

If all of the office paper used in Germany (800,000 t per year) was made from waste paper, then the process water requirement would be about 25.4 million m^3 less than for producing the same quantity of virgin fibre paper. This equals the capacity of the Wuppertal dam.

Summary and recommendations

For all of the indicators considered, the environmental impact of producing recycled paper is the lowest. The recommendation of the Federal Environmental Agency to use recycled paper and paper with the highest possible proportion of waste paper should therefore be followed, in the opinion of IFEU.

This applies in particular if long distances are covered in transportation for the manufacturing of virgin fibre paper. Thus pulp from overseas should be refused for ecological reasons, and waste paper for the production of recycled paper should be collected locally.

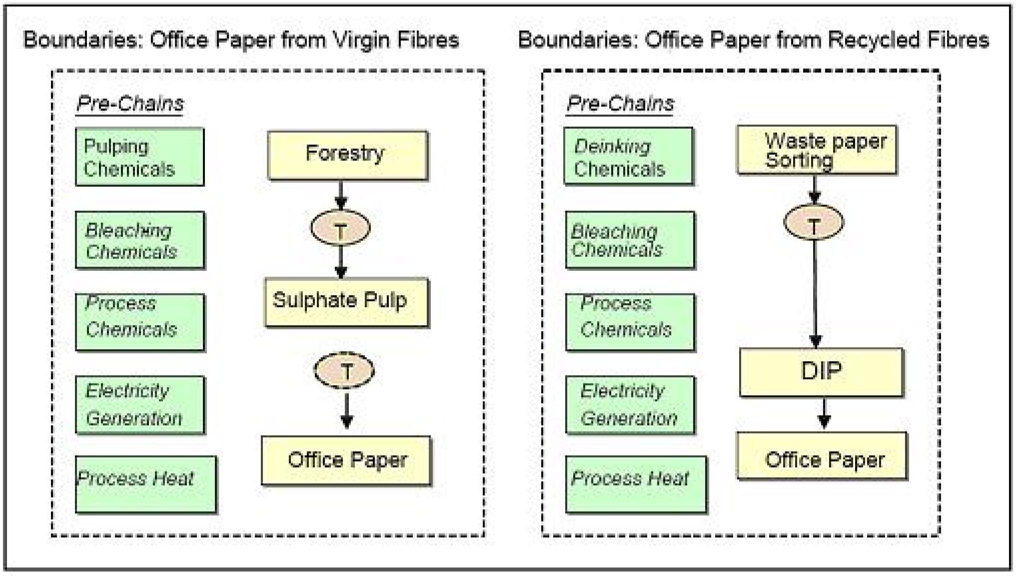


Figure 1: Limits of the analysis for the processes considered in the current environmental evaluation. T here stands for transportation

Comparison of virgin fibre paper from northern pulp with recycled paper	Resources [kg crude oil equivalent]	Greenhouse effect / global warming [kg CO_2 equivalent]	Process water [kg]
With reference to one pack of office paper (500 sheets)			
	0.08	0.5	80
With reference to 1 t of paper (400 packs of 500 sheets)			
	33	183	31,800
With reference to 800,000 t of office paper (average annual consumption in Germany)			
	26,500,000	146,000,000	25,400,000,000

Table 1: Emissions saved in the production of recycled paper compared to the production of virgin fibre paper from northern pulp

Comparison of virgin fibre paper from southern pulp with recycled paper	Resources [kg crude oil equivalent]	Greenhouse effect / global warming [kg CO_2 equivalent]	Process water [kg]
With reference to one pack of office paper (500 sheets)			
	0.21	0.9	80
With reference to 1 t of paper (400 packs of 500 sheets)			
	82	347	31,800
With reference to 800,000 t of office paper (average annual consumption in Germany)			
	65,900,000	278,000,000	25,400,000,000

Table 2: Emissions saved in the production of recycled paper compared to the production of virgin fibre paper from southern pulp

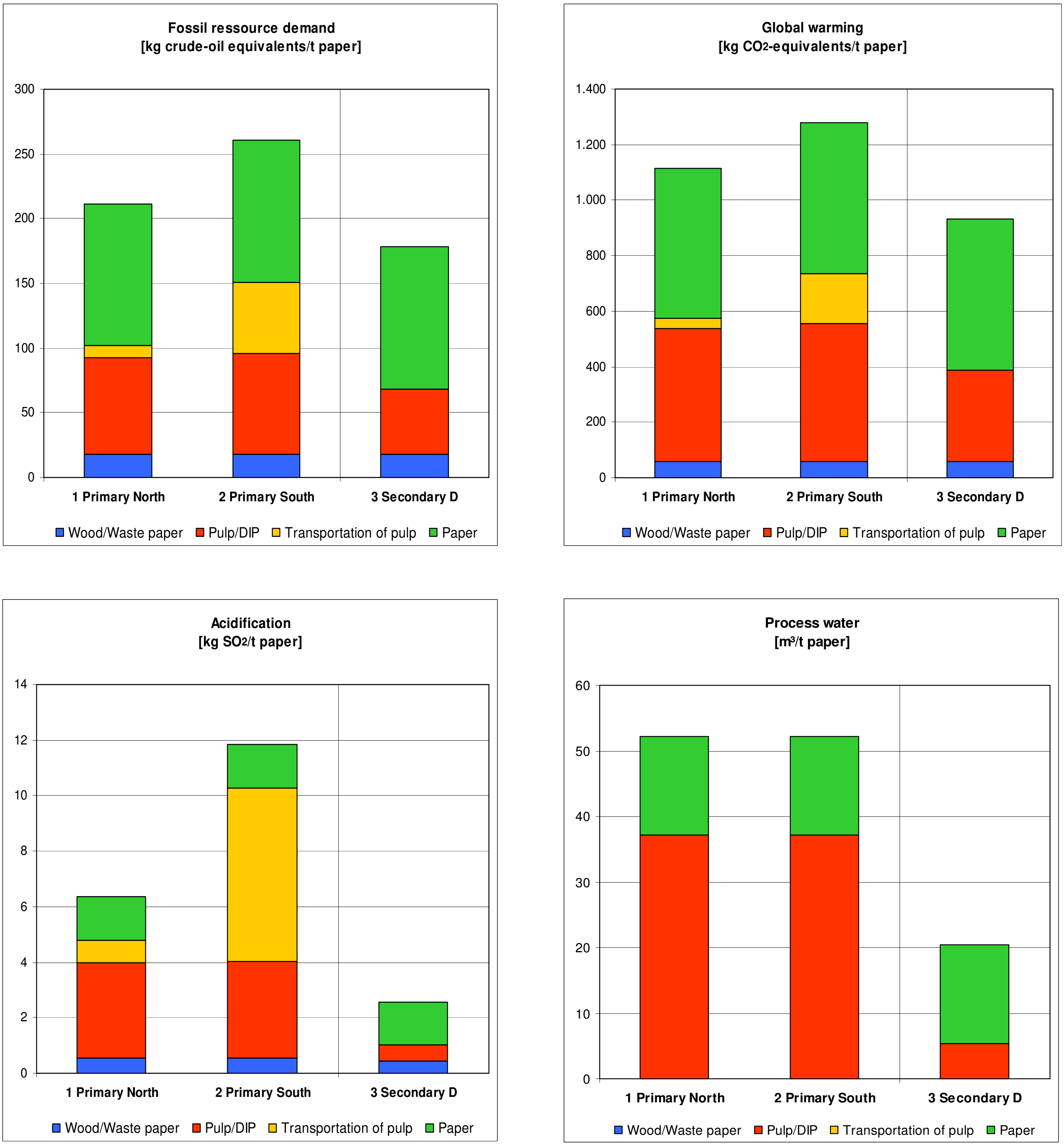


Figure 2: Results of the ecological comparison of virgin fibre and recycled papers using the indicators of fossil resource demand, greenhouse effect, acidification and process water as an example

Long Version

1 Background and aims

Germany is the largest manufacturer and consumer of graphic paper in Europe. In the field of office paper, suppliers offer an extensive range of different paper types, which are differentiated by their weight, degree of whiteness or fibrous raw material. For fibrous raw materials, a differentiation is made between primary fibres and secondary fibres. Primary fibres are derived from fresh wood, whilst secondary fibres are obtained through the recycling of waste paper.

In 2000, the Federal Environmental Agency published a background information paper on the ecological evaluation of graphic papers [UBA 2000]. This was based on the Life-cycle Analysis for graphic papers, which the Institute for Energy and Environmental Research (IFEU) in Heidelberg had been in charge of carrying out [IFEU 1998].

In its background information paper, the Federal Environmental Agency highlighted as one of the central results that “it is significantly more environmentally friendly to produce graphic papers from waste paper than to use virgin fibre from the raw material of wood“. As a conclusion, the Federal Environmental Agency recommended the use of recycled paper and papers with the highest possible proportion of waste paper.

The ecological benefits of recycled paper have led to recycled paper products being entitled to carry the “Blue Angel“ environmental symbol, amongst other things.

The life-cycle analysis, along with the stated background information paper, has until now also been used by the “Initiative Pro Recyclingpapier“ (IPR), an “economic alliance to improve the acceptance of recycled paper“[1], as an important ecological argument. In addition, the IPR has fallen back on other data from literature on the environmental impact of the production of fibre and paper [Trauth 1997], which has also found its way onto the “sustainability reckoner” located on the homepage of the IPR.

The stated works are based on data that is now ten years old. For this reason, the IPR commissioned the IFEU Heidelberg to carry out a study to update the basic data for the ecological evaluation of copying/office paper from recycled fibres compared to that made from virgin fibres. In this, the important process steps from obtaining the raw materials, i.e. forest or waste paper processing, to the finished paper manufactured in Germany, were to be taken into account.

The paper pulp used in Germany comes primarily from the northern neighbours of Sweden and Finland. However, an increasing amount of paper pulp comes from overseas in the southern hemisphere. Thus Brazil is currently the fourth largest supplier [VDP 2005]. These facts should also be included in the investigation.

As an additional aspect, an examination was also made of the problem of increasing pulp production in countries such as Brazil, and also in southern Europe through the cultivation of rapidly-growing eucalyptus woodland that thus generates a high yield per hectare. The cur-

[1] See www.papiernetz.de

rent results on the subject of “Eucalyptus plantations for pulp production“ are available free of charge as a separate document from the “Initiative Pro Recyclingpapier“.

2 Environmental evaluation of paper production

2.1 Procedure

The ecological analysis of this study shows several differences compared to the works named above [UBA 2000; Trauth 1997], and these can primarily be seen in the so-called limits of the analysis (see also figure 2-1).

In the UBA Life-cycle Analysis for Graphic papers, the same graphic paper market in Germany was examined in all investigation scenarios. On the one hand, this means that a model was provided of not only the production of paper but also the disposal of used paper. On the other hand, different graphic papers, i.e. magazines, newsprint and office paper were simultaneously analysed using a large material flow model. Statements regarding individual areas of use, e.g. office papers, were not directly possible.

While the environmental effects resulting from both the prior raw material and the energy chains were also incorporated in the UBA life-cycle analysis, these were not taken into account in the collection of data by Trauth [1997]. In the latter case, on the other hand, the data looked at the specific requirements of raw materials, energy and water in the production of pulp and paper.

The approach of this study is certainly a middle course. The production of virgin fibre paper and recycled paper will each be regarded separately and will end with the finished office paper leaving the gate of the paper factory. On the other hand, the prior chemical and energy chains as well as the transportation required along the process chain will be taken into consideration. This is shown in a simplified form in figure 2-1 for purposes of clarity.

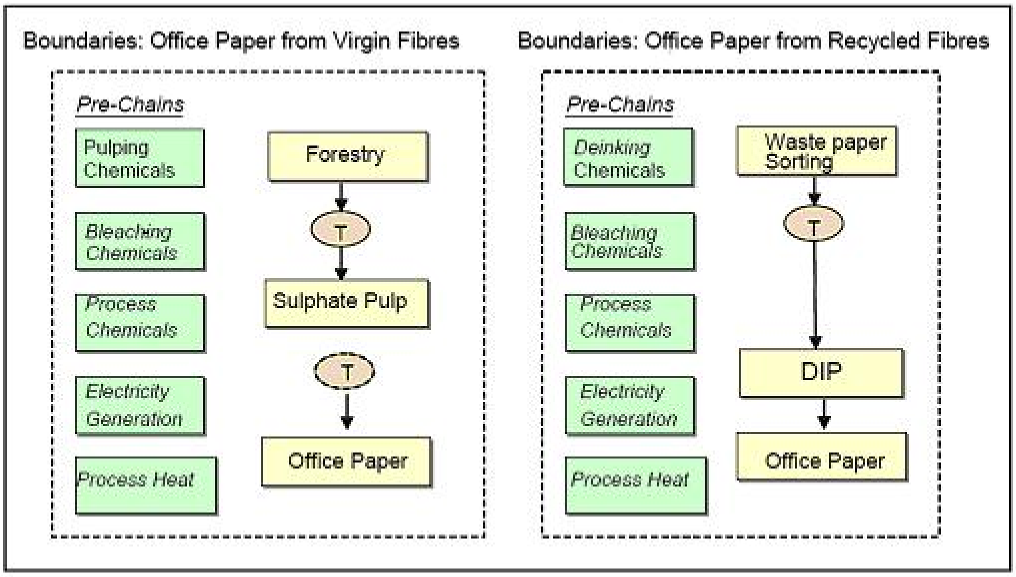


Figure 2-1: Limits of the analysis for the processes taken into account in the current environmental evaluation; here, T stands for transport

2.2 Scenarios considered and their modelling bases

2.2.1 General assumptions

A good proportion of the office paper consumed in Germany comes from domestic production but is also obtained from the world market. Because of the data that could be ascertained within the stated scope, and for better comparability, a model was selected for these calculations that only considers production in Germany.

The secondary fibre paper researched is produced from deinking pulp and primary fibre paper from bleached sulphate pulp. Secondary fibre papers from non-deinking recycled fibres (so-called environmental protection papers) and papers from sulphite pulp have not been taken into consideration due to their relatively low significance in the German office paper market.

For the process of office paper manufacturing, there is no significant difference from a technical point of view whether the paper machine is operated using sulphate pulp or deinking pulp. Differences between individual paper products are determined more by the efficiency of the respective paper machine or the general conditions specific to the location. In order to screen out such effects, the production of paper is approached as being the same in all scenarios in this investigation.

Office papers made from secondary fibres are produced in so-called integrated procedures. Here, the manufacture of deinking pulp from waste paper and the subsequent production of office paper take place in the same location. The sulphate pulp used in Germany for the production of office paper does, however, come primarily from imports. The most important countries of origin are Sweden and Finland. These are followed closely by overseas countries such as Brazil.

In this study, this situation is depicted as an approximation using one scenario with pulp from a northern origin and one with pulp from overseas.

It is assumed that the market pulp comes primarily from factories that are remote from settlements and thus do not have a connection to a local heat supply. In the case of factories close to settlements, the excess heat can be fed into the local heat supply. This aspect was not taken into consideration in this study.

This study thus focuses on three scenarios:

1. Office paper from primary fibres of northern origin (in short: “Primary north“)
2. Office paper from primary fibres of southern origin (in short: “Primary south“)
3. Office paper from secondary fibres (in short: “Secondary D“)

The comparison was based on the production of 1,000 kg of office copying paper.

2.2.2 Data

One significant component of the project was to research current data to reflect the production of sulphate and deinking pulp. In this, the focus lay on the evaluation of publicly accessible information. This data was supplemented by data obtained from the company Steinbeis Temming, as well as additional enquiries by telephone.

In total, the following data sources were used:

- Data report on the Life-cycle Analysis of Graphic Papers [UBA 1998b]
- Environmental reports on producers of fibrous material and paper (list in appendix)
- Reference document on "The best available techniques in the pulp and paper industry" [BREF Pulp]
- Ecoinvent data collection [ECOINVENT 2003]
- Data acquired from Steinbeis Temming Papier, Glückstadt [STP 2006]
- Telephonic communication with the Rosenthal pulp factory
- Internal database of the IFEU Heidelberg.

There follows a short description of how the available data was used for modelling the scenarios.

Scenario: Office paper from secondary fibres

The production of office paper from secondary fibres covers the following processes:

- *Sorting of waste paper and delivery for waste paper processing*

  Data used: [UBA 1998], the prior energy chains were updated to 2004; source: IFEU-database.

- *Waste paper processing, DIP production*

  Data on final energy consumption, chemical demand and effluent: [STP 2006].

  The mix of energy carriers was selected so that it depicted an approximation of the average German situation in DIP production. It was roughly derived from publicly accessible information from the largest German DIP producers. Source: [IFEU 2006b].

- *Office paper production*

  Paper is manufactured from the DIP in the final process step under consideration. The data necessary for paper production come from [UBA 2000], and the data for the prior chains of energy and preliminary materials come from [Ecoinvent 2003, UBA 2000, Umberto 2005].

Scenarios for office paper from primary fibres

The production of office paper from primary fibres includes the following processes:

- *Wood provision from forestry*

  Provision of wood of northern origin [UBA 2000].

- *Manufacture of market sulphate pulp*

  Essentially, the set of data for elementary chlorine-free (EFC) bleached sulphate pulp manufacture from [Ecoinvent 2003] was used.

  Data sources for the prior chains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prior chains: [Ecoinvent 2003, UBA 2000, Umberto 2005].

- *Milling of pulp*

  Milling follows on from pulp production in market pulp. The energy consumption values used for the beating are based on [Bos 1999] and are tailored using experimental values from [STP 2006].

- *Office paper production*

  Paper is made from the supplied pulp in the last process step considered. The necessary data for paper production comes from [UBA 2000], and that of the prior chains for energy and preliminary materials from [Ecoinvent 2003, UBA 2000, Umberto 2005].

The important difference of both scenarios to office paper made from primary fibres lies in the transportation of the pulp from the pulp factory to the paper mill. In the first scenario “Office paper from primary fibres of northern origin“, combined transportation is assumed from Scandinavia (water and land transport) [UBA 2000], and in the second scenario “Office paper from primary fibres of southern origin“, combined transportation from is assumed from Brazil (IFEU assumptions).

A list of the data sets used is provided in tabular form in appendix II.

2.2.3 Scenario scope

From the preceding chapters, it can be seen that the scenarios under consideration do not include the whole of the German office paper market but just one relevant subarea.

The data used for the analysis comes on the one hand from original data enquiries, but a larger proportion comes from publicly accessible data sources. All of the data used was checked for plausibility. The most correct data in the opinion of the authors was used for the analysis. To make the results more comprehensible, the main calculation values are documented in the appendix.

The focus on subareas of the market and the compilation of data sets from different data sources necessarily lead to certain restrictions in the field of application of the scenarios and/or study, which are indicated below.

Modelled scenarios instead of individual depictions

The scenarios modelled for this study do not represent a certain mill or a definite paper product. Data for individual manufacturers can differ from the data used here.

The underlying input/output data on sulphate pulp production generally lies within a range that can be considered typical according to [BREF Pulp 2001]. This evaluation can be confirmed by IFEU's available internal data. Thus there are modern pulp factories that clearly show better values than those in the data used in this study with regard to the energy balance or air and water emissions. On the other hand, in Germany, pulp with less favourable values was able to be handled. This can be assumed in the case of overseas pulp, in particular; the availability of data in this area is insufficient to be able to make safe statement on this.

In the case of the data used, this is generic data that does not represent any definite mill but does, however, provide the best possible depiction of the average of northern market pulp production.

For DIP production in Germany, much the same applies, and here also an average has been determined. Thus the generic data set covers the production of DIP for office paper and other paper applications. This provides a certain analogy to the data set for northern pulp production, which has the same limited exclusive use in the production of office paper.

In addition, it remains to be mentioned that imported primary fibre papers, particularly those from northern countries, are also frequently produced in integrated paper mills. For the reasons mentioned at the start, however, these have not been considered in this study.

2.3 Indicators for the environmental evaluation

The following environmental effect categories and indicators have been considered:

- Consumption of fossil resources – stated as crude oil equivalents
- Greenhouse effect
- Acidification
- Aquatic eutrophication
- Chemical oxygen demand (COD)
- Process water demand
- Primary energy demand (fossil energy demand, total energy demand)
- Summer smog
- Effects on health – expressed as particulate matter

The *fossil resource demand* is represented as a crude oil resource equivalent value and is stated in kg. It is calculated from the amount consumed of a fossil energy carrier (hard coal, lignite, crude gas, crude oil) and the so-called crude oil resource equivalence factor. This takes into consideration the static range of the respective raw material (how far into the future these stocks will last) as well as their net calorific value. The crude oil resource equivalence factor is greater the lower the static range, and the greater the net calorific value of the raw material under consideration. For crude oil, the equivalence factor = 1.

The term *greenhouse effect* describes all greenhouse-relevant emissions – converted into a CO_2 equivalent. This includes, amongst other things, emissions from fossil carbon dioxide or methane.

The environmental effect category of *acidification* includes the emissions from hydrochloric acid, sulphur oxides, hydrogen sulphides, nitrogen oxides and ammonia, amongst others. They are stated as SO_2 equivalents (sulphur dioxide). Acidification can occur both in waterways and in the soil (acid rain).

The *chemical oxygen demand* (COD) provides information on the total burden of oxidizable organic (dissolved) pollution in effluent. The COD gives the quantity of oxygen (in mg/l) that would be required to oxidize this burden of pollution if oxygen were the oxidizing agent. It can therefore represent a measure of the possible oxygen depletion in waterways. Recently, COD has also been discussed as an indicator of substances with a toxic effect in water.

The *process water demand* is a measure of the water used in the production process. In this is considered the water that comes into direct contact with the process. Coolant water is not considered here as this is generally used in peripheral systems and only undergoes minimal chemical changes.

The indicator *aquatic eutrophication* represents the environmental problem of “oxygen depletion“. It considers the parameter of COD (chemical oxygen demand) and emissions in water of nitrite, nitrate, ammonia, nitrogen compounds and phosphates. Here the emissions in the water (without COD) first cause the entry of nutrients into the surface waters, which as a result of the plant growth caused by this can then lead to oxygen depletion just like COD. The effects are stated as a PO_4 equivalent (phosphate equivalent).

The indicator *primary energy demand* represents the primary energy – not to be confused with final energy – needed to generate process energy, expressed as CED (cumulated primary energy demand) and stated as MJ per tonne of paper. A differentiation is made here between *fossil primary energy demand* and *total energy demand*. While the fossil primary energy demand simply describes the provision of fossil energy carriers such as coal, gas or crude oil, the CED takes into consideration the demand for regenerative energy carriers such as wood, amongst others, in addition to the fossil energy demand. In virgin fibre paper production, the wood residues and waste materials that are obtained in the pulp process are used to cover a large part of the energy demand.

Summer smog or ground-level ozone is expressed as *POCP* (photochemical ozone creation potential). The photochemical ozone creation potential describes the formation of ground-level ozone that is classified as a harmful trace gas and is suspected of leading to damage in vegetation and materials, as well as causing health problems. Photo-oxidants are reactive materials that can trigger numerous chemical reactions in the environment that contribute to air pollution. The POCP refers to the effect of the reference material ethylene and includes hydrocarbons. The indicator results are given accordingly in kg of ethylene equivalent per tonne of paper. POCP values are not constant; they vary according to time and place due to meteorological conditions.

The parameter *particulate matter/PM10* expresses effects on human health. Particulate matter is particulates with an aerodynamic diameter smaller than 10 µm. Particles of this size are only restrained to a limited extent by the mucous membranes in the nose/throat area or the little hairs in the nose. In addition to direct emissions, new particle formations made from precursor substances such as sulphur dioxide, nitrogen oxide, ammonia or volatile organic compounds are also taken into account.

2.4 Result graphs

Graded bar charts are used to show the ecological analysis. A differentiation is made here between different sectors of paper generation. In addition to the main processes, the individual sectors also contain all of the relevant prior chains such as energy provision or the provision of process materials, such as the transportation of raw materials or process materials (wood, recovered paper, caustic soda, etc.). The quantities involved in the pulp/DIP manufacturing process and the paper manufacturing process are given in appendix II. For pulp production, they are essentially based on data from [Ecoinvent 2003], for DIP production on data from [STP 2006] and additional publicly accessible data, and for paper production on [UBA 2000].

The results depicted in the graphs are again given as numerical values in a table in the appendix. They refer to the framework conditions described in Chapter 2.2.2. **Paper production using virgin fibres** is broken down into the following sub-processes:

- Wood provision [wood/waste paper]
- Pulp production [pulp/DIP]
- Transportation of pulp to paper mill [transportation of pulp] and
- Paper production from pulp [paper]

For the sake of better orientation, the name used in the diagrams is additionally stated in square brackets in the enumeration of sub-processes.

Paper production from waste paper is broken down into the following sectors:

- Waste paper provision [wood/waste paper]
- Production of deinking pulp (DIP) [pulp/DIP] and
- Paper production from recycled fibres [paper]

Transportation of pulp to the paper mill was considered exclusively for the sulphate pulp from northern countries and the sulphate pulp from Brazil. Processing of DIP from Germany takes place in integrated factories in which paper is produced directly from DIP, so no transportation is required.

The size of the sub-bar for paper is the same size for all of the scenarios considered within one effect category because the same paper production process is assumed for the fibre types under consideration (see also paragraph 2.2.2 Data).

One tonne of produced paper was selected for each as the reference amount.

2.4.1 Environmental burdens through energy and acidification

First, the environmental effects characterised primarily through the provision of energy, namely the *fossil resource demand*, the *greenhouse effect* and *acidification* will be considered. As an illustration, example results are converted into clear amounts in the final subchapter.

The results shown here in graphic form are again listed in tabular form in appendix I as calculated results.

The energy demand of pulp production from wood is clearly higher than that from waste paper provision. In spite of the significant use of production residues (waste liquor, bark), the results for virgin fibre paper production are clearly higher than for recycled paper production in the case of fossil resource demand, the greenhouse effect and acidification.

Fossil resource demand/Greenhouse effect

Overall, recycled paper production has the lowest *fossil resource demand* of the three cases considered, and provides the lowest contribution to the *greenhouse effect*. Thus the *fossil resource demand* of recycled paper production is up to one third lower under the selected general conditions than for primary fibre paper production using overseas transportation.

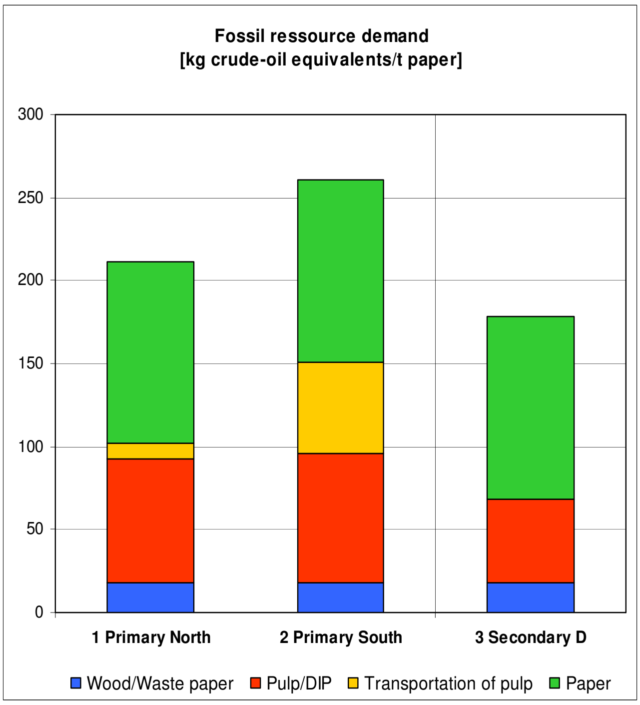
The long transportation distances have a clearly negative effect on the results of fossil resource demand and the greenhouse effect of paper from primary fibres of southern origin.

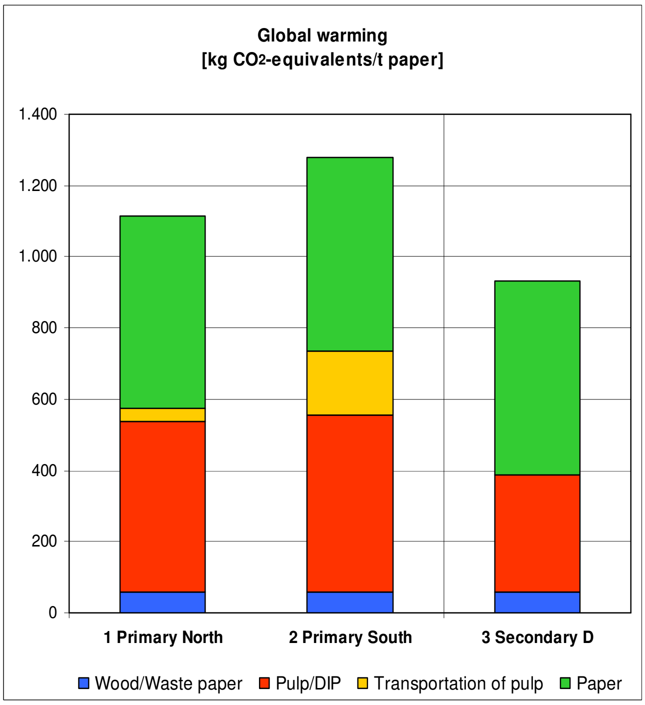
If both of the primary papers are compared, then one can see that the difference between primary paper using pulp of northern or southern origin is caused by the clearly longer transportation distances of the pulp from South America.

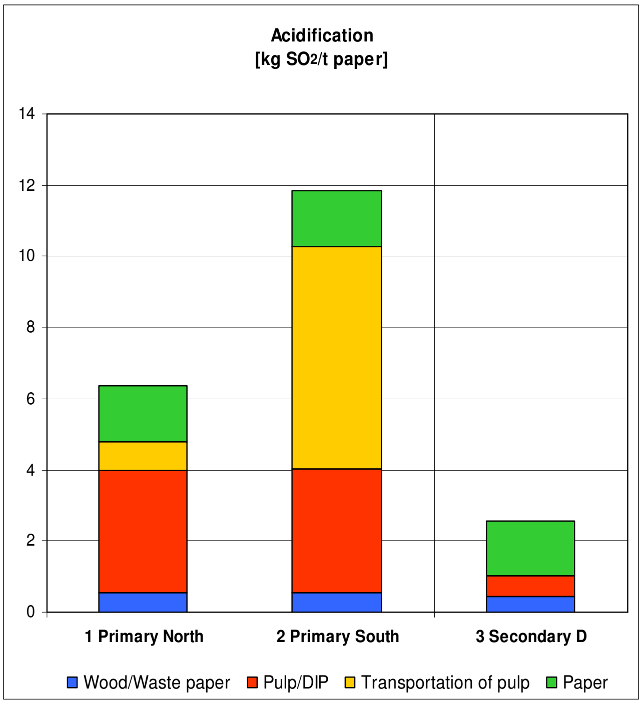
Acidification

In the case of the acidification indicator, the pattern repeats itself in the results, but clearly is marked in favour of recycled paper: recycled paper production makes the lowest contribution to acidification by far per tonne of paper – it is less than half as high as the contribution made by primary paper production (pulp of northern origin). The cause of this lies primarily in the use of sulphurous, thermally energetic waste process liquor as an energy carrier in primary fibre production. The sulphur oxide compounds produced make a significant contribution to acidification.

In the case of pulp of southern origin, additional high levels of emissions caused by transportation also come into effect. However, as these are caused principally on the high seas, they are less crucial as an environmental burden. In the graph shown (Figure 2-2), the results can be seen to their full extent. In evaluating the effects, one must take into separate account where these effects occur.







Results overview:

- The energy demand of pulp production from wood is clearly higher than that of waste paper processing. In spite of the significant use of production residues (waste liquor, bark), the results of virgin fibre paper production are clearly higher than for recycled paper production in the case of fossil resource demand, the greenhouse effect and acidification.
- The long transportation distances have a clearly negative effect on the results of fossil resource demand and the greenhouse effect for paper from primary fibres of southern origin.
- The increased sulphur content of the waste liquor leads additionally to a clear increase [in the result] of acidification in primary paper production for energy recovery for virgin fibre production.

Figure 2-2: Results of the ecological comparison of virgin fibre paper and recycled paper using as an example the indicators of fossil resource demand, acidification and greenhouse effect

2.4.2 Environmental effects on water

Looking at environmental effects on water gives a further view of the ecological effects of paper production. This includes *aquatic eutrophication*, *chemical oxygen demand (COD)*, and *process water demand*.

The results shown here in the graphs are also listed as arithmetical results in appendix I in tabular form. For the three indicators under consideration, the results are clearly in favour of recycled paper. As can be seen in Figures 2-3, the profiles are similar for process water demand, COD and aquatic eutrophication, and simply differ in their value.

The contribution to aquatic eutrophication of paper production using virgin fibres is twice as high as for recycled paper production under the general conditions examined.

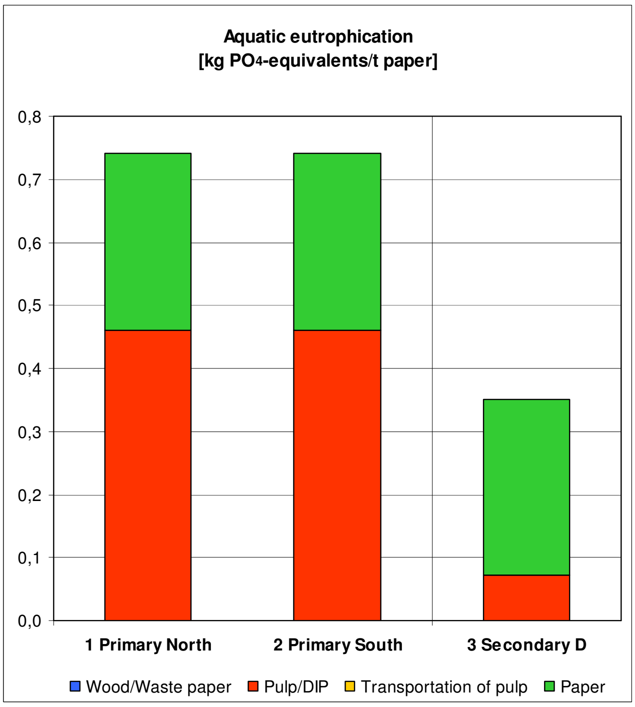
The clearly higher demand for process water in virgin fibre paper production can be traced back to differences in the production of pulp and DIP: boiling the wood to obtain fibre is a more water-intensive procedure than the procedure for recycled paper. The process water demand for paper production from wood is about two-and-a-half times as high as for the production of paper from waste paper.

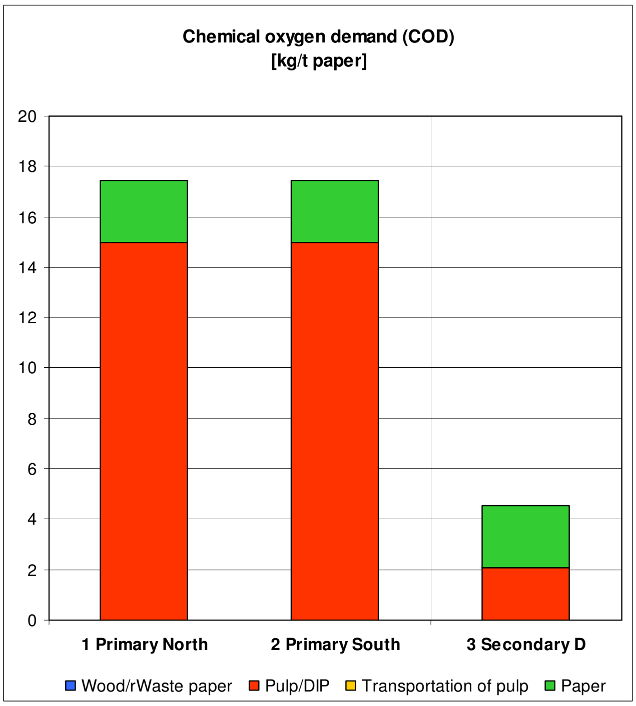
The organic burden of pollution in the effluent from virgin fibre paper production is clearly higher than for recycled paper production. This is reflected in a COD value for virgin fibre paper production that is almost four times as high.

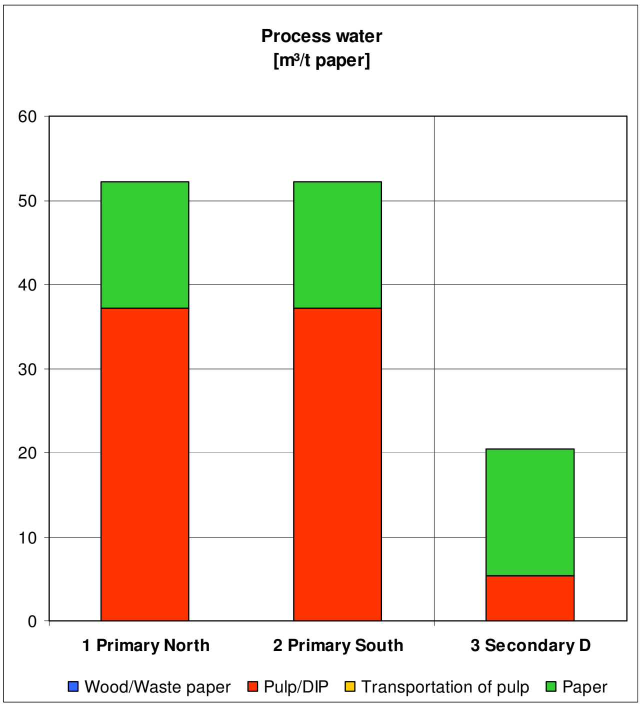
The calculated values for these indicators are additionally listed in tabular form in appendix I.

It should be noted that the process water demand of modern paper machines for producing paper from pulp/DIP can lie markedly below the values used. As the same paper process was assumed for all three cases under consideration – virgin fibre paper from pulp of northern and southern origin, as well as recycled paper from DIP (see Chapter 2.2.1) – this does not have any effect, however, on the absolute differences for the indicators depicted.

Transportation effects that can be seen in the greenhouse effect or the resource demand do not play a part here.







Results overview:

- For all three ecological aspects under consideration, the results for recycled paper production are by far the most favourable.
- The results can be traced back to differences in the production of pulp and DIP: obtaining fibre from wood is associated with a high demand for water. In addition, there is a relatively heavy burden on the effluent from dissolved material and the bleaching process.

Figure 2-3: Results of the ecological comparison of virgin fibre paper and recycled paper using as an example the amounts of chemical oxygen demand, process water demand and aquatic eutrophication

2.4.3 Primary energy demand and summer smog

To supplement Chapter 2.4.1, the indicators for primary energy demand – *fossil primary energy demand* and *total primary energy demand* – are described here. The indicator results for *summer smog/POCP* are also shown.

The results for recycled paper production are also clearly lower than for the production of virgin fibre paper for these three indicators.

Fossil energy demand in paper production

To produce recycled paper, fewer *fossil energy carriers* have to be provided than in the production of virgin fibre paper. Depending on the origin of the pulp, up to one quarter of the fossil energy carriers can be saved by producing office paper from waste paper.

The differences in this category occur in fibre production and transportation. The production of fibre is about one quarter more economical for recycled paper than for primary paper.

Relevance of non-fossil energy carriers

The fossil energy carriers, however, only represent one part of the energy required in the process. In virgin fibre pulp factories, the overwhelming majority of energy required (over 90 %) is provided by the use of biogenous residues and waste materials from the pulp process (wood, wood components, waste liquor). Only a small amount of the energy is provided by – external – fossil energy carriers. The additional use of residues and waste materials is taken into consideration in the indicator *total energy demand*. Here, the energy demand in the form of primary energy from both fossil and renewable energy carriers is considered.

The total primary energy carrier demand of paper production from wood is about two-and-a-half times as high as for recycled paper production.

A comparison between the total primary demand and fossil energy demand shows what has already been indicated above: the total energy demand for primary paper production is about two-and-a-half times higher than the fossil energy demand for this same primary paper production.

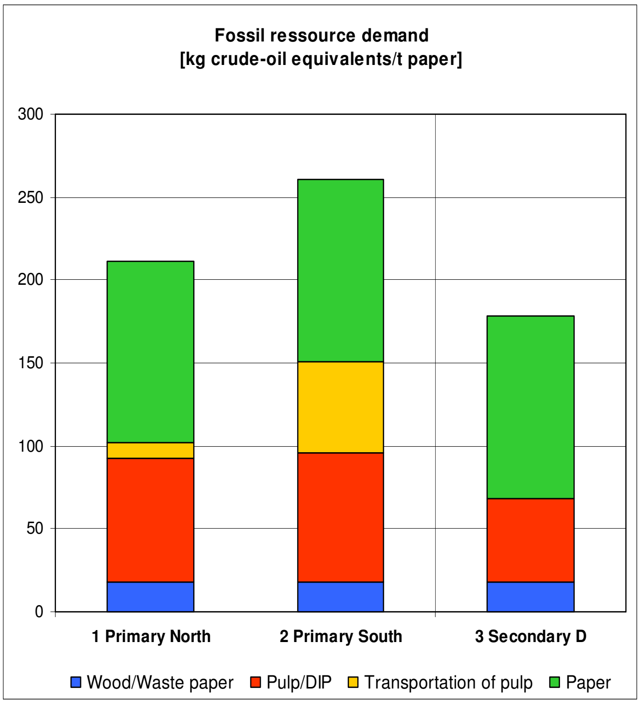
Summer smog

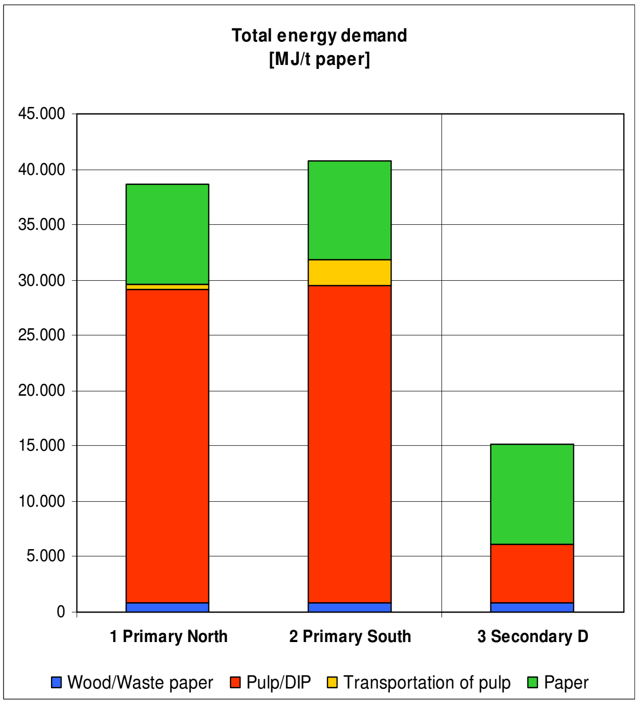
In considering the results for summer smog, the high contribution from the transportation of overseas pulp leaps to the eye. However, for the same reasons as for acidification (Chapter 2.4.1), the result should not be overrated, as the effect of summer smog on the high seas takes only a subordinate role.

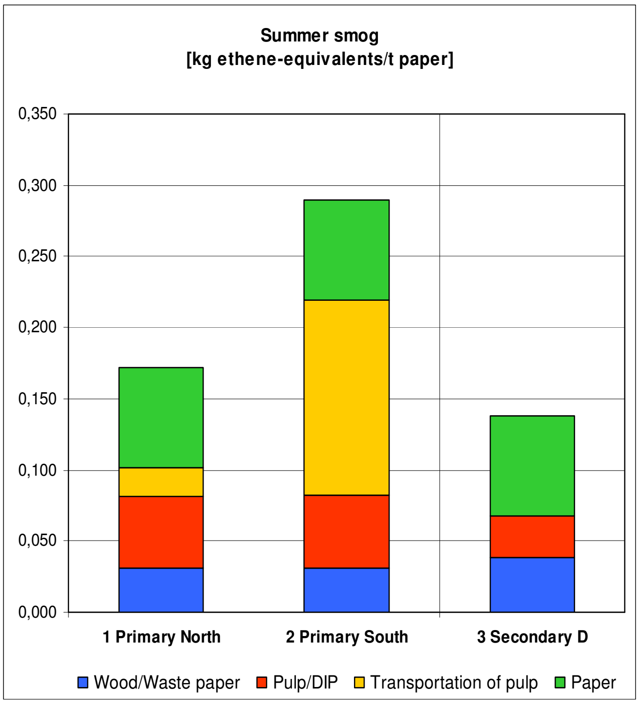
Even without taking into consideration the contribution caused by transportation, the results of recycled paper production for the indicator of summer smog lie about one fifth below those of paper production from virgin fibres.

While the results for waste paper and wood provision in the other environmental effect categories considered so far balance one another out, for this indicator the results for wood provision are lower than for waste paper. In wood provision, the contributions to the summer smog indicator are essentially caused by transportation and, in the case of waste paper processing, the contribution of the work required in sorting. These results in the wood and waste paper processing sector are compensated in the total picture, however, by the clearly lower indicator results in the production of recycled fibre compared to virgin fibre production.

The individual results of the calculations are listed in appendix I.







Result overview:

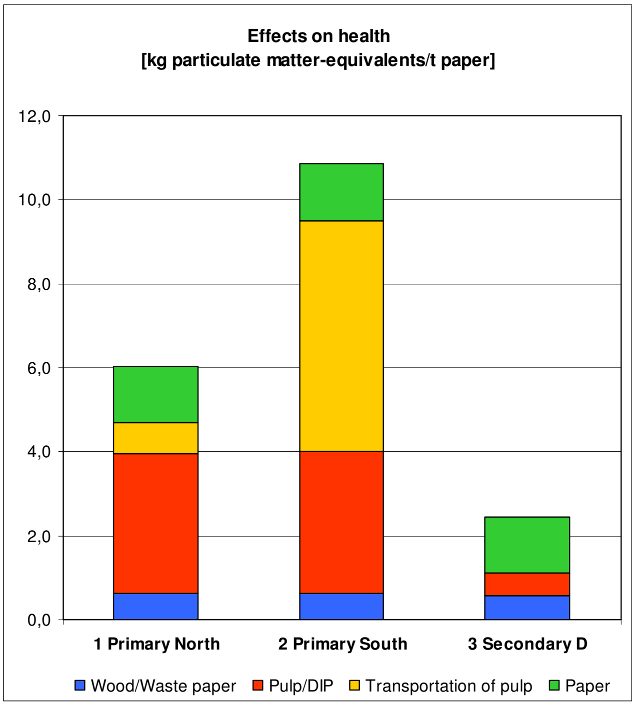
- The results for recycled paper production are the most favourable for all three ecological aspects under consideration.
- The fossil and total primary energy demand for recycled paper is clearly lower than for primary paper production.
- The result of the total energy shows that the process of pulp production from wood is clearly more energy-intensive than DIP production from waste paper due to the more expensive boiling process.
- Even without taking into consideration overseas transportation, the contribution to summer smog of recycled paper production is about one fifth lower than primary paper production.

Figure 2-4: Results of the ecological comparison of virgin fibre paper and recycled paper using as an example the fossil primary energy demand, the total primary energy demand and summer smog

2.4.4 Effects on health – particulate matter

Emissions of particulate matter in paper production

According to the figure, the emission of particulate matter in the production of paper from secondary fibres lies clearly below that from the whole process chain for producing paper from sulphate pulp. This can essentially be traced back to the lower energy demand and the lower transportation demand in the production of recycled paper.



Results overview:

- The burden of PM10 equivalents from recycled paper production is clearly lower than that of virgin fibre paper production.

Figure 2-5: Results of the ecological comparison of virgin fibre paper and recycled paper for the PM10 equivalent (particulate matter) environmental indicator

2.5 Conversion examples from practice

The following comparisons clarify why it is worth using recycled paper instead of virgin fibre paper, even in standard domestic quantities:

Table 2-1 and table 2-2 show the saving in emissions that results, or would result – depending on the reference size - from the production of recycled paper compared to virgin fibre paper production, using different examples. As an example, the differences are related to one pack of office paper (500 sheets of 80 g), one tonne of office paper (corresponding to 400 packs of 500 sheets) or the total annual office paper demand in Germany (approx. 800,000 t).

The production of just one pack of recycled paper saves enough fossil resources compared to virgin fibre paper of southern origin to light – using the fossil part of the German energy grid – a 100 W lightbulb for 44 hours.

One tonne of recycled paper, compared to virgin fibre paper of northern origin, saves the amount of CO_2 that an average car emits travelling 1,000 km.

If all of the office paper used in Germany (800,000 t per year) was produced from waste paper, then the process water demand would be about 25.4 million cubic metres less than in the production of the same quantity of virgin fibre paper – and this corresponds to the volume of water held in the Wuppertal dam, for example.

Comparison of virgin fibre paper from northern pulp with recycled paper	**Resources [kg crude oil equivalent]**	**Greenhouse effect [kg CO_2 equivalent]**	**Process water [kg]**
With reference to one pack of office paper (500 sheets)			
	0.08	0.5	80
With reference to 1 t of paper (400 packs of 500 sheets)			
	33	183	31,800
With reference to 800,000 t office paper (average annual consumption in Germany)			
	26,500,000	146,000,000	25,400,000,000

Table 2-1: Savings in emissions in the production of recycled paper compared to the production of virgin fibre paper made from pulp of northern origin

Comparison of virgin fibre paper from southern pulp with recycled paper	**Resources [kg crude oil equivalent]**	**Greenhouse effect [kg CO_2 equivalent]**	**Process water [kg]**
With reference to one pack of office paper (500 sheets)			
	0.21	0.9	80
With reference to 1 t paper (400 packets of 500 sheets)			
	82	347	31,800
With reference to 800,000 t of office paper (average annual consumption in Germany)			
	65,900,000	278,000,000	25,400,000,000

Table 2-2: Savings in emissions in the production of recycled paper compared to the production of virgin fibre paper from pulp of southern origin

3 Conclusion

In this study, the ecological profile of office paper produced in Germany from secondary fibres was compared with that from primary fibres. In the case of primary fibres, it was assumed that this was sulphate pulp of northern origin, transported to Germany as market pulp. One scenario variant for primary fibre paper was the transportation of pulp from overseas.

The selected scenarios do not represent a certain mill or a definite paper product. Rather, they depict as best they can the average situation of the northern production of market pulp and the German production of deinking pulp. The data used reflects the current state of affairs as far as this could be researched using publicly accessible sources.

For the evaluation of the ecological profile of the papers under comparison, the indicators of *fossil resource demand*, *greenhouse effect*, *acidification*, *aquatic eutrophication, water demand* and *COD* proved to be the most reliable and meaningful.

The environmental burden from the production of recycled paper is the lowest for all of the indicators considered. The recommendation of the Federal Environmental Agency to use recycled paper and paper with the highest possible proportion of waste paper should therefore be followed, in the opinion of the IFEU.

This applies in particular if long transportation distances are covered in the production of virgin fibre paper. So for ecological reasons, pulp from overseas should be rejected and waste paper for the production of recycled paper should come from regional collections.

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Appendix I: Results (numerical)

Overview of the calculatory results of analysed scenarios

Fossil resources [kg crude oil equivalent/t paper]	1 Primary North	2 Primary South	3 Secondary D
Wood/Waste paper	17.8	17.8	18.3
Pulp/DIP	74.8	77.8	50.4
Transportation of pulp	9.2	55.5	–
Paper	109.7	109.7	109.7
Total	**211.5**	**260.8**	**178.4**

Greenhouse effect [kg CO_2 equivalent/t paper]	1 Primary North	2 Primary South	3 Secondary D
Wood/Waste paper	57	57	60
Pulp/DIP	481	500	329
Transportation of pulp	34	179	–
Paper	543	543	543
Total	**1,116**	**1,280**	**933**

Acidification [kg SO_2 equivalent/t paper]	1 Primary North	2 Primary South	3 Secondary D
Wood/Waste paper	0.55	0.55	0.45
Pulp/DIP	3.43	3.47	0.57
Transportation of pulp	0.80	6.26	–
Paper	1.56	1.56	1.56
Total	**6.35**	**11.83**	**2.57**

Aquatic eutrophication [PO_4 equivalent/t paper]	1 Primary North	2 Primary South	3 Secondary D
Wood/Waste paper	0.000	0.000	0.000
Pulp/DIP	0.461	0.461	0.071
Transportation of pulp	–	–	–
Paper	0.280	0.280	0.280
Total	**0.741**	**0.741**	**0.352**

COD **[kg/t paper]**	**1 Primary North**	**2 Primary South**	**3 Secondary D**
Wood/Waste paper	0.00	0.00	0.00
Pulp/DIP	15.01	15.01	2.09
Transportation of pulp	–	–	–
Paper	2.44	2.44	2.44
Total	**17.45**	**17.45**	**4.53**

Process water **[kg/t paper]**	**1 Primary North**	**2 Primary South**	**3 Secondary D**
Wood/Waste paper	0	0	1
Pulp/DIP	37,179	37,179	5,408
Transportation of pulp	–	–	–
Paper	15,055	15,055	15,055
Total	**52,234**	**52,234**	**20,463**

Fossil energy demand (primary) **[kJ/t paper]**	**1 Primary North**	**2 Primary South**	**3 Secondary D**
Wood/Waste paper	730,486	730,486	774,053
Pulp/DIP	5,507,890	5,768,549	4,221,246
Transportation of pulp	419,278	2,269,836	0
Paper	7,956,721	7,956,721	7,956,721
Total	**14,614,374**	**16,725,591**	**12,952,019**

Total energy demand (primary) **[kJ/t paper]**	**1 Primary North**	**2 Primary South**	**3 Secondary D**
Wood/Waste paper	803,563	803,563	807,501
Pulp/DIP	28,365,846	28,708,851	5,352,290
Transportation of pulp	463,494	2,314,052	0
Paper	8,975,756	8,975,756	8,975,756
Total	**38,608,659**	**40,802,221**	**15,135,547**

Summer smog **[kg ethylene equivalent/t paper]**	**1 Primary North**	**2 Primary South**	**3 Secondary D**
Wood/Waste paper	0.031	0.031	0.038
Pulp/DIP	0.050	0.051	0.029
Transportation of pulp	0.020	0.137	0.000
Paper	0.070	0.070	0.070
Total	**0.171**	**0.290**	**0.138**

Effects on health (particulate matter) [kg PM10 equivalent/t paper]	1 Primary North	2 Primary South	3 Secondary D
Wood/Waste paper	0.62	0.62	0.57
Pulp/DIP	3.35	3.38	0.54
Transportation of pulp	0.73	5.51	0.00
Paper	1.35	1.35	1.35
Total	**6.037**	**10.856**	**2.453**

Appendix II: Basis of data

The following shows the essential characteristic values used in modelling the production of sulphate pulp, DIP and office paper.

Sulphate pulp

Production of primary pulp of northern and southern origin

Input per 1000 kg market sulphate pulp		
Basis of data: Ecoinvent		
Wood/Process water	**Coefficient**	**Unit**
Coniferous wood	911	kg
Hardwood	909	kg
Sawn wood remnants (air dried)	390	kg
Water (process)	38,000	kg
Chemicals	**Coefficient**	**Unit**
Calcium oxide	8.4	kg
Oxygen	23.7	kg
Sulphuric acid	30.1	kg
Sulphur dioxide	2	kg
Sodium chlorate	30.8	kg
Sodium hydroxide	35.6	kg
Hydrogen peroxide	5.4	kg
Calcium carbonate	1	kg
Methanol	2.7	kg
Magnesium sulphate	3.6	kg
Talcum	2.2	kg
Energy	**Coefficient**	**Unit**
Energy, electrical	0	kJ
Hard coal	8.69	kg
Natural gas	24.1	kg
Fuel oil, heavy	17.56	kg

Table A-1: Basis of calculations for sulphate pulp production – input data

Output per 1000 kg market sulphate pulp			
Basis of data: Ecoinvent			**Data sources that differ**
Waste water	**Coefficient**	**Unit**	
Effluent (process)	37.000	kg	
BOD-5	0.9	kg	BREF
COD	15.5	kg	BREF
Solids, dissolved	1.05	kg	BREF
Phosphorus compounds as phosphorus	0.02	kg	BREF
Nitrogen compounds as nitrogen	0.175	kg	BREF
AOX	0.19	kg	
Exhaust air	**Coefficient**	**Unit**	
Sulphur dioxide	0.83	kg	
TRS	0.19	kg	
Nitrogen oxides, non-specific	1.85	kg	
Particulate matter	0.05	kg	
Carbon dioxide, fossil	168.87	kg	
Particulate matter (PM10)	0.4	kg	
Waste	**Coefficient**	**Unit**	
Ashes and clinkers (WfD)	5.1	kg	
Hazardous waste (WfD)	0.26	kg	
Sludge (WfD)	8.1	kg	
Waste, non-specific (WfD)	8.1	kg	
Green liquor (WfD)	4.5	kg	

Table A-2: Basis of calculations for sulphate pulp production – output data

Milling	
Basis of data: Steinbeis Temming	
Energy, electrical	900,000 kJ/t pulp (northern)
	1,080,000 kJ/t pulp (Brazilian)*
Energy split as for paper production	

Table A-3: Basis of calculations for sulphate pulp production – energy demand for pulp milling

* Based on [Bos 1999] in agreement with experiential values from [STP 2006]

Deinking Pulp

Production of secondary pulp in Germany

Input per 1000 kg DIP (TS90)		
Basis of data: STP		
Raw material/Water	**Coefficient**	**Unit**
Waste paper, sorted (WfR)	1,379	kg
Water (process)	5,400	kg
Chemicals	**Coefficient**	**Unit**
Hydrogen peroxide	9	kg
NaOH	8.5	kg
Fatty acids	9	kg
Soluble sodium	18	kg
Sodium dithionite	3	kg
Energy	**Coefficient**	**Unit**
Energy, electrical	2,070,000	kJ
Output: DIP production		
Waste liquor	**Coefficient**	**Unit**
Effluent (process)	5,400	kg
COD	2.16	kg
BOD-5	0.135	kg
AOX	0.0162	kg
Phosphorus compounds, as phosphorus	0.004	kg
Nitrogen compounds, as nitrogen	0.029	kg
Air emissions	**Coefficient**	**Unit**
Particulate matter	0.01	kg

Table A-4: Basis of calculations for DIP production – input and output data

Approximate analysis of the energy carriers used in DIP production

Reference year	2005	2005	2005	2004	2004	? (ap-proval)	2005	2005
Operator	**UPM**	**UPM**	**UPM**	**Stora Enso**	**Mylly-koski**	**Mylly-koski**	**Leipa**	**STP**
Location	**Schon-gau**	**Augsburg**	**Schwedt**	**Eilen-burg**	**Ettringen**	**Hürth**	**Schwedt**	
Waste paper use [t/a]	678,300	185,900	363,200	484,977	574,466	355,600	606,518	180,000
Wood?	Wood, pulp, pigments	Wood, pulp, pigments	No	No	Wood + pulp	No	No	
Quantity pro-duced (paper, DIP etc.) [t/a]	712,600	457,300	286,300	381,099	571,542	280,000	680,392	230,000
Total steam demand				841 kWh/t				5.8 GJ/t
Total electricity demand				588 kWh/t				1000 kWh/t
Electricity (ex-ternal power) [MWh]	609,100	516,800	212,100	101,223	627,000	348,000	578,287	
Steam						617,700 t	818,824 MWh	
Natural gas [MWh]	958,100	751,700	172,100	879,410	437,000		83,886,31 7 m³	
Biogas							2,754,522 m³	
Fuel oil, light [MWh]		690	840		409,000			
Regenerative energy carriers without rem-nants	151,072		210,180					
Remnants	321,028		140,120					20 %
Surrogate fuels [MWh]				8,396				
Water power [MWh]	61,900							
Fuels [MWh]	2,290	3,160	2,900					
Hard coal								80 %
Brown coal						Electricity and steam provision		

Table A-5: Basis of calculations for DIP production – use of energy carriers by different DIP producers in Germany

Mix of energy carriers used in DIP production

Energy split, electrical: DIP	
Mix: Germany, for DIP	**Proportion**
Mains power	50 %
Natural gas	32.5 %
Fuel oil, light + heavy	2.5 %
Remnants + regenerative energy carriers	10 %
Hard coal	2.5 %
Lignite	2.5 %

Table A-6: Basis of calculations for DIP production

The energy carrier mix for DIP production in Germany was generally derived from looking at the largest DIP producers. The data was used as a basis for calculations in this investigation.

Basis: UPM Augsburg, UPM Schongau, UPM Schwedt, StoraEnso Eilenburg, Myllykoski Ettringen, Rheinpapier Hürth, Leipa Schwedt, STP (see table above). The proportion of mains power was derived from Basis of Data for UBA/Graphic Papers.

Paper production from primary and secondary fibres

Input per 1000 kg paper		
Basis of data: UBA, recycled office paper		
Material	**Coefficient**	**Unit**
DIP (TS90)/Market pulp	968	kg
Binders, synthetic	18.9	kg
Kaolin (TS90)	130	kg
Starch	56	kg
Process chemicals (paper production)	6.23	kg
Water (process)	14,800	kg
Energy	**Coefficient**	**Unit**
Energy, electrical	1,803,600	kJ
Energy, thermal	5,800,000	kJ
Output per 1000 kg paper		
Material	**Coefficient**	**Unit**
Paper	1,000	kg
Effluent (process)	14,800	kg
COD	2.44	kg
BOD-5	0.1525	kg
AOX	0.0183	kg
Phosphorus compounds, as phosphorus	0.0061	kg
Nitrogen compounds, as nitrogen	0.127	kg

Table A-7: Basis of calculations for paper production – input and output data

Energy split, electrical	
Basis for data: UBA	**Proportion**
Mains power	45 %
CHP, gas	27.5 %
CHP, remnants	27.5 %

Table A-8: Basis of calculations for paper production – power provision

Energy split, thermal	
Basis of data: IFEU estimates*	**Proportion**
Natural gas	65 %
Fuel oil, light + heavy	5 %
Regenerative energy carriers + remnants	20 %
Hard coal	5 %
Lignite	5 %

Table A-9: Basis of calculations for paper production – provision of thermal energy

* The energy split for thermal energy was derived in general from looking at the largest DIP producers. Basis: UPM Augsburg, UPM Schongau, UPM Schwedt, StoraEnso Eilenburg, Millkoski Ettringen, Rheinpapier Hürth, Leipa Schwedt, STP (see table above).

Transportation of pulp/DIP

Transportation	
Model 1 – Pulp of northern origin	Combined transportation of pulp from Scandinavia
Model 2 – Pulp of southern origin	Overseas transportation of pulp from Brazil
Model 3 – DIP, Germany	No transportation

Table A-10: Basis of calculations for paper production – pulp transportation