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Updated life-cycle assessment of graphic and tissue paper

background report

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Abstract: Updated life-cycle assessment of graphic and tissue paper

The last life-cycle assessment of the German Environment Agency for graphic papers, in which the environmental impacts of virgin papers and recycled papers were comprehensively examined, dates from the year 2000 (Tiedemann et al. 2000). A key finding of this study was that "it is much more environmentally friendly to produce graphic papers from recycled fibres than to use virgin fibres from wood as a raw material".

The award criteria of the Blauer Engel (Blue Angel) eco-label for paper products are also based on the results of this study and demand the highest possible use of recycled paper, preferably from post-consumer waste, as raw material for paper production.

The present study is an update of this LCA. It has been extended to include the consideration of tissue papers, a variety of scenarios on pulp type and origin, and a discussion on land use. A special focus is also placed on paper recycling in Germany.

The updated results largely support the previous UBA recommendations and the requirements of the Blue Angel eco-label for the promotion of recycled paper. Additional recommendations are given.

Kurzbeschreibung: Aktualisierte Ökobilanz von grafischen und Hygienepapieren

Die letzte Ökobilanz des Umweltbundesamtes für grafische Papiere, in der die Umweltwirkungen von Primär- und Recyclingpapieren umfassend untersucht wurden, stammt aus dem Jahr 2000 (Tiedemann et al. 2000). Ein zentrales Ergebnis dieser Studie war, dass "die Herstellung von grafischen Papieren aus Recyclingfasern wesentlich umweltfreundlicher ist als die Verwendung von Frischfasern aus Holz als Rohstoff".

Die Vergabekriterien des Umweltzeichens Blauer Engel für Papierprodukte basieren ebenfalls auf den Ergebnissen dieser Studie und fordern die höchstmögliche Verwendung von Recyclingpapier, vorzugsweise aus Post-Consumer-Abfällen, als Rohstoff für die Papierherstellung.

Die vorliegende Studie stellt eine Aktualisierung dieser Ökobilanz dar. Dabei wurde sie um die Betrachtung von Hygienepapieren, eine Vielzahl von Szenarien zu Zellstoffart und -herkunft sowie eine Diskussion über Landnutzung ergänzt. Besonderer Fokus liegt zudem auf dem Papierrecycling in Deutschland.

Die aktualisierten Ergebnisse stützen weitgehend die bisherigen Empfehlungen des UBA und die Anforderungen des Ökolabels Blauer Engel zur Förderung von Recyclingpapier. Weitere Empfehlungen werden abgeleitet.

Preface

This background report to the Updated life-cycle assessment of graphic and tissue paper acts as an additional report to the spotlight report UBA (2021). It includes a more comprehensive and detailed description of methodology and data and also addresses several additional aspects not covered in the spotlight report. These are for example the consideration of different fibre compositions including the use of grass fibres or the assessment of a final product on the consumer level.

The study was commissioned by the German Environment Agency UBA on the 21st of June 2017. Main contractor is Institut für Energie- und Umweltforschung Heidelberg gGmbH (Institute for Energy and Environmental Research, Heidelberg) (ifeu), sub-contractor is FÖP for market research.

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ADMT	Air-dried metric ton
AGRAPA	Arbeitsgemeinschaft Graphische Papiere
AOX	Adsorbable organically bound halogens
BREF	Best available techniques reference document
CED	Cumulated energy demand
CHP	Combined heat and power plant
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DIP	Deinked pulp
ECF	Elementary chlorine-free
EPD	Environmental Product Declaration
ifeu	Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research, Heidelberg)
ILCD	Guideline for the creation of an ecological footprint of paper (intermediate) products based on the proposed EU methodology for Life Cycle Assessment
IPR	Initiative Pro Recyclingpapier (Initiative for Sustainable Use of Paper)
LCA	Life Cycle Assessment
LWC	Lightweight coated (paper)
NMIR	Maximum incremental reactivity taking into account NOx sensitivity
NO_x	Nitrogen oxide
MIR	Maximum incremental reactivity
MSWI	Municipal Solid Waste Incineration
PEFC	Programme for the Endorsement of Forest Certification Schemes
PEFCR	Product Environmental Footprint Category Rules
PM 10	Particulate matter with particle diameter smaller than 10 µm
PCR	Product Category Rules
PEF	Product Environmental Footprint
PO_4	Phosphate
POCP	Photochemical Ozone Creation Potential
SC	Super calandered (paper)
SO_2	Sulphur dioxide
TCF	Total chlorine-free
UBA	Umweltbundesamt (German Environment Agency), Dessau

ADMT	Air-dried metric ton
VDP	Verband Deutscher Papierfabriken

Units and dimensions used

µm	micrometre, 10^{-6} metre
L	litre
m²	square metre
m³	cubic metre, 1.000 litres
mg	milligram
g	gram
kg	kilogram, 1.000 grams
t	tonne, 1.000 kilograms
kJ	kilojoule, 1.000 joules
kt	kilotonne, 1000 tonnes
MJ	megajoule, 1.000.000 kilojoules
W	watt
MWh	megawatt hours, 1.000 kilowatt hours
a	year

Note on decimal separator:

The symbol used as the decimal separator throughout this document is a comma. This is in line with the recommendations of (ISO 80000-1 2013) for international documents.

1 Introduction

This background report to research project "Updated life-cycle assessment of graphic and tissue paper" supplements the spotlight report with further elements.

The spotlight report contains core facts and main findings of the LCA study and additionally addresses land use criteria that are difficult to quantify, such as biodiversity, land use change and carbon storage in forests. It also includes a section providing a better understanding on how the paper cycle related to office and tissue paper can be strengthened and on how Eco-labels can contribute to this objective.

The background report contains further information on existing work on the topic as well as on the goal and scope of the LCA section. Furthermore, additional LCA scenarios are included. Additional results are presented for technical variants regarding fibre composition and sources including alternative fibre materials. Also, scenarios of a final paper product in an extended system framework (cradle-to-grave) are examined.

2 Overview of existing reference works and LCA studies

Various studies have already been carried out on the German, but also on the European level. They are briefly presented below and were taken into account in developing the methodology for this study.

Apart from the study for graphic paper already mentioned in the spotlight report from the year 2000, UBA commissioned another LCA study for graphic paper in 2008. Ifeu, in cooperation with FÖP, carried out an environmental assessment of virgin fibre and recycled fibre-based copy paper (Detzel et al. 2008). This environmental assessment was designed as a background study and was intended to provide information on the market and the state of knowledge at that time regarding the life cycle assessment classification of copy papers made from virgin fibres. As this was a background study, not the complete report was published, but substantial extracts were available on the homepage of the German Environment Agency.

The impact assessment in (Tiedemann et al. 2000) and, to a large extent, the impact assessment in (Detzel et al. 2008) were based on the then valid UBA guidelines on life cycle assessment, which are set out in UBA texts 23/95 (UBA 1995) and 92/99 (UBA 1999). These methodological guidelines were under revision by UBA at the time of this project. Unfortunately a new set of methods has not been published until the final stage of this project.

At the European level, there are also relevant methodological developments in the course of EU activities to develop a harmonised methodology for calculating environmental footprints of products. In 2016 a draft of product category rules for intermediate paper products was presented (Schau et al. 2016), which in turn are based on the methodological guidelines according to Guideline for the creation of an ecological footprint of paper (intermediate) products based on the proposed EU methodology for Life Cycle Assessment (ILCD) and Product Environmental Footprint (PEF). This refers to paper products from the exit gate of a paper mill or paper roll goods without including further processing into an end product. Product category rules (Environmental Product Declaration) for writing and packaging papers (EPD 2015) and tissue papers (EPD 2016) have been in existence for some time now. They were developed by the Environdec platform based on ISO 14025, the standard for life-cycle assessment based product declarations.

In the opinion of the authors, the most important methodological reference works for the deduction of the methodological specifications in the current research project have thus been identified. In addition, a literature search was carried out to determine which life cycle assessments of paper products (graphic papers and tissue papers) have been conducted in the last 10 years and whether these have given rise to additional new aspects of the methodology of life-cycle assessment of papers that should be considered in this project. In the following, various aspects of these studies are briefly presented and the methodology is described.

2.1.1 Short description of the central reference documents

The documents identified in the previous section as of central importance for the methodological definition of the present study are briefly described here.

(Tiedemann et al. 2000) Life Cycle Assessment Graphic Papers of the German Environment Agency

<u>Content:</u> Comparison of recycling and disposal processes for recycled graphic paper and product comparisons for newsprint, magazine paper and printing paper from an environmental point of view.

Relevance for the project: The study was based on a comprehensive primary data collection by ifeu from the German and Nordic paper industry. From the data collection, inventory data for all essential processes of wood production, fibre preparation, paper production and recycling were derived. Comparable procedures and knowledge are needed in the current UBA project.
The life cycle assessment was carried out in full compliance with DIN EN ISO standards 14040 and 14044. The detailed knowledge of the methods and scenarios used at the time forms the basis for a comparison with the current discussion of methods and the current status of publicly available life-cycle assessments and life-cycle inventories for paper.

- (Detzel et al. 2008) Data basis for the climate and resource efficiency of copy paper on the German market on behalf of the German Environment Agency, March 2008

  Content: Preparation of environmental information on the production of copying paper from virgin and recycled fibres for the German Environment Agency. The aim was to provide UBA with fact-based opinion-forming and public information on the ecologically sound purchase of copying paper. Market research and comparative analyses of virgin paper and recycled paper were carried out.

  Relevance for the project: The approach to market research developed in the project and the review of life cycle assessments with narrower scope compared to the UBA Paper Life Cycle Assessment provide a good starting point for further and more comprehensive consideration of the market situation and environmental impacts of copying/writing and tissue paper in the specifications.

- (Schau et al. 2016) Product Environmental Footprint Category Rules (PEFCR) Intermediate Paper Products, 2016

  Content: Guideline for the creation of an ecological footprint of paper (intermediate) products based on the proposed EU methodology for Life Cycle Assessment (ILCD).

  Relevance for the project: According to the EU, the method proposal should be considered in all future EU projects that include an environmental assessment of products. Since the current project is also intended to serve the German Environment Agency as a basis for positioning itself in the context of the development of award criteria for the EU eco-label for paper products, it is considered appropriate to include it in the comparative methodological assessment.

- (EPD 2015) and (EPD 2014): Category rules for environmental declarations of (a) processed paper and board and (b) tissue products.

  Content: Methodological requirements for the accounting of paper products based on ISO 14025,

  Relevance for the project: Further international reference point for the derivation and classification of methodological specifications for the life cycle assessment of paper products.

2.1.2 References from supplementary research of LCA studies

As mentioned above, an online-based search for publicly available life cycle assessments on paper products was carried out within the framework of WP1 in order to gain further insights into the common international practice of (LCA based) environmental assessment of writing and tissue papers.

Altogether, only a few publicly available sources were found that are related to the questions of the current project. These are listed below:

- (Silva et al. 2015) Life cycle assessment of offset paper production in Brazil: hotspots and cleaner production alternatives, 2015
- (Leon et al. 2015) Quantifying GHG emissions savings potential in magazine paper production: a case study on supercalendered and light-weight coated papers, 2015
- (Ghose et al. 2013) Environmental aspects of Norwegian production of virgin paper and printing paper, 2013
- (James 2012) An investigation of the relationship between recycled paper and board and greenhouse gas emissions from land use change, 2012
- (Hong et al. 2012) Environmental assessment of recycled printing and writing paper: A case study in China, 2012
- (Manda et al. 2012) Innovations in papermaking: An LCA of printing and writing paper from conventional and high yield pulp, 2012
- (González-García 2009) Environmental impact assessment of total chlorine free fibres from Eucalyptus globulus in Spain, 2009
- (Dias et al. 2007) Life cycle assessment of printing and writing paper produced in Portugal, 2007
- (Schmidt et al. 2007) Life cycle assessment of the waste hierarchy – A Danish case study on waste paper, 2007
- (Gromke and Detzel 2006) Ökologischer Vergleich von Büropapieren in Abhängigkeit vom Faserrohstoff. Im Auftrag der „Initiative Pro Recyclingpapier“, Berlin; 2006
- (AFPANDA) Printing & Writing Papers: Life-Cycle Assessment Summary Report
- (Meinl et al. 2016) D1.4 EUROPEAN FIBRE FLOW MODEL
- (Lindberg et al. 2018) Life Cycle Assessment (LCA) of Specialty Paper for Holmen Paper

These studies are referred to at the appropriate points.

2.1.3 Methodological comparison

General reference for this study:

As minimum requirements, the life cycle assessments should be carried out in accordance with the DIN EN ISO standards 14040:2006 and 14044:2006 as well as DIN ISO/TS 14067:2014.

Within the rules of the DIN EN ISO standards the following methodological aspects have to be chosen for this study:

- Definition of the system boundaries of the product systems under consideration
- Definition of the functional unit
- Definition of the method of impact assessment, in particular the impact categories and indicators to be considered

The following sections give an overview of the corresponding methodological choices that have been made in the reference documents mentioned. This information serves as base for the choices made for this study.

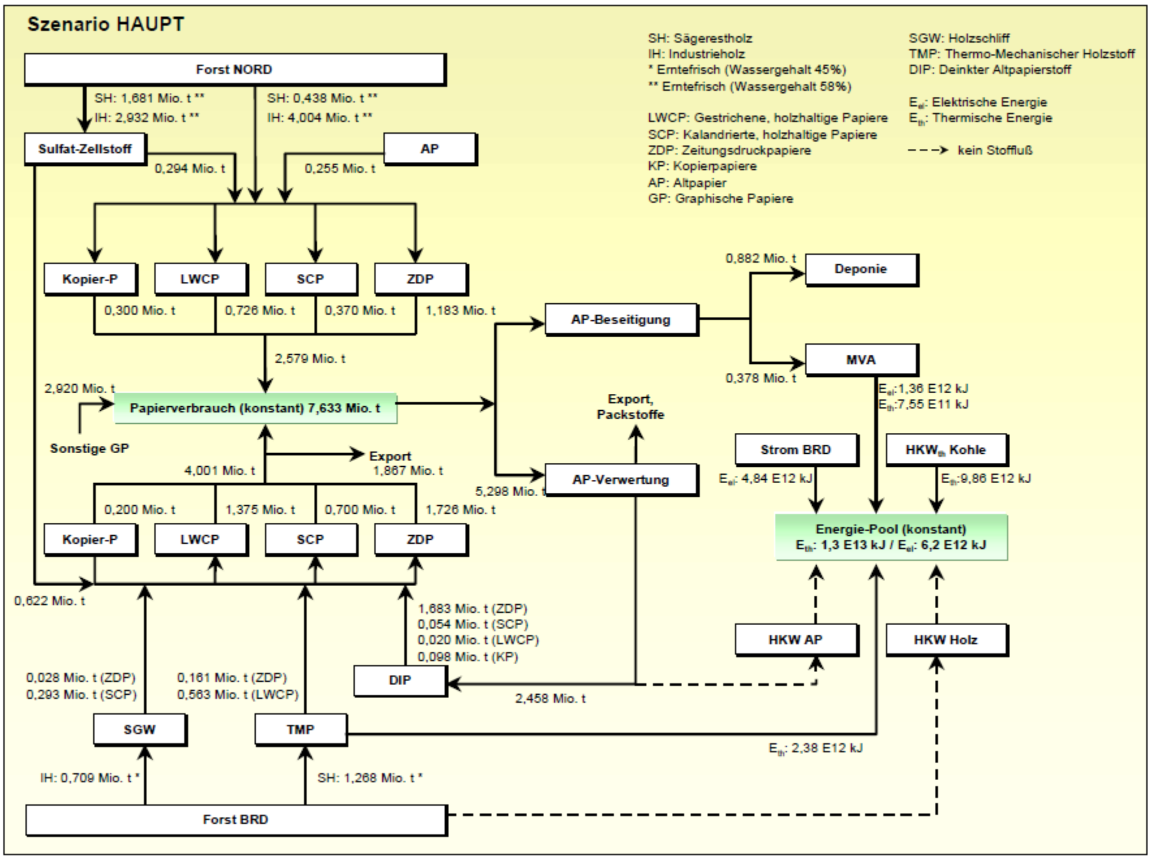
2.1.3.1 System boundaries

2.1.3.1.1 Tiedemann et al. 2000 (UBA)

The system boundaries as set in (Tiedemann et al. 2000) are shown in Figure 1. They covered the entire graphic paper market in Germany, taking into account import flows of market pulp and graphic paper from the Nordic countries. They also included the graphic printed products newspapers and magazines, which are not shown as separate modules in Figure 3. The life cycles of the paper products considered started with the forestry production of wood and went up to and including the disposal of the paper products.

In the basic model of the graphic paper system the volume flows were mapped according to the real paper flows in the reference year of the project. All graphic papers were always considered together with their respective proportions of the different virgin fibre types and the recycled paper stock. Starting from the basic model, scenarios with higher and lower recycled paper contents in the graphic paper products were assessed. The total amount of graphic paper was always kept constant, only the composition of the fibre flows differed. It was therefore not possible to separately consider individual paper grades such as copy paper, newsprint, LWC or SC paper or different recycled paper contents in these papers.

Figure 1: System boundaries in Tiedemann et al. 2000 (UBA)

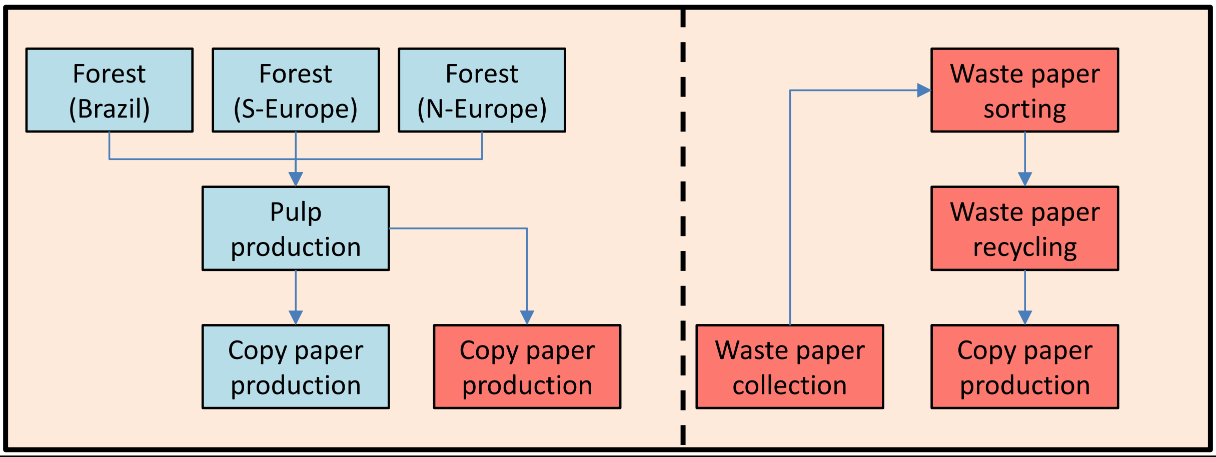


Source: ((Tiedemann et al. 2000), main report)

2.1.3.1.2 Detzel et al. 2008 (UBA)

The system boundaries as set in (Detzel et al. 2008) are shown in Figure 2

Figure 2: System boundaries in Detzel et al. 2008 (UBA)



Blue boxes: Processes that are located outside Germany according to the model assumption

Red boxes: Processes that are located within Germany according to the model assumption

Source: ifeu, based on (Tiedemann et al. 2000)

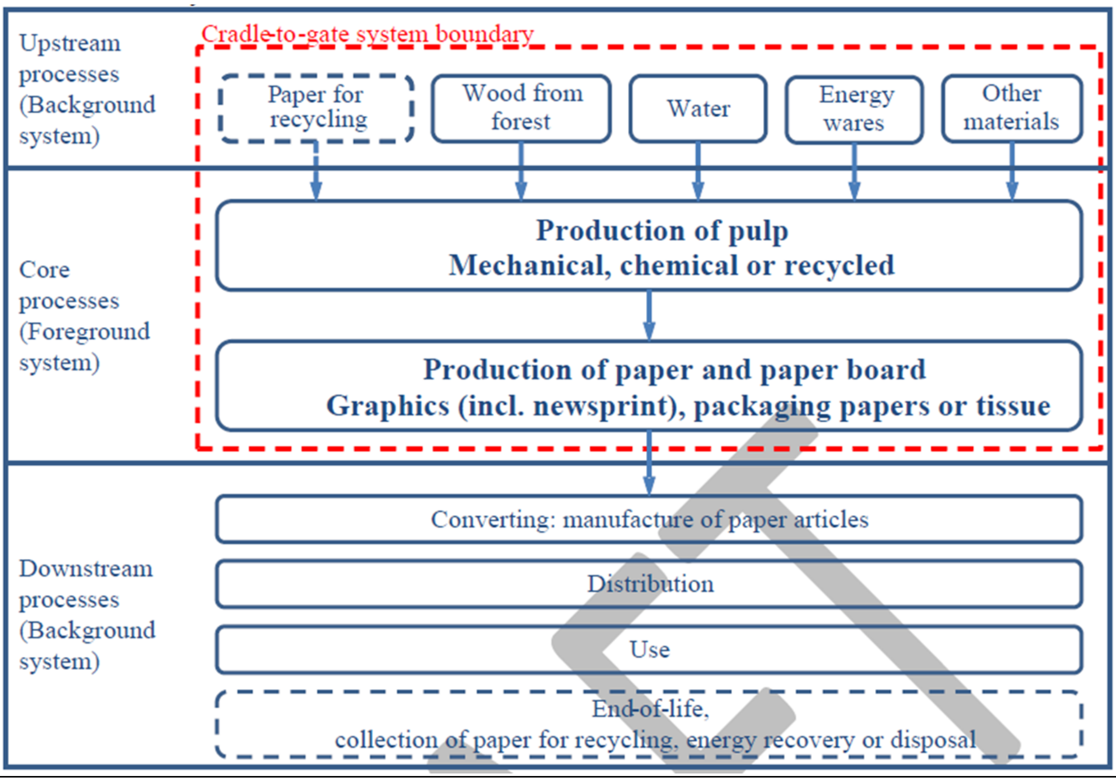
The dotted line in the middle indicates that the virgin paper (left side) and the recycled paper (right side) were examined as separate scenarios. Neither was the paper product given a credit for possible recycling after use, nor was the recycled paper given a debit from the previous life cycle. In terms of modelling, this corresponds to a so-called cut-off process.

In the project, imports of fibres (from the Nordic countries and overseas), of integrated copy paper from virgin fibres (from the Nordic countries and Portugal) and paper production in Germany were considered.

2.1.3.1.3 Schau et al. 2016

The system boundaries for an intermediate paper product according to (Schau et al. 2016) are shown in Figure 3. The fibre life-cycle begins with forestry and ends at the exit gate of the paper mill.

Figure 3: System boundaries in Schau et al. 2016



Source: (Schau et al. 2016)

For fibres from recycled paper, the life cycle begins with waste paper collection followed by waste paper sorting (neither of which is visible in Figure 3).

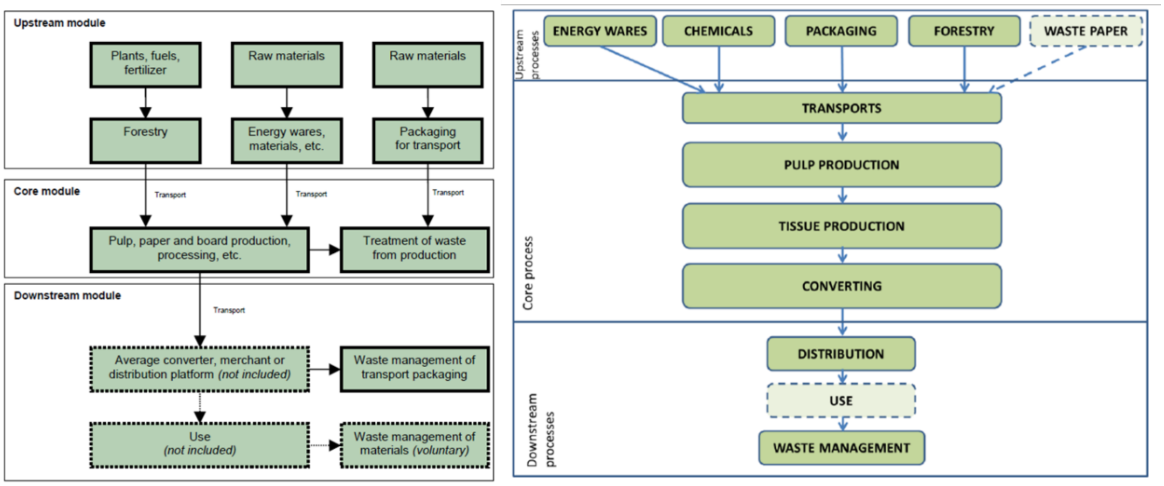
Each paper product is assessed according to its actual fibre mix. Use and disposal are outside the system boundaries and possible credits associated with this (system allocation) are therefore not considered or would only have to be considered in the assessment of an end product (e.g. magazine).

In (Schau et al. 2016) a so-called end-of-life recycling formula is proposed, which is based on a formula from the ILCD Guidelines that has since become obsolete. Currently, a formula is under discussion in which specific allocation factors are proposed for material groups. For paper, an allocation factor of "0.5" for graphic and tissue paper is mentioned. As far as the authors know, the factors have not yet been finally agreed. If these factors remain as they are, this would mean that 50 % of the burden from the previous life cycle would be allocated to the use of recycled fibres.

2.1.3.1.4 Environmental Product Declaration (EPD)

The system boundaries for determining an environmental declaration for paper products according to the product category rules of the Environdec platform are shown inFigure 4. On the left side is a diagram of the product life-cycle for graphic papers and boards (Product Category Rules (PCR) Processed Paper and Board), on the right side a diagram of the product life cycle for tissue papers (PCR Tissue Products)

Figure 4: System boundaries at EPD



Source: (EPD 2015 and EPD 2016)

The fibre life-cycle begins with forestry and ends with disposal, excluding the trade and use phase. For waste paper fibres, the life cycle begins with the transport of waste paper for the production of recycled paper. At the end of the life-cycle, all processes up to the point where the waste paper is transported for recycled fibre production are included.

The issue of system allocation is not explicitly addressed, but it can be deduced from the presentation of the system boundaries that a cut-off approach is used.

2.1.3.1.5 Additional studies

The choice of system boundaries in the supplementary researched studies is briefly listed below:

- (Silva et al. 2015)

Virgin fibre based offset paper is considered. The system boundaries cover forestry up to the finished paper at the factory gate of the paper mill.

- (AFPANDA 2012)

Two assessment areas are defined:

- A: from forestry to the finished paper at the factory gate

- B: from forestry to disposal of the finished printed paper product

System allocation:

- Principle: the waste paper fibre bears the burden of virgin fibre production. Objective: to promote the recycling of paper products after the use phase. Consequence: the supplying system is relieved according to the recycling rate, the receiving system is charged with the corresponding virgin fibre production

- Allocation factors: The allocation factors are derived on the basis of the number of consecutive uses. The study refers to ISO TR 14049; the allocation factors actually used are not documented.

► (Manda et al. 2012)

The entire life-cycle of office paper with different fibre mixes (cellulose, mechanical fibre, recycled fibre) is considered.

System allocation:

- Use of recycled paper without consideration of the previous life-cycle (cut-off)

- Life-cycle recycling, basic approach: Consequential modelling, assuming that the wood saved by paper recycling is used to generate electricity and replaces grid electricity (EU mix).

- Recycling at the end of the life-cycle, variant: Attributive modelling, assuming that the wood saved by paper recycling leads to reduced use of forest land. In the single-score results of the study, where the results of different impact categories are calculated into a single score for environmental performance (this necessitates weighting and is therefore beyond the rules of the ISO standards for LCA) this leads to a greatly reduced overall environmental impact.

► (Schmidt et al. 2007)

Fibre and paper flows are considered in relation to total paper consumption in Denmark, considering the geographical origin of the fibres and papers.

Scenarios: depending on whether an additional 1 tonne is recycled or not

a. either less wood is needed for paper production, with the wood saved being used for energy production and replacing natural gas

b. more wood is needed for paper production, but more energy is obtained from waste incineration (of waste paper)

c. more wood is needed for paper production, but more waste paper is landfilled

► (González-García 2009)

Production of pulp from eucalyptus wood is considered. The system limits range from forestry to the finished market pulp at the factory gate of the paper mill.

► (Leon et al. 2015)

The production of graphic paper is considered from the forestry to the finished paper at the factory gate. Papers with standard grammages are compared with grammages reduced by process optimisation.

► (Ghose et al. 2013)

It covers the production of writing paper in Norway from fibre production (excluding forestry) to the finished paper, including the transport of the paper to the customer.

System Allocation: Recycled paper use without load from previous life (cut-off)

► (Hong et al. 2012)

The production of writing paper in China from virgin fibres and recycled fibres is examined. The entire life-cycle is included.

System allocation: recycled paper use without the burden of previous life (cut-off)

- (Dias et al. 2007)

The study looks at the production of office paper from virgin fibres in Portugal with two variants for final consumption:

(a) Marketing and disposal in Portugal; and

(b) Marketing and disposal in Germany. Specific waste paper recycling quotas are used for Germany and Portugal. System allocation:

a) Waste paper recycling with subsequent production of packaging paper receives a credit for packaging paper made of virgin fibres

b) Recycled waste paper with subsequent production of tissue paper shall be credited for tissue paper made from virgin fibres

- (Gromke and Detzel 2006)

The production of copy paper in Germany from virgin fibre and recycled fibre is examined. This includes forestry up to the finished copy paper at the factory gate of the paper mill; without packaging.

System allocation: recycled paper use without load from previous life (cut-off).

- (Meinl et al. 2016)

The report for the European Fibre Flow Model is not an LCA study, but delivers invaluable information regarding the mean age and number of uses of paper fibres.

- (Lindberg et al. 2018)

The production of Specialty Paper in Sweden from virgin fibres is examined and compared with the production of Specialty Paper from recycled fibres under assumed German production conditions.

System allocation: 50 % / 50 % allocation for base scenarios, includes sensitivity analysis with cut-off approach.

2.1.3.2 Functional unit (FU)

The functional units used in the reference documents considered here are listed below in enumeration mode:

- (Tiedemann et al. 2000)

The total consumption of graphic paper in Germany in the reference year of the study and an amount of electrical and thermal energy fixed at a given value.

- (Detzel et al. 2008)

1 tonne of copy paper (80 g/m^2) at the exit gate of the paper mill in Germany.

- (Schau et al. 2016)

1 tonne of paper ready for sale at the exit gate of the paper mill

- EPDs for paper (EPD 2015), (EPD 2016).

1 tonne of paper ready for sale as well as the necessary packaging at the exit gate of a paper mill or at a defined point of sale between paper mill and paper merchant.

- (Silva et al. 2015)

1 tonne offset paper Din A4 size, 75 g/m^2

- (AFPANDA 2012)

- Office paper (uncoated): 1 ream of paper for consumer use

- Telephone directory (uncoated) made of mechanical pulp: 1 standard telephone directory (36 inner pages a 68 g/m^2 + 2 cover pages a 90 g/m^2) for consumer use

- Catalogue: 1 standard catalogue (600 inner sheets a 36 g/m^2 + 2 cover sheets a 200 g/m^2) for consumer use

- Magazine (uncoated) of mechanical pulp: 1 standard catalogue (60 inner sheets a 57 g/m2 + 2 cover sheets a 90 g/m2) for consumer use

- (Manda et al. 2012)

1 tonne of office paper (80 g/m2)

- (Schmidt et al. 2007)

1 tonne of additionally recycled paper in Denmark

- (González-García 2009)

1 tonne sulphate pulp produced from eucalyptus wood in a Spanish paper mill

- (Leon et al. 2015)

1 m^2 of ready-to-print magazine paper

- (Ghose et al. 2013)

1 tonne of newsprint or SC paper produced in Norway

- (Hong et al. 2012)

1 kg Chinese office paper (50 g/m^2)

- (Dias et al. 2007)

1 tonne of white office paper (80 g/m^2) produced in Portugal from sulphate pulp of eucalyptus globulus

- (Gromke and Detzel 2006)

1 tonne of copy paper (80 g/m^2) at the factory gate of the paper mill

- (Lindberg et al. 2018)

Production of 1 kilogram of Specialty Paper. Paper from Braviken and Hallsta and

Production of 1 kilogram advertising flyer including recycling management of the flyer.

2.1.3.3 Impact assessment

When determining the procedure for impact assessment in the current project, the current consensus-building process at UBA is considered as far as possible. It is therefore particularly interesting to compare the preliminary UBA method with the method proposed by the EU (ILCD 2011), which is also the basis for the PEF Guidelines. The UBA method has not yet been officially adopted, which is why the information provided here is subject to change. The two methods are compared in Table 1, and the "old" UBA method from 1995 is also listed.

Table 1: Overview of impact assessment categories and methods including characterisation factors (cf)

Impact category	ILCD 2011		UBA 1995ff		UBA 2016	
	Recommended LCIA method	CF	based on	CF	based on	CF
Classification I	Recommended and satisfactory					
Climate Change	IPCC 2013	GWP100 [kg CO2/kg]	IPCC 2007	GWP100 [kg CO2/kg]	IPCC 2013	GWP100 [kg CO2/kg]
Ozone depletion	WMO 1998	ODP	CML 2002	ODP [kg CFC-11 eq./kg] (incl. N2O)	WMO 2010	ODP [kg CFC-11 eq./kg] (incl. N20)
Respiratory inorganics	Humbert 2009	[kg PM2.5-eq/kg]	De Leeuw 2002	[kg PM10-eq/kg	De Leeuw 2002	AFP [kg PM2.5-eq/kg]
Classification II	Recommended but in need of some Improvements					
Ionising radiation, human health	Frischknecht et al. 2000	[kg U235-eq/kg]		-	Frischknecht et al. 2000	IRP-NE: Ionizing Radiation Potential Nuclear Energy [Person-Sv/kBq]
Photochemical ozone formation	Van Zelm et al. 2007	OFP [kg NMVOC eq/kg]	CML 2002	POCP [kg ethylene eq/kg] (ohne NO_x)	Carter 2010	MIR [g O3-e/kg]
Acidification	Seppälä et al. 2006, Posch et al. 2008	Accumulated exceedance [H+ eq./kg]	Heijungs et al. 1992	AP [kg SO2 eq./kg]	Heijungs et al. 1992	AP [kg SO2 eq./kg]

Impact category	ILCD 2011		UBA 1995ff		UBA 2016	
	Recommended LCIA method	CF	based on	CF	based on	CF
Eutrophication, terrestrial	Seppälä et al. 2006, Posch et al. 2008	Accumulated exceedance [H+ eq./kg]	Heijungs et al. 1992	EP [kg PO4 eq. in air/kg]	Heijungs et al. 1992	EP [kg PO4 eq. in air/kg]
Eutrophication, freshwater	Recipe 2008	[kg P eq./kg]	Heijungs et al. 1992	EP [kg PO4 eq. in air/kg]	Heijungs et al. 1992	EP [kg PO4 eq. in water/kg]
Classification II/III						
Resource depletion, mineral	Schneider et al. 2015 & Hierschier et al. 2010	AADP [kg antimony eq./kg] CED [MJ/kg]		-	Giegrich et al. 2012	WP(KRA) [kg-e/kg] WP(KEA) [MJ-e/kg]
Resource depletion, fossil			UBA 1999	FDP [kg crudeoil eq./kg]		
Resource depletion, renewable			-	-		
Human toxicity cancer	USEtox	[CTUh]	IRIS 2006 (USEPA)	Unit risk values [kg As eq. to air/kg]	USEtox	[CTUh]
Human toxicity non-cancer	USEtox	[CTUh]		-	USEtox	[CTUh]
Ecotoxicity (freshwater)	USEtox	[CTUe]		-	USEtox	[CTUe]
Classification III	Recommended but to be applied with caution					
Land use	Bos et al. 2016	LANCA Erosion resistance LANCA Mechanical filtration LANCA Ground water	UBA	Land occupation by classes of nature proximity [m² xa/kg]	Fehrenbach et al. 2015	Naturferne potential (NFP) [m²*a/kg]

Impact category	ILCD 2011		UBA 1995ff		UBA 2016	
	Recommended LCIA method	CF	based on	CF	based on	CF
		replenishment LANCA Biotic Production				
Resource depletion, water	Boulay et al. 2016	AWARE model (water scarcity)	Inventory data	[m³/kg]	Pfister et al. 2009, Ridoutt and Pfister 2012	Wasserstressindexi WSII [m³ H2Oe/kg]

Sources: (ILCD 2011), (Klöpffer et al. 1995), (Detzel et al. 2016)

The comparison in Table 1 shows that the current UBA method in principle covers the same impact categories as the ILCD guidelines. There are differences with regard to aquatic eutrophication and resource consumption. For the former, the ILCD guidelines distinguish between marine and freshwater eutrophication, whereas the UBA method combines both in one impact category. In the latter case, the ILCD guidelines distinguish between fossil, mineral and renewable resource consumption, while the UBA method distinguishes between the cumulative raw material demand measured once as mass (CRD) and once as cumulative energy demand (CED). The choice of categories by UBA is more recent than ILCD and explained in detail in (Detzel et al. 2016).

There are differences between the UBA method and the ILCD guidelines with regard to the characterisation methods for calculating the indicator results of the respective impact categories for most impact categories.

► Indicators with environmental relevance in (Detzel et al. 2008)

The following indicators were considered in the background study for the German Environment Agency:

- Primary energy demand (total)

- Primary energy demand (non-renewable)

- Process water demand

- Wood demand

- Greenhouse effect

► Environmental performance indicators according to (EPD 2015) and (EPD 2016)

The EPDs for paper products distinguish between

1. Resource consumption

- Non-renewable resources (material/energy)
- Renewable resources (material/energy)

- Water consumption, differentiated by
  - Total
  - Core processes

2. Potential environmental impacts

- Greenhouse effect
- Acidification
- Ground level ozone formation
- Aquatic eutrophication.

2.1.3.4 Biodiversity, CO2 storage in forests, land use change

In connection with land use for wood production, the aspects of biodiversity, CO_2 storage in the forest and land use change are increasingly coming into focus. They are not easy to take into account in the context of life cycle assessments because there is a lack of generally accepted methods and the necessary data. It is therefore not surprising that the three aspects mentioned above are hardly addressed in the well-known life-cycle assessments or methodological guidelines on paper.

In (Tiedemann et al. 2000) forest land is classified as a natural area used in a defined hemerobic class.

In (Detzel et al. 2008) the use of natural areas was not evaluated.

In (Schau et al. 2016) there is a requirement to provide information on biodiversity. There are two ways to do this:

1. Route 1
   a. Indication of the content of fibres from certified supply chains, where the certification criteria shall include biodiversity and ecosystem services
   b. Indication of the remaining fibre content from sources that can be shown not to be problematic (e.g. illegal logging, logging to convert forests into plantations, use of genetically modified species etc.)
2. Route 2, if information according to route 1 is not available:
   a. Indication of the content of fibres from stands that are designed to maintain or increase biodiversity and are subject to regular monitoring of biodiversity

CO_2 flows associated with land-use changes must be taken into account in the balance. PAS2050-1:2012 Horticultural Products is cited as the method reference for this.

In the LCA studies selected within the framework of the extended research, the aspects of biodiversity, CO_2 storage in forests and land-use change are practically not addressed. In this context, the most interesting part could be the literature reference (James 2012). There, considerations are made whether a change from virgin fibres to recycled fibres or vice versa could promote or slow down deforestation. This is based on a consistent approach, considering paper flows across several countries or even continents.

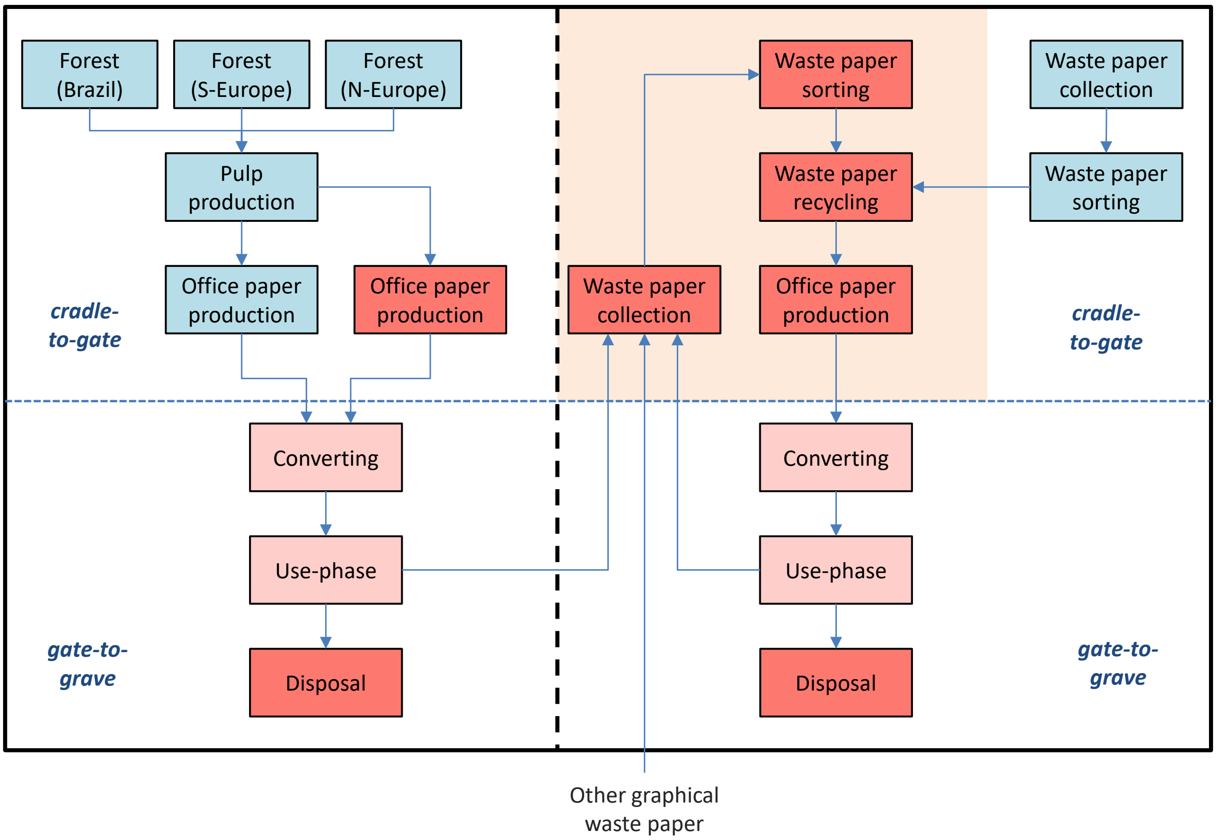
2.2 LCA scope

2.2.1 System boundaries

In this present study three different perspectives on paper and paper products respectively were considered. In the spotlight report only the first is included. This background report adds the remaining two perspectives.

1. Paper at the paper mill outlet (intermediate paper product)
   This was modelled in form of a cradle-to-gate system boundary (Figure 5)
2. Ready-for-use paper products (final paper product)
   This was modelled in form of a cradle-to-grave system boundary (Figure 5)
3. Paper in a multiple recycling chain
   This perspective is presented in the discussion section of this background report (section 5).

Figure 5: System boundaries for the current study



Blue boxes: Processes that are located outside Germany
Red boxes: Processes that are located within Germany
Cradle-to-gate: Basic model of the system boundaries, which allows a direct comparison of the centrally different steps in the production process.
Gate-to-grave: Exemplary inclusion of processing into consumer-related products (e.g. exercise books) and disposal processes to determine the environmental profiles of the entire life cycle and the related hotspots.
Source: Own depiction 2021, ifeu

2.2.2 Functional unit

The functional unit for this study is defined individually for the different sets of scenarios.

For the technology comparison within a cradle-to-gate boundary it is:

- The production of 1 tonne of office paper 80 g/m^2 (as representative for writing paper) and its provision for transport at the gates of the production site
- The production of 1 tonne of tissue paper 16 g/m^2 (corresponds to one layer of toilet paper) and its provision for transport at the gates of the production site

For the assessment of a final consumer product within a cradle-to-grave boundary it is:

- The production of 1 tonne of exercise books 80 g/m^2 (as representative for a writing paper product) and its provision at the point-of-sale.

2.2.3 Allocation

"Allocation refers to partitioning of input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14044, definition 3.17). This definition comprises the partitioning of flows regarding re-use and recycling, particularly open loop recycling.

For the scenario sets of the technology comparison for office and tissue paper, as presented in the spotlight report and the scenario variants of this report, the system boundaries are set to a cradle-to-gate approach. The system "starts" with the raw materials and does not include an end-of-life model. Thus, it does not need a specific system allocation approach.

In case the full life-cycle is included, as in the scenarios regarding the exercise book, a choice of system allocation has to be made. The UBA methodology recommends an approach with an allocation factor of 50 %. That means that 50 % of the burdens and credits of end-of-life processes are attributed to the examined product system. This is applied in the base scenarios for the exercise book. It considers the incineration process in Municipal Solid Waste Incineration (MSWI) as well as the material recycling processes. As the material recycling of paper, though, leads to recycled fibres, and these can theoretically stay within the same product system, it is modelled as a kind of quasi-closed loop. That means no system allocation factor is necessary. The burdens for the primary production stay with the first production, and the recycled fibres only carry the burdens of the recycling process.

This approach is consistent with past LCA studies for paper that have been commissioned by UBA. Another option is to apply the 50 % allocation factor to the burdens and credits of recycled paper as well. In that case the product made from recycled paper still carries half of the burdens of the production of virgin fibres. An additional scenario is added to the study to apply this approach as a sensitivity analysis. However, in that case not only one subsequent system is assumed but 2,2 subsequent systems based on the average fibre age of 3,2 cycles. Thus, the burdens attributed to the recycled paper are reduced by this factor. An overview of all scenarios modelled is given in section 2.4.7 (scenario overview).

2.2.4 Environmental impact categories and inventory indicators

The selection of environmental impact categories and the methods used for environmental assessment in the current project are based on the current methodological developments at UBA. In 2016 a review and update of life cycle assessments for beverage packaging was carried out on behalf of UBA. In the course of this study the "UBA method" for impact assessment was also started to being updated. In a project currently underway to define methods for life cycle assessments, the methods proposed there will be taken up and further developed. Unfortunately that project has not been finalised before the finalisation of this LCA. Therefore, the choice of impact categories is based on earlier LCA studies for UBA and the provisional "UBA method" from (UBA 2016).

The following environmental impact and inventory categories are covered in this study:

- Climate Change
  Climate change addresses the impact of anthropogenic emissions on the radiative forcing of the atmosphere. Greenhouse gas emissions enhance radiative forcing, resulting in an increase of global temperature. The characterisation factors proposed are based on the category indicator Global warming potential (GWP) for a 100-year time horizon (IPCC 2013). The category indicator results, i.e. GWP results, are expressed as kg CO_2-e per functional unit.

- Acidification
  Acidification affects aquatic and terrestrial ecosystems by changing the acid-base-equilibrium through the input of acidifying substances. Effects include damage to plants (e.g. root, foliage or needle damage), animals (e.g. fish) and entire ecosystems (e.g. increased eluviation and leakage of nutrients and heavy metals from soils). The category indicator proposed by UBA (2016) is the acidification potential expressed as SO_2-equivalents per functional unit according to (Heijungs et al. 1992).

- Aquatic eutrophication and Terrestrial eutrophication
  Eutrophication describes the excessive supply of nutrients (inorganic phosphorus (P) and nitrogen (N) compounds – hereafter referred to as P and N) to surface waters and soils. Increased levels of nutrients primarily stimulate the growth of biomass, which may lead to excess production and thus disrupt the food web with consequences for plant and animal species and the functioning of the entire ecosystem. Both aquatic and terrestrial ecosystems are affected by the supply of nutrients, but in different ways. An increased biomass production in terrestrial ecosystems could have a lasting effect on the sufficient availability of water and nutrients other than nitrogen and could result in potential displacement of species that are adapted to nutrient-poor conditions. Most aquatic ecosystems are primarily affected by excessive production of primary biomass (algae growth), which could lead to secondary effects like oxygen depletion. In addition to phosphorus and nitrogen compounds, organic carbon input may also disturb oxygen levels. Chemical oxygen demand (COD) is used as a measure for organic carbon input.

  The terrestrial eutrophication potential and the aquatic eutrophication potential expressed as kg PO_4^{3-}–e/functional unit according to (Heijungs et al. 1992) are proposed as category indicators.

  For simplification purposes, the potential impacts of atmospheric nitrogen deposition on oligotrophic waters (i.e. with very low available nutrients) are included in the impact category terrestrial eutrophication.

- *Process water (freshwater) demand*
  Most of the inventories applied in this study do not include the water released from the technosphere. Therefore, the amount of water consumed cannot be determined. For the inventory assessment of freshwater, a consistent differentiation and consistent water balance in the inventory data is necessary as basis for a subsequent impact assessment. Due to the lack of mandatory information to assess the potential environmental impact, water scarcity cannot be assessed on LCIA level within this study. However, the use of freshwater will be included in the inventory categories. A differentiation between process water, cooling water and water, unspecified is made. However, it includes neither any reference to the origin of this water, nor to its quality at the time of output/release. The respective results in this category are therefore of mere indicative nature and are not suited for conclusive quantitative statements related to either of the analysed product systems. The unit is m^3.

- *Adsorbable Organic Halogenated Compounds (AOX)*
  The AOX is a sum parameter that can be measured in water. It indicates the total emission of organic compounds that contain halogens into the wastewater (e.g. chlorine). Those compounds are formed e.g. during pulp bleaching processes with e.g. chlorine-containing process chemicals. The compounds are typically persistent in the environment and may lead to adverse effects on environment and health. The indicator is at the inventory level and thus directly measured as kg AOX.

- *Cumulative energy demand (CED total)*
  The category non-renewable primary energy (CED total) considers the total primary energy consumption. The unit for total Primary Energy is MJ. No environmental impact assessment takes place, therefore this category remains on the inventory level.

- *Cumulative energy demand (CED non-renewable)*
  The category non-renewable primary energy (CED non-renewable) considers the primary energy consumption based on non-renewable, i.e. fossil and nuclear energy sources. The unit for non-renewable Primary Energy is MJ. No environmental impact assessment takes place, therefore this category remains on the inventory level.

- Photo-oxidant formation
  Photo-oxidant formation, also known as summer smog or Los Angeles smog, is the photochemical creation of reactive substances (mainly ozone), which affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight.

  The 'Maximum incremental reactivity' (MIR) developed in the USA by William P. L. Carter is proposed as the category indicator for the impact category photo-oxidant formation. MIRs expressed as (kg O_3-e / emission i) are used in several reactivity-based VOC regulations by the California Air Resources Board (CARB 1993, 2000). Current work of William P. L. Carter includes characterisation factors for individual VOCs, VOC sum parameters and NO_x. The MIRs and NMIRs are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NO_x inputs. Thus, a conservative approach is adopted. The factors proposed by UBA (2016) were published by (Carter et al. 2010). The unit for Photo-oxidant formation potential is kg O_3-e/functional unit.

- Particulate matter (PM 2.5)
  The particulate matter category covers effects of fine particulates with an aerodynamic diameter of less than 2.5 µm (PM 2.5) emitted directly (primary particles) or formed from precursors as NO_x and SO_2 (secondary particles). Epidemiological studies have shown a correlation between the exposure to particulate matter and the mortality from respiratory diseases as well as a weakening of the immune system. Following an approach of (De Leeuw 2002), the category indicator Aerosol formation potential (AFP) expressed as kg PM 2.5-e/functional unit is proposed.

- Ozone depletion
  In the impact category the anthropogenic impact on the earth's atmosphere, which leads to the decomposition of naturally present ozone molecules, thus disturbing the molecular equilibrium in the stratosphere. The underlying chemical reactions are very slow processes and the actual impact, often referred to in a simplified way as the 'ozone hole', takes place only with considerable delay of several years after emission. The consequence of this disequilibrium is that an increased amount of UV-B radiation reaches the earth's surface, where it can cause damage to certain natural resources or human health. In this study, the ozone depletion potential (ODP) compiled by the World Meteorological Organisation (WMO) in 2011 (WMO 2011) is used as category indicator. In reference to the functional unit, the unit for Ozone Depletion Potential is kg CFC-11-e/fu.

- *Forest area*
  It is aimed to include the use of nature or land use into LCA. The currently available methods demand more detailed data on land use than most inventory data sets are able to provide. For this reason the used area is only presented on an inventory level for this LCA study. As no agricultural land use takes place for the examined products and land occupation data for mining and infrastructure is very limited this category is limited to forest area. The unit is m^2*a.

Biodiversity and land use change as well as CO_2 storage in forests are also addressed in this project. These topics discussed on a mainly qualitative level in the spotlight report. In addition, it also includes the application of an assessment methodology for biodiversity.

2.2.5 Market research and cluster development

The following section on market research is also included in the spotlight report. It is repeated here as it is also important for the understanding of the following variant scenarios.

In order to be able to make LCA comparisons of papers made from virgin fibres and papers based on recycled fibres, their origin, raw material procurement and manufacturing methods must be known. To this end, the contractors (for the most part FÖP) have surveyed paper wholesalers and retailers to determine as completely as possible the amount of copy and tissue paper used in Germany and its producers. In a second step of the research, the paper manufacturers were contacted to supply the data on the respective production sites and methods as well as on the supplier countries or regions of the virgin and recycled fibres used.

Only a few of the contacted producers supplied any market data, so that it was not possible to assess the overall market based on the collected data.

For this reason, data research based on publicly available data sources has been carried out in order to define suitable paper product clusters that will be examined by means of LCA scenarios.

Public data sources used to derive mass flows on the market that define paper product clusters to be examined are the following:

- Report on recycled paper (IPR 2015)
- Public statistics (StBA 2019)
- Environmental reports of producers of fibrous material and paper
- Annual report of German Pulp and Paper Association (Moldenhauer et al. 2018)
- Primary data provided by a German recycling paper producer
- Reference document on "The best available techniques in the pulp and paper industry" (EU COM, PPP BREF 2015)

2.2.5.1 Market analysis

Market results office papers:

Annual consumption of office papers in Germany is around 600.000 t/a (IPR 2016). According to (IPR 2015), the market share of recycled office papers in Germany is 14 %, which corresponds to 84.000 t/a.

In a next step, A4 paper imports to Germany were analysed based on import statistics (StBa 2019) for the year 2017. As imports from non-European countries are below 5 % of total office paper imports, only European imports are considered for the further clustering process. Relevant imports are summarised in the following Table 2. Individual countries of origin as listed in the import statistics are then classified into a production type (integrated versus non-integrated), based on public information available from office paper production companies / site-specific public information (UPM 2020, Storaenso 2020, Leipa 2020).

Production types are distinguished between integrated and non-integrated production. These are defined by (EU COM PPP BREF 2015) as:

- integrated production
  Both pulp and paper/board are produced at the same site. The pulp is normally not dried before paper/board manufacture.
- non-integrated production
  Either (a) production of market pulp (for sale) in mills that do not operate paper machines, or (b) production of paper/board using only pulp produced in other plants (market pulp).

Table 2: Classification of imported office papers into paper production types

Country of origin	Production type	Imported mass (2017) kt/year*	Important production sites
Austria	virgin, non-integrated	100	Mondi (Theresienthal)
France	virgin, non-integrated and virgin, integrated	48.5 48.5	International Paper (Saillat), Clairefontaine
Slovakia	virgin, integrated	80	Mondi Rezemberok
Poland	virgin, non-integrated	15	International Paper (Kwidzyn)
Portugal	virgin, non-integrated and virgin, integrated	34.5 34.5	Navigator
Sweden	virgin, integrated	56	Stora Enso (Nymölla)
Finland	virgin, integrated	40	UPM (Kymi), Stora Enso (Kemi)
Total import	*virgin, non-integrated and virgin, integrated*	*198* *+259* *=457*	

*Source of import numbers: (StBA 2019), reference year 2017
The split between integrated and non-integrated for countries France and Portugal is assumed to be 50/50.

Besides the origin of imported papers, also information on pulp origin especially for non-integrated paper production is relevant in order to derive representative market clusters. As no primary information could be collected from office paper companies in course of the research project, pulp import statistics based on (Moldenhauer et al. 2018) are used instead as data source for pulp origin, differentiated into long and short fibres. The following Table 3 summarizes the most important pulp imports as considered for the non-integrated office paper production.

Table 3: Origin of market pulp (for paper from non-integrated production)

Fibre type	Country of origin	Imported mass (2017) kt/year*
Short fibre, hardwood	**Brazil**	**1.140**
	Uruguay	**165**
	Chile	**199**
	Portugal	**380**
	Spain	**213**
Total hardwood pulp		***2.097***
Long fibre, softwood	**Sweden**	**510**
	Finland	**310**

Fibre type	Country of origin	Imported mass (2017) kt/year*
	Canada	35
	United States	95
Total softwood pulp		***950***

*Source of import numbers: (Moldenhauer et al. 2018)

For the cluster definition, a distribution of fibre origin based on the above presented data is derived as 72 % from Latin America and 28 % from Southwest Europe for short fibres and as 87 % from Northern Europe 13 % from North America for long fibres, respectively. This covers >88 % of short fibre imports and >98 % of long fibre imports into Germany in 2017. The typical share of different virgin fibres for both integrated as well as non-integrated office papers are 85 % short fibres and 15 % long fibres.

Derived clusters office papers:

The following Table 4 summarizes the derived office paper clusters and their market shares for the German office paper market, based on raw data shown in the previous tables. The difference between imported office papers, recycled office papers produced in Germany and the German office paper market of 600.000 tons is assumed to come from non-integrated German paper production and thus forms part of the non-integrated paper production in Central Europe.

Table 4: Cluster Office Paper: Total Consumption Germany 2016: ~600.000 t/a[1]

Source: (Own depiction 2021, ifeu)

Cluster	Type of paper	Production	Location paper machine	Calculated market volume (kt/a)	Calculated proportion of the german market (representative status 97.4 %)
O1	virgin	Non integrated	Central Europe & Southwest Europe	257	43 %
O2a	virgin	Integrated	Northern, Central & Southwest Europe	259	43 %
O3	Recycling	Integrated	Central Europe	84	14 %

[1] Source: IPR, additional sources: VDP: Paper Performance Report 2018 (reference year 2017) / External trade statistics, Federal Statistical Office (reference year 2017)/ primary data collection in the project

Market results and derived clusters tissue papers:

Annual consumption of tissue papers in Germany (machine production) is around 1.572.000 t/a (Moldenhauer et al. 2018). Primary data on tissue paper production volumes in Central Europe for the German market could be obtained in course of the present research project from several tissue paper companies (WEPA 2018, Essity 2018, Fripa 2019).

Based on the primary data collected, the classification of tissue paper production types as shown in the following Table 5 is derived.

Table 5: Cluster Tissue Paper: Total Consumption Germany 2017*: 1.592.000 t/a

Cluster	Type of paper	Production	Location paper machine	Calculated market volume (kt/a)	Calculated market share on the German market (representative status 92,4 %)
T1a	Primary	Not integrated	Central Europe	1162	73,9 %
T2a	Recycled	Not integrated	Central Europe	159	10,1 %
T2b	Recycled	Integrated	Central Europe	132	8,4 %

*Source of tissue paper market number: (Moldenhauer et al. 2018)

Information regarding pulp origin gathered in course of the present research project from primary data collection is not sufficient to derive an overall pulp origin mix. For this reason, pulp origin for long fibre and short fibre are assumed to be the same as described in the previous paragraphs for office papers, as pulp import statistics do not differentiate by paper product use. So for tissue papers, origin of short fibre is assumed to be 72 % from Latin America and 28 % from Southwest Europe and as 87 % from Northern Europe 13 % from North America for long fibres, respectively. The typical share of different virgin fibres for tissue paper is 80 % short fibres and 20 % long fibres.

2.2.6 Life Cycle Inventory data used

One significant component of the project was to collect current unit process data to reflect the production of virgin pulp, as well as data for the production of recycled deinked pulp (DIP) and recycled office and tissue paper production. One approach to collect as much primary data as possible was to ask for the support of the paper industry to provide process datasets. Unfortunately several meetings with representatives of the industry did not lead to an agreement that process data would be provided for this project. Apart from limited market data from some companies and process data for recycled office paper no primary data could be obtained.

2.2.6.1 Overview on data sources

Without the support of the paper industry regarding process data collection the focus lay on the evaluation of publicly accessible information. This data was supplemented by data on DIP and recycled office paper production obtained from a Germany recycling paper producer. Overall, the following data sources are used for setting up the LCA models:

- Reference document on "The best available techniques in the pulp and paper industry" (EU COM PPP BREF 2015)
- Ecoinvent life cycle inventor database, Version 3.6 (Ecoinvent 2019)
- Primary data provided by a German recycling paper producer
- Data report on the Life-cycle Analysis of Office Papers (Detzel et al. 1998)
- Environmental reports of producers of fibrous material and paper
- Internal database of ifeu Heidelberg
- Ökologischer Vergleich von Büropapieren in Abhängigkeit vom Faserrohstoff. (Gromke, U.; Detzel, A. 2006)

In the following there is a short description regarding how the available data is used for modelling the paper types developed as clusters to be modelled as described in Table 4 and Table 5.

2.2.6.2 Non-integrated virgin office paper

The non-integrated production of office paper from virgin fibres, includes the following processes:

- Wood provision from forestry

For Northern pulpwood, the inventory dataset softwood forestry, pine, Sweden and softwood forestry, spruce, Sweden taken from (Ecoinvent 2019) are used. For Brazilian eucalyptus wood, the inventory dataset hardwood forestry, *eucalyptus ssp*., planted forest management, Brazil taken from (Ecoinvent 2019) are used. An average of the three Brazilian eucalyptus plantation regions available in the Ecoinvent database (Goiás, Minas Gerais, São Paulo) are used. For Iberian eucalyptus wood, no full inventory dataset is publicly available. For this reason, the Brazilian dataset is used as a proxy dataset with an adaption of harvesting yield. For Central European hardwood pulpwood, inventory datasets hardwood forestry, oak, Germany and hardwood forestry, beech, Germany taken from (Ecoinvent 2019) are used. For provision of North American softwood, no full inventory dataset is publicly available. For this reason, the Northern Europe softwood dataset is used as a proxy dataset.

The timber yield or land use of the individual countries and timber species is based on the sources mentioned. It is based on the annual growth of the forests and includes round wood as well as thinning wood that is harvested during the rotation period. As the share of thinning wood for Central European paper production is potentially higher than assumed in the present study, the forest area needed for Central European paper production might be overestimated. The same yield is assumed for different types of forest management (selective logging forestry, clear-cutting or retention forestry).

► Manufacture of market sulphate pulp

The manufacture of sulphate pulp in North America is based on the inventory dataset “sulfate pulp production, from hardwood, bleached” in Canada, Quebec, which is taken from (Ecoinvent 2019). It covers the production of elementary chlorine-free (ECF) bleached sulfate pulp from the kraft process. Underlying data refer to a mix of Canadian mills that pulp both softwood and hardwood. Production is assumed to take place 50 % in Canada and 50 % in the United States.

The manufacture of Latin American sulfate pulp production from eucalyptus is based on the inventory dataset “sulfate pulp production, eucalyptus, bleached, Latin America and the Caribbean”, which is taken from (Ecoinvent 2019). It covers the production mix of ECF and total chlorine free (TCF) bleached sulfate pulp from the kraft process in Latin America. As no specific inventory dataset is publicly available for Iberian eucalyptus pulp production, this dataset is also used for Iberian eucalyptus pulp. However, external energy prechains (e.g. electricity) are adapted to Latin America and Iberia.

The manufacture of Northern sulphate pulp is based on “sulfate pulp production, from softwood, bleached, Europe” taken from (Ecoinvent 2019). It covers ECF and TCF kraft pulp, obtained from northern European softwood.

Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019).

► Refining of pulp

Before entering the paper machines, the dried pulp has to be refined and fibrillated. The energy consumption values used for the milling are based on (Bos 1999) and where required to be adapted to pulp type using experimental values based on (Gehr 2006).

► Office paper production

Paper is made from the supplied pulp in the last process step considered. The inventory dataset “paper production, woodfree, uncoated, at non-integrated mill” taken from (Ecoinvent 2019) is used. Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019).

2.2.6.3 Integrated virgin office paper

The production of integrated office paper from virgin fibres, includes the following processes:

► Wood provision from forestry

For Northern European integrated production, both Northern hardwood and softwood is required as raw material. For Northern pulpwood, the inventory dataset softwood forestry, pine, Sweden and softwood forestry, spruce, Sweden taken from (Ecoinvent 2019) is used. For hardwood forestry in Northern Europe, the inventory dataset hardwood forestry, birch, Sweden taken from (Ecoinvent 2019) is applied.

In case of Southern European integrated production, short fibre content is assumed to originate from Iberian Eucalyptus. For Iberian eucalyptus wood, no full inventory dataset is publicly available. For this reason, the Brazilian dataset (Ecoinvent 2019) is used as a proxy dataset with an adaption of harvesting yield according to (Shibu et al. 2018). Long fibre content is assumed to use Central European softwood, as a Southern European dataset on softwood forestry is not available. Inventory datasets softwood forestry, pine, Germany and softwood forestry, spruce, Germany taken from (Ecoinvent 2019) are used.

Regarding Central European integrated production, both short fibre and long fibre need to be covered by Central European pulpwood. For Central European hardwood pulpwood, inventory datasets hardwood forestry, oak, Germany and hardwood forestry, beech, Germany taken from (Ecoinvent 2019) are used, as inventory datasets for further relevant Central European hardwood species (such as aspen, poplar) are not available. Long fibre content is based on inventory datasets softwood forestry, pine, Germany and softwood forestry, spruce, Germany taken from (Ecoinvent 2019).

- Integrated office paper production

Paper is made from the supplied wood in an integrated paper mill. The inventory dataset "paper production, woodfree, uncoated, at integrated mill" taken from (Ecoinvent 2019) is used. Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019). Externally provided energy (grid electricity) is adapted to the required geography for Northern, Central European and Southwest European integrated paper production.

2.2.6.4 Integrated recycled office paper

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

- Sorting of waste paper and delivery for waste paper processing

Data used: (UBA 1998), energy prechains taken from (Ecoinvent 2019, ifeu 2019).

- Waste paper processing, DIP production

Data on final energy consumption, chemical demand and effluent (STP 2018).

The mix of energy carriers was selected so that it depicted an approximation of the typical German situation in DIP production, sources: (Gehr 2018, Gromke and Detzel 2006).

- Office paper production

Paper is manufactured from the DIP in the final process step. The data necessary for paper production comes from (STP 2018). Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019).

2.2.6.5 Virgin tissue paper

The production of tissue paper from virgin fibres, non-integrated, includes the following processes:

- Wood provision from forestry

For the base scenarios, Northern European softwood as well as Eucalyptus from Latin America and Southern Europe is used as a raw material for pulping processes. For Northern pulpwood, the inventory dataset softwood forestry, pine, Sweden and softwood forestry, spruce, Sweden taken from (Ecoinvent 2019) are used. For Brazilian eucalyptus wood, the inventory dataset hardwood forestry, eucalyptus ssp., planted forest management, Brazil taken from (Ecoinvent

2019) are used. An average of the three Brazilian eucalyptus plantation regions available in the Ecoinvent database (Goiás, Minas Gerais, São Paulo) are used. For Iberian eucalyptus wood, no full inventory dataset is publicly available. For this reason, the Brazilian dataset is used as a proxy dataset with an adaption of harvesting yield according to (Shibu et al. 2018). For provision of North American softwood, no full inventory dataset is publicly available. For this reason, the Northern Europe softwood dataset is used as a proxy dataset.

Some additional forestry data sets are required for the technical variant scenarios with different origin of hardwood and softwood pulp. For Central European hardwood pulpwood, inventory datasets hardwood forestry, oak, Germany and hardwood forestry, beech, Germany taken from (Ecoinvent 2019) are used. For Central European softwood, inventory datasets softwood forestry, pine, Germany and softwood forestry, spruce, Germany taken from (Ecoinvent 2019) are used.

- Manufacture of market sulphate pulp

The manufacture of sulphate pulp in North America is based on the inventory dataset "sulfate pulp production, from hardwood, bleached" in Canada, Quebec taken from (Ecoinvent 2019). It covers the production of ECF bleached sulfate pulp from the kraft process. Underlying data refer to a mix of Canadian mills that pulp both softwood and hardwood. Production is assumed to take place 50 % in Canada and 50 % in the United States.

The manufacture of Latin American sulfate pulp production from eucalyptus is based on the inventory dataset "sulfate pulp production, eucalyptus, bleached, Latin America and the Caribbean" taken from (Ecoinvent 2019). It covers the production mix of ECF and total chlorine free (TCF) bleached sulfate pulp from the kraft process in Latin America. As no specific inventory dataset is publicly available for Iberian eucalyptus pulp production, this dataset is also used for Iberian eucalyptus pulp. However, external energy prechains (e.g. electricity) are adapted to Latin America and Iberia.

The manufacture of Northern sulphate pulp is based on "sulfate pulp production, from softwood, bleached, Europe" taken from (Ecoinvent 2019). It covers ECF and TCF kraft pulp, obtained from northern European softwood.

Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019).

- Refining of pulp

Before entering the paper machines, the dried pulp has to be refined and fibrillated The energy consumption values used for the milling are based on (Bos 1999) and where required to be adapted to pulp type using experimental values based on (STP 2006).

- Tissue paper production

Paper is made from the supplied pulp in the last process step considered. The inventory data for tissue paper production is based on (EU COM PPP BREF 2015). Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019).

2.2.6.6 Recycled tissue paper

The production of tissue paper from recycled fibres covers the following processes:

- Sorting of waste paper and delivery for waste paper processing

Data used: (UBA 1998), energy prechains taken from (Ecoinvent 2019, ifeu 2019)

- Waste paper processing, DIP production

Inventory data for DIP process is based on (EU COM PPP BREF 2015).

- Tissue paper production

Paper is manufactured from the DIP in the final process step under consideration. The data necessary for paper production come from (EU COM PPP BREF 2015). Data sources for prechains of externally procured energy and all relevant preliminary materials and auxiliary chemicals, including their prechains are taken from: (Ecoinvent 2019, Tiedemann et al. 2000, ifeu 2019).

2.2.7 Scenario overview

The following section gives an overview of all scenarios of the LCA including those that are presented in the spotlight report.

2.2.7.1 Office paper

Scenario overview office papers (Cradle-to-gate):

Base scenarios are cradle-to-gate scenarios (for an illustration of system boundaries 2.4.1) that aim for a comparison of virgin office paper and recycled office paper production technology including assessment of variants from non-integrated production regarding pulp composition. The following Table 6 gives a scenario overview of base (shown in bold print) and variant scenarios (shown in italics). The base scenarios are differentiated into 3 groups:

- Virgin fibres, non-integrated production abbreviated: virgin non-integrated
- Virgin fibres, integrated production abbreviated: virgin integrated
- Recycled fibres, integrated production abbreviated: recycled integrated

Base scenarios are based on the outcome of relevant office paper type clusters as described in the previous paragraphs (see Table 4), where each of the base scenarios represent one of the market clusters. Both integrated and non-integrated office papers are assumed to consist of 85 % short fibres and 15 % long fibres. This office paper composition is intended to represent a typical office paper composition. Short fibre content of virgin non-integrated office paper is assumed to consist of Eucalyptus fibre for the base case, as based on short fibre import statistics both Latin American and Southern European Eucalyptus fibre plays a predominant role. Long fibre content originates predominantly from Northern European softwood, and a smaller share from North American softwood based on long fibre import statistics.

Technical variant scenarios shall give an indication on environmental performance of papers with alternative fibre composition (short fibre versus long fibre) and/or pulp origin. Nevertheless, product characteristics need to be equal for a valid comparison, thus the variant scenarios keep the 85 % short fibre content fixed or remain very close to the 85 % (e.g. 80 % short fibre instead of 85 % in the base case). That means that in case of a non-integrated virgin office paper with fully Central European fibre origin, the short fibre content needs to be based on Central European hardwoods. Typical hardwood types processed into pulp in Central Europe (e.g. International Paper mill in Saillat, France and Sappi mill in Stockstadt, Germany) are e.g. Aspen, Beech, Oak, Poplar. For reasons of data availability, Central European hardwood pulp was implemented as a mixture of beech and oak pulps, as for the other named wood types consistent forestry life cycle inventory datasets are not available. Regarding the long fibre content in the Central European variant scenarios, consistent German spruce and pine life cycle inventory data is available and thus applied.

In addition, further variants are considering alternative fibre material sources. These should examine alternative or innovative paper products currently on the German market. Such paper products are made from grass pellets instead of virgin fibres and the so-called stone paper, that is not really a paper but a PE film with a high share of calcium carbonate, and that is mainly used for niche products like water-resistant maps or business cards. LCA results are only presented for grass paper, as it was impossible to obtain process data for the production of stone paper. Requests for data from stone paper producers remained unanswered.

Grass paper is a product that replaces virgin fibres or recycled fibres partially with grass pellets. The production can run on ordinary paper machines and the share of grass pellets is only limited by the required quality of the final product. It is mainly used for packaging paper, but office paper is also possible to produce. The highest reasonable share of grass for office paper is estimated at 40 %, which is the share applied in the model of the variant scenarios. According to the provider of grass paper (D'Agnone 2019), it is assumed that the grass originates only from non-fertilised fields, of which the grass is not used otherwise so far (e.g. side areas of golf courses and similar).

Table 6: Office paper base scenarios as well as pulp type variant scenarios

Scenario shortname *Office paper*	**Type of paper**	**Production**	**Location paper machine**	**Fibre composition**
O1 virg. non-int. CE **[base:** **85 % Euca LA/SE** **15 % softwood]**	**Virgin**	**Non-integrated**	**Central Europe (CE)**	**85 % short fibre, 15 % long fibre**
O1 virg. non-int. CE **[100 % Euca LA/SE]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*100 % short fibre*
O1 virg. non-int. CE **[80 % Euca LA/SE** **20 % softwood]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*80 % short fibre 20 % long fibre*
O1 virg. non-int. CE **[85 % hardwood CE** **15 % softwood]**	*Virgin*	*Non-integrated*	*Central Europe(CE)*	*85 % short fibre from Central Europe (CE)*
O1 virg. non-int. CE **[85 % Euca LA** **15 % softwood]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*85 % short fibre from Latin America (LA)*

Scenario shortname	Type of paper	Production	Location paper machine	Fibre composition
O1 virg/grass non-int. CE - **[51 % Euca LA/SE 9 % softwood 40 % grass fibre]**	*Virgin and residual grass biomass*	*Non-integrated*	*Central Europe (CE)*	*40 % grass fibre, 51 % short fibre, 9 % long fibre*
O2a virg. int. CE [85 % hardwood CE 15 % softwood CE]	**Virgin**	**Integrated**	**Central Europe (CE)**	**85 % short fibre, 15 % long fibre**
O2b virg. int. NE [85 % hardwood NE 15 % softwood NE]	**Virgin**	**Integrated**	**Northern Europe (NE)**	**85 % short fibre, 15 % long fibre**
O2c virg. int. SE [85 % hardwood SE 15 % softwood CE]	**Virgin**	**Integrated**	**Southwest Europe (SE)**	**85 % short fibre, 15 % long fibre**
O3 rec. int. CE	**Recycled**	**Integrated**	**Central Europe (CE)**	**100 % recycled fibre**

Source: (Own depiction 2021, ifeu)

2.2.7.2 Tissue paper

Base scenarios are cradle-to-gate scenarios (for an illustration of system boundaries see 2.4.1) that aim at a technological comparison of virgin and recycled tissue paper production including assessment of paper variants from non-integrated production regarding pulp composition. The following Table 7 gives a scenario overview of base (shown in bold print) and variant scenarios (shown in italics).

The base scenarios are differentiated into 2 groups:

- Virgin fibres, non-integrated abbreviated: T1
- Recycled fibres, integrated abbreviated: T2

The cluster non-integrated recycled fibre that is shown in Table 5 is integrated into the integrated recycled fibre cluster, as underlying data for differentiation are assessed to be insufficient by the authors of the present study (e.g. typical transport distances of recycled fibres are not available from public data sources). Furthermore, the differences in environmental performance between integrated and non-integrated recycled fibre tissue papers is expected to be smaller than the difference between virgin fibre-based integrated versus non-integrated paper production.

Similar as for office paper it was planned to include an assessment of tissue paper from an alternative fibre source. Currently, obtainable on the German market is tissue paper made from bamboo. Throughout the whole project FÖP and ifeu have been in contact with the producer of bamboo-based tissue paper. A Chinese language data collection sheet has been developed and sent to the bamboo fibre suppliers in China. Unfortunately, no data has been received. Therefore, no production scenario could be modeled.

Table 7: Tissue paper base scenarios as well as pulp type variant scenarios

Scenario shortname *Tissue paper*	**Type of paper**	**Production**	**Location paper machine**	**Fibre composition**
T1 virg. non-int.	**Virgin**	**Non-integrated**	**Central Europe (CE)**	**80 % short fibre, 20 % long fibre**
T1 virg. non-int. **[100 % Euca LA/SE]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*100 % short fibre*
T1 virg. non-int. **[75 % Euca LA/SE** **25 % softwood]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*75 % short fibre, 25 % long fibre*
T1 virg. non-int. **[80 % hardwood CE** **20 % softwood]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*80 % short fibre from Central Europe (CE)*
T1 virg. non-int. **[80 % Euca LA** **20 % softwood]**	*Virgin*	*Non-integrated*	*Central Europe (CE)*	*80 % short fibre from Latin America (LA)*
T2 rec. int.	**Recycled**	**integrated**	**Central Europe (CE)**	**100 % recycled fibre**

Source: (Own depiction 2021, ifeu)

2.2.7.3 Exercise book

Besides the technological comparison of office papers based on various virgin fibre sources as well as recycled fibres, also insights into the environmental performance of final paper products are of interest in the present research project. As an example product, an exercise book as typically used in schools has been selected for this purpose. This assessment includes the same cradle-to-gate boundaries of the intermediate office paper production. Following these transports, converting, retail, use phase and end-of-life processes complete the life-cycle. For the scenarios of this study though, converting steps, retail and use phase are excluded. As the data availability for these steps is not sufficient, proxy data sets would have been used. As there are no differences regarding these processes in relation to the use of virgin fibres or recycled fibres, it was decided to exclude these steps as their modelling would only increase uncertainty and would not contribute any meaningful information for a comparison. Instead, the focus is on the end-of-life processes. After use a paper fraction collection rate for recycling is assumed to be 83 % according to (BMU 2018). The remaining share of used exercise books is assumed to end up at MSWI plants.

Two sensitivity analyses are added to this section. First, another allocation approach than the one described in 2.4.3 is taken. This scenario uses the circular footprint formula (CFF) of the environmental footprint project of the EU commission. In this approach different allocation factors, depending on the material are applied. As, according to the Annex C to the current PEF Guidance document (PEF 2019), the allocation factors of graphic and tissue paper is 0.5, the allocation is very similar to the one used for the base scenarios. The only difference is that there is currently no allocation for energy recovery processes.

The second sensitivity analysis deals with the choice of how to deal with the carbon uptake of wood in the forest growth phase. The standard approach chosen by the authors for the base scenarios of the present study considers the carbon dioxide emissions that are generated as a result of incineration of used paper products as carbon-neutral. This follows the recommendations of IPCC and therefore does not allow taking into account the fixation of atmospheric CO_2 by plants. This approach will be referred to as the “carbon neutral” approach throughout the present report. The sensitivity applies an alternative approach that is sometimes selected in life cycle assessment of bio-based products and that is often referred to as the “carbon fixation” approach. In that case, the system that puts the bio-based material on the market for the first time, hence starting the first life cycle (in case of paper products), gets a carbon dioxide “credit” in order to value the carbon dioxide fixation of the trees during the growth phase. This case is referred to as the “carbon fixation” approach throughout the present study.

In case of recycled fibre-based paper products, a methodological decision that has to be taken is the allocation of burdens (and benefits) between the first (virgin fibre – based paper product) and further (recycled fibre) paper products. Especially, the question if the recycled fibre carries a burden from its first life cycle (e.g. forestry and virgin fibre production) or not. In all base cases of the present study, it is assumed that the recycled fibre does not get such a burden. In the sensitivity including biogenic C the uptake as well as these burdens are allocated to the recycled fibre. To allocate these burdens not only to one subsequent product system but to the number of systems depending on the average number of uses of fibres the sensitivity scenario is calculated with 2,2 subsequent systems.

The following Table 8 provides an overview on the exercise book scenarios (cradle-to-grave scenarios).

Table 8: Exercise book scenarios

Scenario shortname	Type of paper	Production	Location paper machine	Fibre composition / methodology
Exercise book – base scenarios 50:50 allocation				
E1 ex. book virg. non-int.	Virgin	Non-integrated	Central Europe (CE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon neutral“ approach
E2a ex. book virg. int. CE	Virgin	Integrated	Central Europe (CE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon neutral“ approach
E2b ex. boot virg. int. NE	Virgin	Integrated	Northern Europe (NE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon neutral“ approach
E2c ex. book virg. int. SE	Virgin	Integrated	Southern Europe (SE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon neutral“ approach
E3 ex. book rec. int.-	Recycled	Integrated	Central Europe (CE)	100 % recycled fibre, cradle-to-grave, „carbon neutral“ approach
Exercise book – sensitivity analysis regarding methodological aspects (allocation according to PEF)*				
E1 ex. book virg. non-int. PEF allocation	Virgin	Non-integrated	Central Europe (CE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon neutral“ approach, PEF allocation
E2a ex. book virg. int. CE PEF allocation	Virgin	Integrated	Central Europe (CE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon neutral“ approach, PEF allocation
E3 ex. book rec. int. PEF allocation	Recycled	Integrated	Central Europe (CE)	100 % recycled fibre, cradle-to-grave, „carbon neutral“ approach, PEF allocation
Exercise book – sensitivity analysis regarding methodological aspects (carbon uptake, burden first life cycle)				
E1 ex. book virg. non-int. “Carbon fix”	Virgin	Non-integrated	Central Europe (CE)	85 % short fibre, 15 % long fibre, cradle-to-grave, „carbon fixation“ approach
E3 ex. book rec. int. “Carbon fix”	Recycled	Integrated	Central Europe (CE)	100 % recycled fibre, , cradle-to-grave, share (1/3,2) in burden of first life cycle of the fibre, „carbon fixation“ approach

*PEF: according to Product Environmental Footprint methodology (PEF 2019) Source: (Own depiction 2021, ifeu)

3 Life Cycle Assessment Results

This section presents the results of the additional scenarios. Results of the base scenarios within cradle-to-gate boundaries are presented in the spotlight report and not repeated here.

Stacked bar charts are used to show the environmental assessment. A differentiation is made here between different sectors of the paper production chain. In addition to the main processes, the individual sectors also contain all of the relevant prechains such as energy provision or the provision of process materials, such as the transportation of raw materials or process materials (wood, recycled paper, caustic soda, etc.) if not shown separately. The following paragraphs describe how the results are broken down into sub-processes. For the sake of better orientation, the short name of sub-processes as used in the diagrams is additionally stated in square brackets in the enumeration of sub-processes.

All results shown refer to the framework conditions described in 2.4.

Non-integrated Paper production using virgin fibres is broken down into the following sub-processes:

- Wood provision (forestry/wastepaper)
- Transport of wood to pulp mill (transport wood/wastepaper)
- Pulp production (pulp/DIP)
- Transportation of pulp to paper mill (transport pulp)
- Paper production from pulp (paper production)
- Transport of paper to the German market (transport paper)

Integrated Paper production using virgin fibres is broken down into the following sub-processes:

- Wood provision (forestry/wastepaper)
- Transport of wood to integrated mill (transport wood/wastepaper)
- Integrated paper production from wood (integrated paper mill)
- Transport of paper to the German market (transport paper)

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

- Waste paper collection & sorting (wood/waste paper)
- Transport of waste paper to paper mill (transport wood/wastepaper)
- Production of DIP chemicals (prechains) (DIP) (pulp/DIP)
- Integrated DIP/paper production from recycled fibres (paper production)
- Transport of paper to the German market (transport paper)

All results shown refer to the production of one tonne of produced paper.

3.1 Results office paper

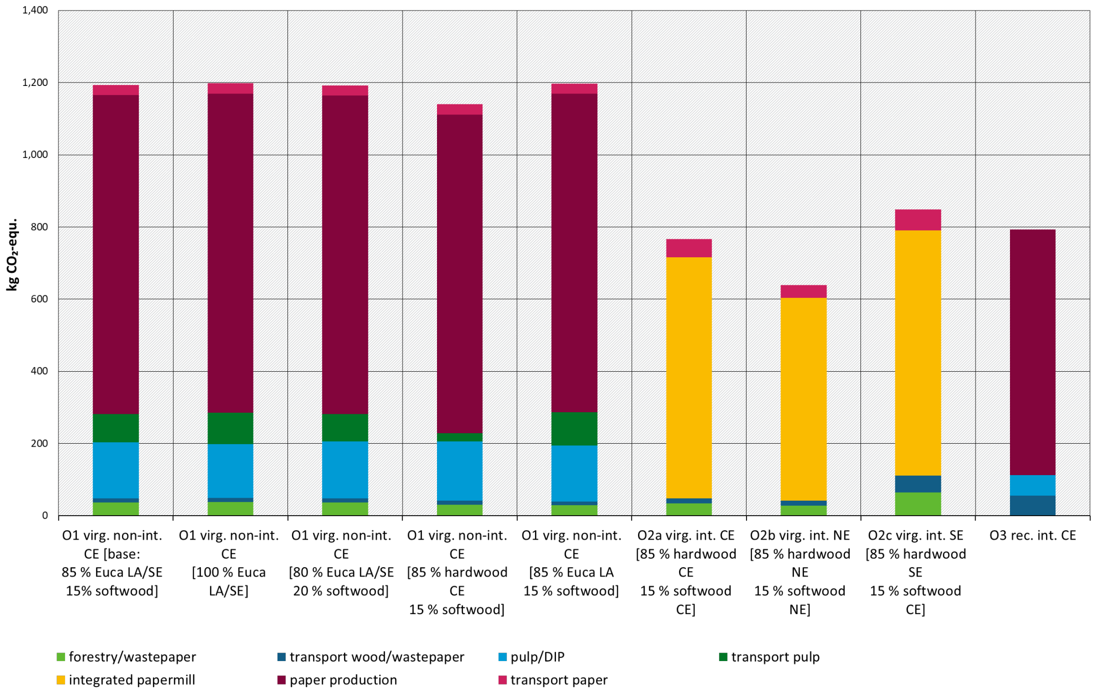
3.1.1 Office paper variant scenario results

Results of office paper variant scenarios are shown in the following Figure 6 to Figure 29, next to the office paper base scenarios as presented in the spotlight report. The individual sections point out specific observations related to paper variants examined.

3.1.1.1 Office paper variant scenario results: Climate Change, Non-renewable Primary Energy Demand & Total Primary Energy Demand

Overall, office papers with maximum and minimum short fibre content show very similar results regarding greenhouse gas emissions and primary non-renewable energy demand. Despite small differences in pulp production and pulp transport contributions, the overall result also shows the same comparison to integrated and recycled office papers as described for base scenarios, regardless the fibre composition. This is also largely true for variations in pulp origin, where only a pure pulp origin from Central Europe leads to slightly lower overall result (associated with savings in pulp transports), but still the comparative picture to other papers remains stable.

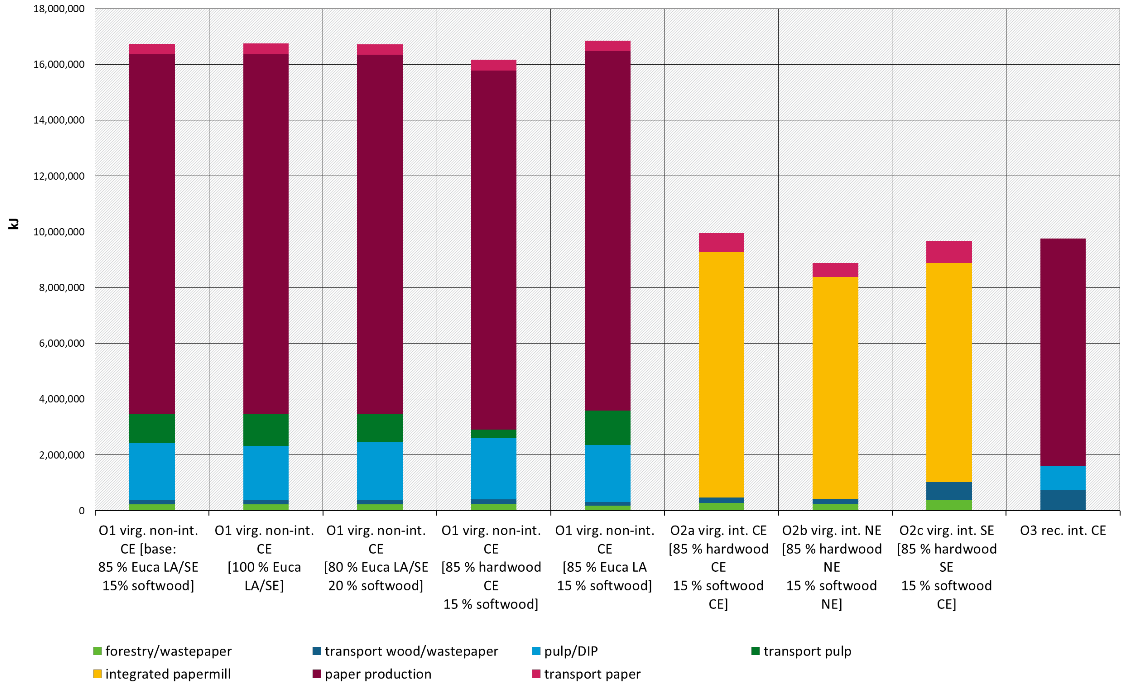
Figure 6: Climate Change, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 7: Cumulative Energy Demand (CED) non-renewable, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

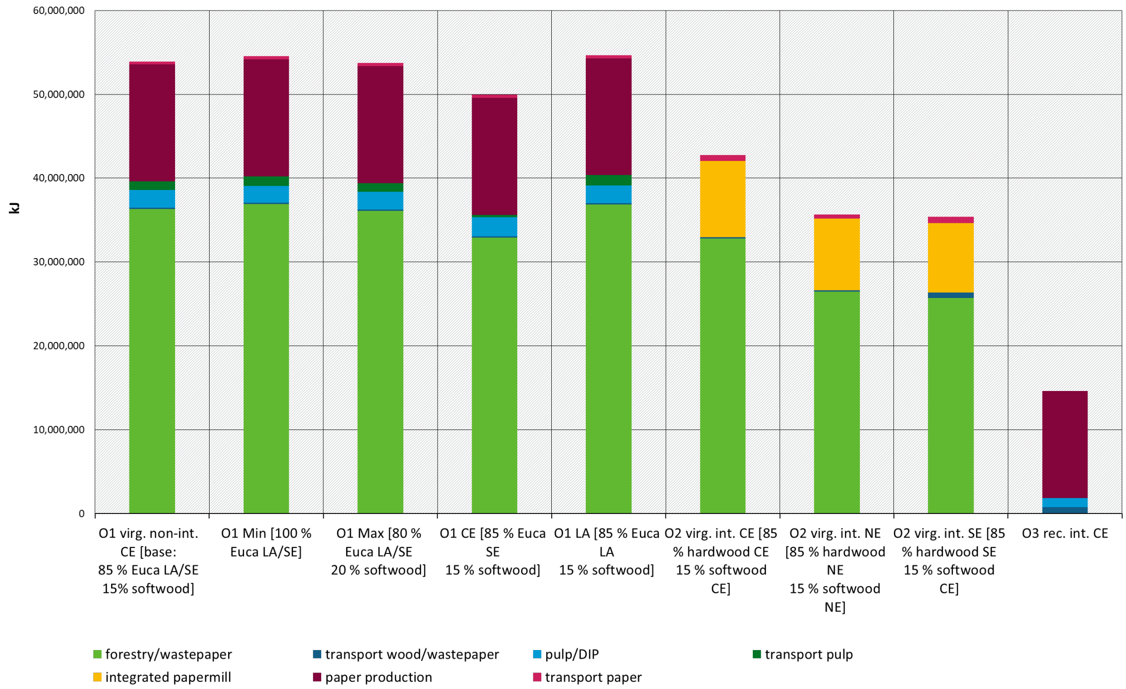
Source: (Own depiction 2021, ifeu)

Figure 8in this section shows the results of the inventory category Cumulative Primary Energy Demand (total).

Integrated recycled office papers are associated with a lower total primary energy demand than non-integrated virgin office papers. It is also lower than the total primary energy demand of virgin integrated office papers, which in turn still show lower results than non-integrated virgin office papers.

Highest contributions to the overall results of virgin office paper are associated with the forestry life cycle step.

Figure 8: Total CED, 1000 kg office paper, variant scenarios



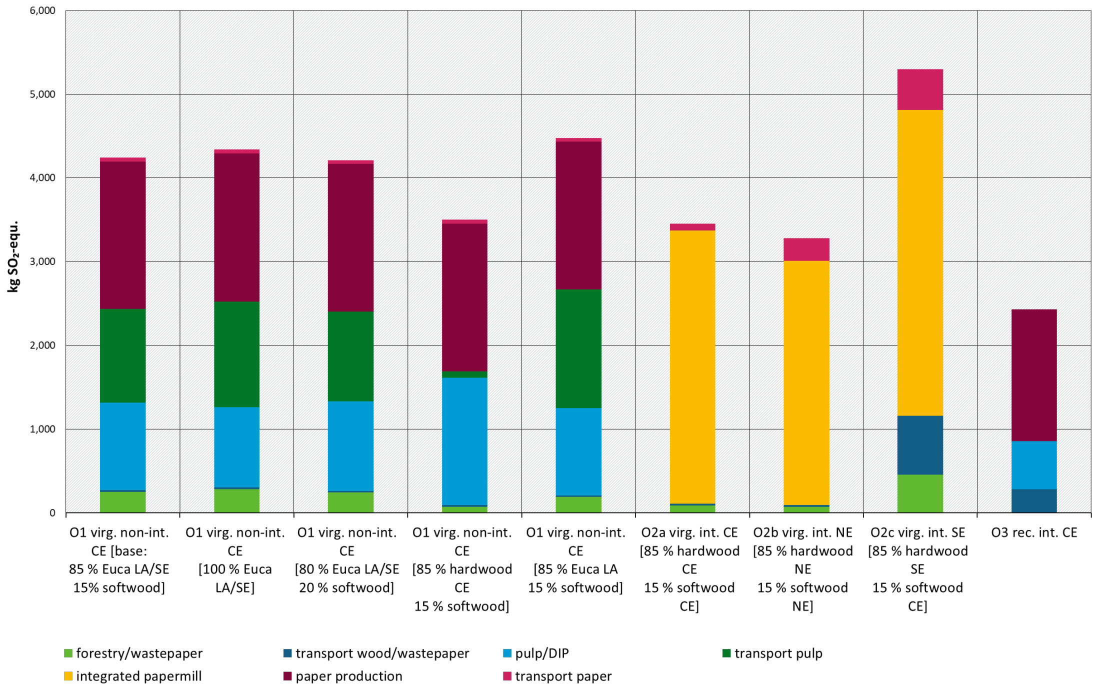
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.1.2 Office paper variant scenario results: Acidification & Terrestrial Eutrophication

Concerning acidification and terrestrial eutrophication, office paper variants with minimum and maximum short fibre content show similar results to the base scenario. If virgin fibres originate from Central Europe (short fibres based on European oak and beech pulpwood, long fibres based on European spruce and pine), office papers are associated with lower acidification and terrestrial eutrophication impacts than if based on the average pulp origin mix that is characterised by a high share of imported eucalyptus pulp.

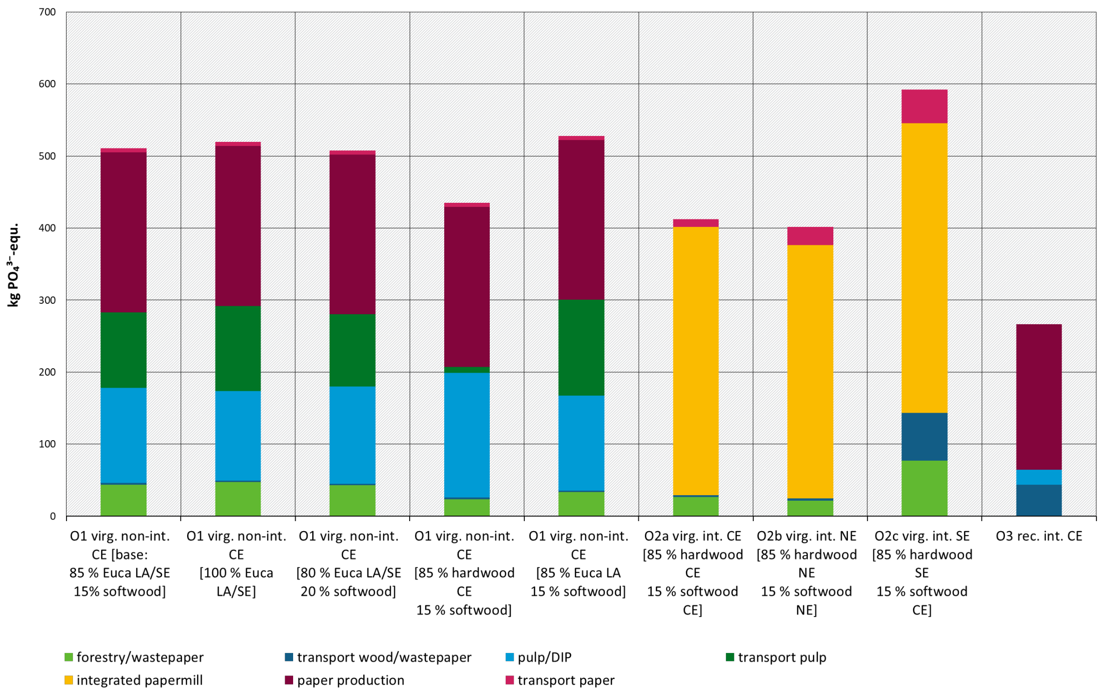
As a result, non-integrated office papers fully based on Central European fibres are in the same order of magnitude regarding acidification and terrestrial eutrophication as Central European papers from integrated production, but still higher if compared to recycled office papers.

Figure 9: Acidification, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 10: Terrestrial Eutrophication, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.1.3 Office paper variant scenario results: Water-related results

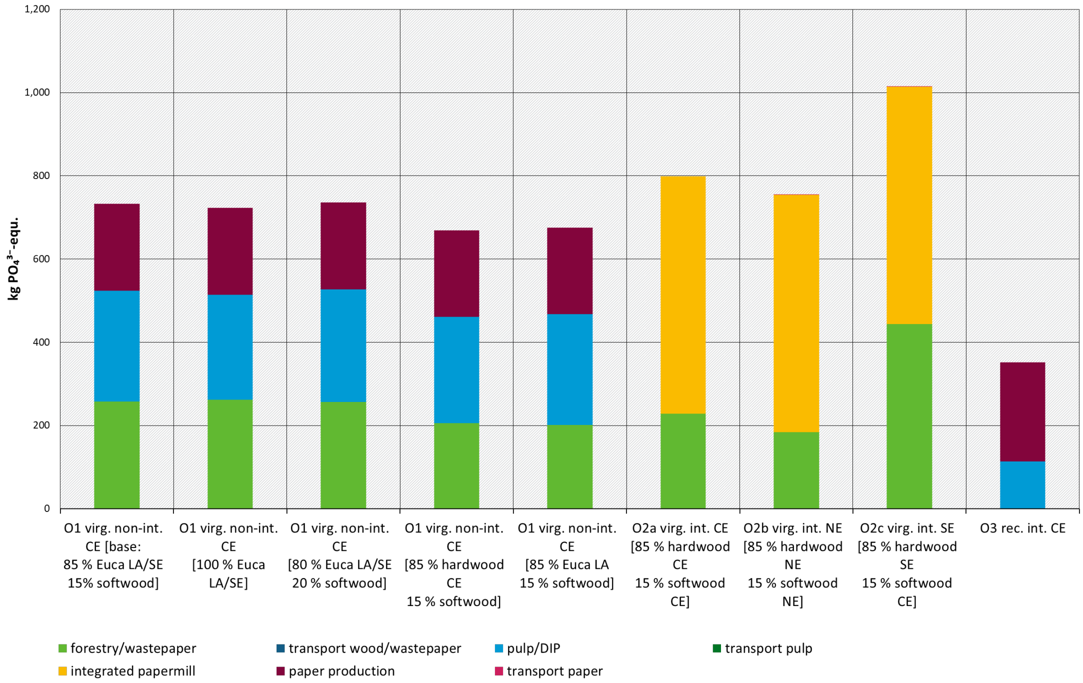
Office papers with variations in short and long fibre contents largely remain in the same order of magnitude than those with the base fibre composition for the water-related indicators results aquatic eutrophication, process water and AOX emissions to water.

Office papers based on pure Central European pulp remains also stable in Aquatic Eutrophication, but the picture changes with regard to process water demand and AOX emissions to water. Here the Central European pulp origin leads to higher demand in process water as well as AOX.

Inventory datasets available indicate higher inputs of both process water and chlorine-containing bleaching chemicals for Central European hardwood pulp than for Latin American Eucalyptus pulp. Overall process water demand strongly depends on the implementation of water recirculation within the pulp mill, and thus also on local conditions, if water savings are either in focus or outside the general awareness.

Required bleaching chemicals are clearly related to applied pulp bleaching sequences and technology as well as individual wood properties (e.g. lignin content). As expected based on the chlorine-based bleaching chemicals input, Latin American Eucalyptus pulp is associated with lower AOX emissions than Central European hardwood pulp. This is the reason for lower AOX emissions associated with the base case office paper based on Eucalyptus pulp compared to a fully European hardwood-based office paper variant. As a result, AOX emissions to water are overall higher for a pure Central European fibre-based office paper than for both integrated and recycled office papers.

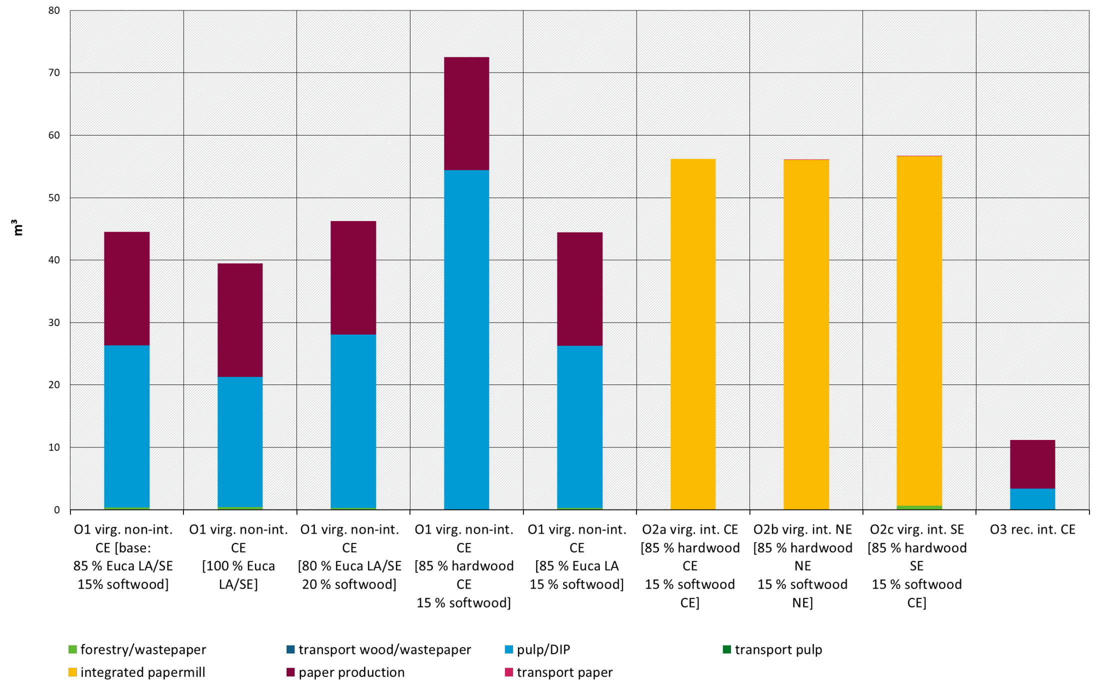
Figure 11: Aquatic Eutrophication, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

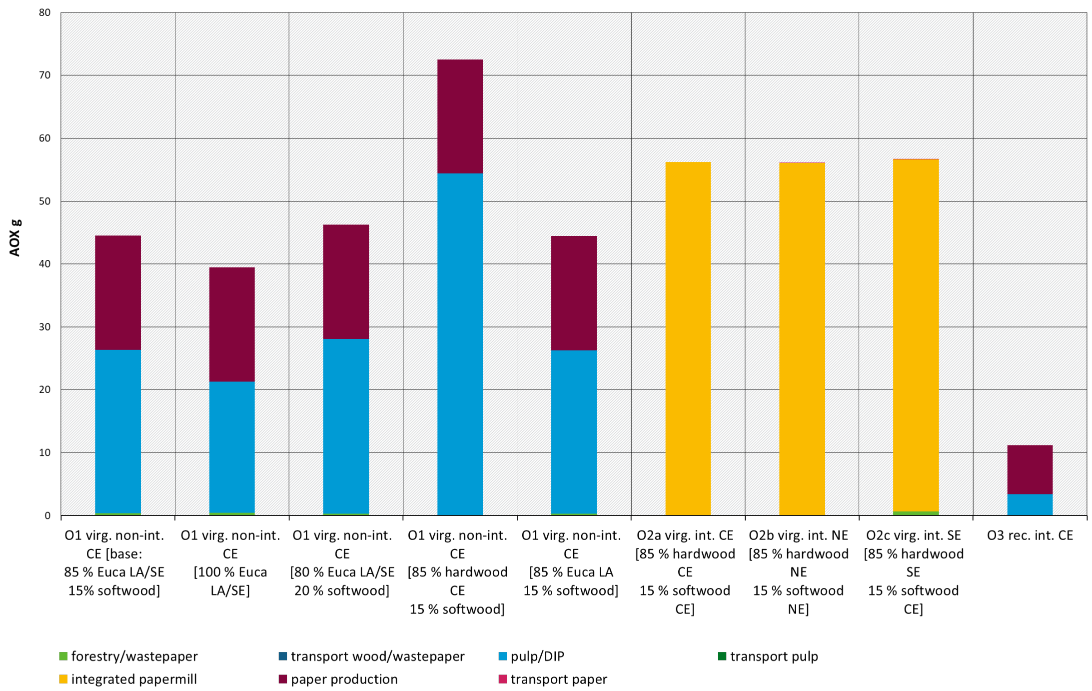
Source: (Own depiction 2021, ifeu)

Figure 12: Freshwater Demand, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 13: Adsorbable Organic Halogenated Compounds (AOX), 1000 kg office paper, variant scenarios



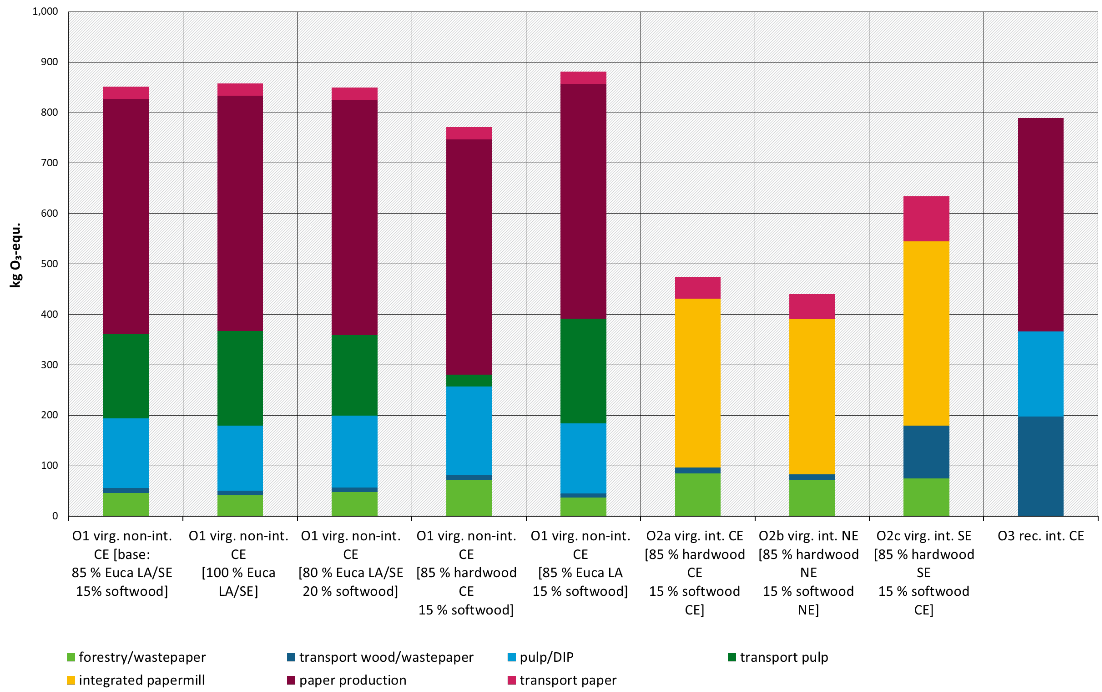
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.1.4 Office paper variant scenario results: Human Health-related results

Office papers with variations in short and long fibre contents largely remain in the same order of magnitude than those with the base fibre composition for the health-related indicators results Photo-oxidant formation and fine particulate matter (PM 2.5).

Office papers based on pure Central European pulp are associated with lower Photo-oxidant formation and fine particulate matter (PM 2.5) than those with average pulp composition in the base scenarios. One reason for this might lie in the stricter emission limit requirements in those countries. As a result, Central European office papers show comparable Photo-oxidant formation than recycled office papers. **However, comparative findings in this aspect have to be handled with care, as data symmetry within the various individual datasets contributing to this result may not be fully given based on the inventory data currently available.** On the other hand, fine particulate matter (PM 2.5) is due to secondary fine particles such as nitrogen and sulfur oxides lower for pure Central European pulp-based office papers than for integrated virgin office papers, but nevertheless remains higher than for recycled office papers.

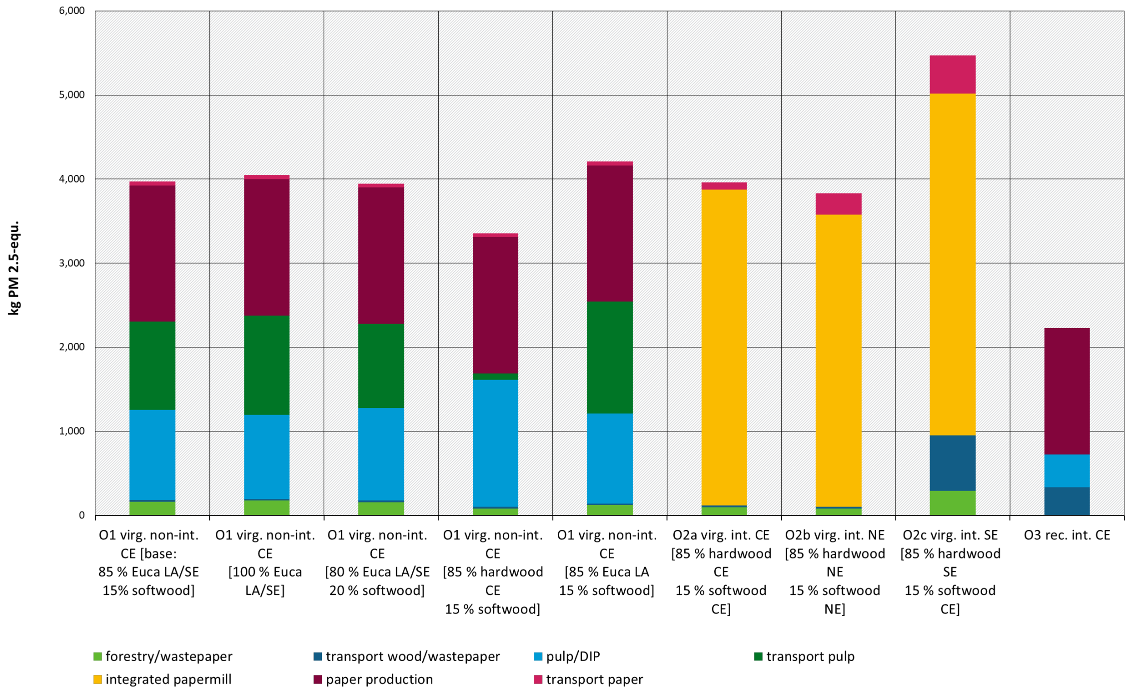
Figure 14: Photo-oxidant formation, 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 15: Particulate Matter (PM 2.5), 1000 kg office paper, variant scenarios



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

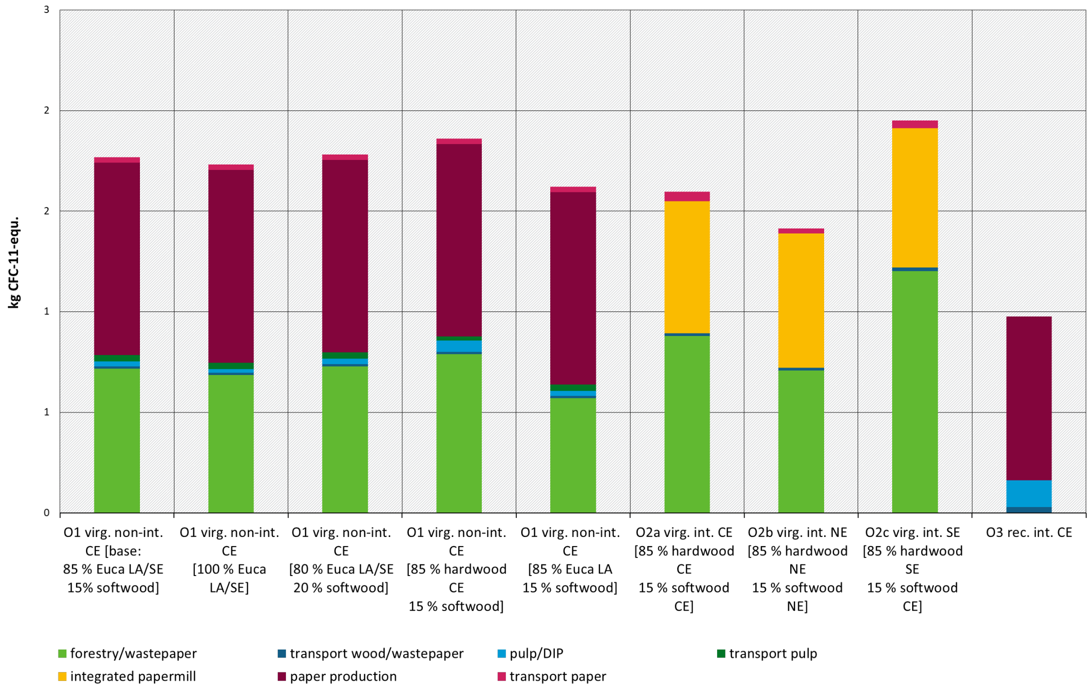
Source: (Own depiction 2021, ifeu)

3.1.1.5 Office paper variant scenario results: Ozone Depletion

Office papers with variations in short and long fibre contents as well as based on pure Central European pulp largely remain in the same order of magnitude than those with the base fibre composition regarding ozone depletion.

Office papers based on pure Latin American eucalyptus pulp lead to lower ozone depletion than virgin non-integrated office papers with average short fibre mix. This is related to the reduced nitrous oxide emissions from eucalyptus forestry, due to relatively high pulpwood harvesting yields in Latin America (Eucalyptus Latin America 33 m^3/ha versus Eucalyptus Iberia 15 m^3/ha). As a result, pure Latin American based office papers are in the same order of magnitude regarding ozone depletion as Northern Europe virgin integrated office papers.

Figure 16: Ozone Depletion, 1000 kg office paper, variant scenarios



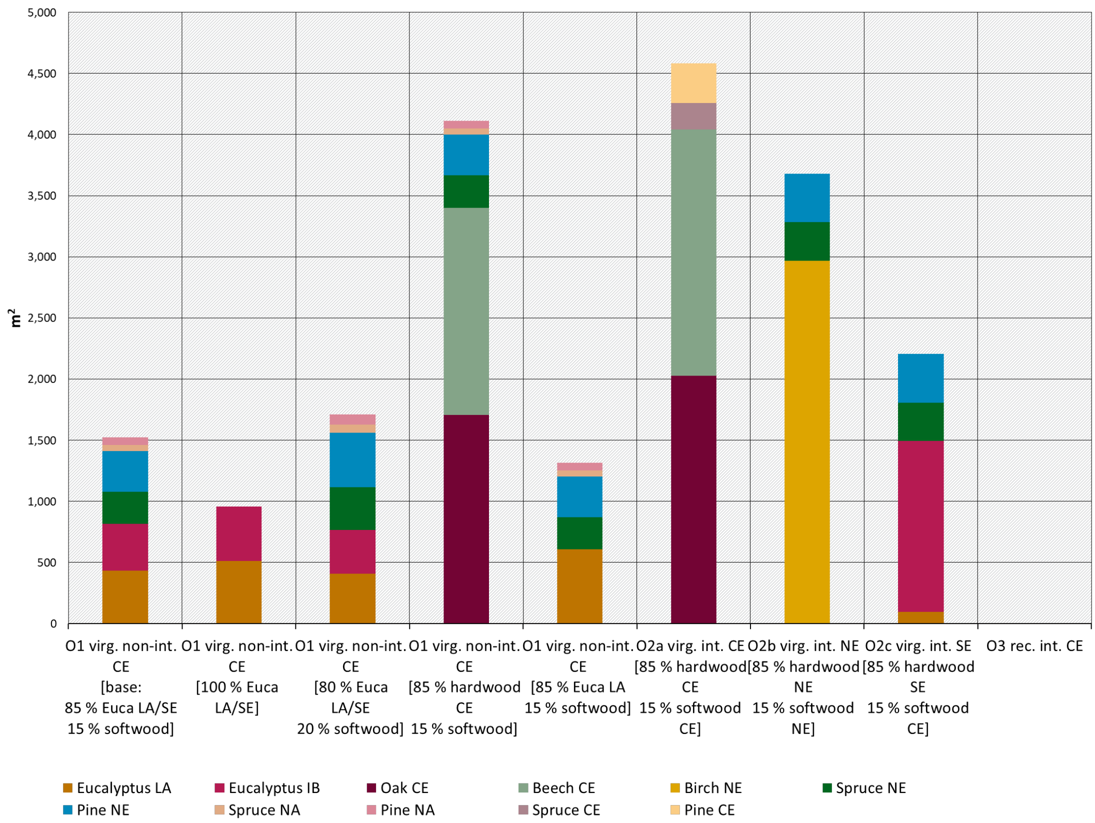
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.1.6 Office paper variant scenario results: Forest Area

Office papers with variations in short and long fibre contents and different pulp origin and pulpwood species are associated with a quite different demand in Forest Area compared to the base pulp composition. Only the variant with slightly reduced short fibre content remains very close to the base forest area.

Clearly, demand in Forest Area directly depends on pulpwood yields, which differ between different forestry regions as well as between different tree types. Hence, a minimum forest area (around 1000 m^2 per t office paper) is required for pure eucalyptus-based office papers, due to high yields of pulpwood in eucalyptus short rotation forestry. On the other hand, forest area required for pure Central European pulp-based office papers is around 4000 m2 per t office paper. The underlying yield per hectare is based on annual forest growth rates and includes round wood as well as thinning wood harvested during the rotation period. As the share of thinning wood for Central European paper production is potentially higher than assumed in the present study, the forest area needed for Central European paper production might be overestimated. However, it has to be kept in mind regarding those findings that those numbers do not include any qualitative forest area aspects, such as biodiversity etc., therefore comparative statements have to be handled with care regarding forest area demand. For an ecological assessment of wood origins in the LCA scenarios please see the spotlight report.

Figure 17: Forest Area, 1000 kg office paper, variant scenarios



CE: Central Europe, IB: Iberia, LA: Latin America, NE: Northern Europe, NA: North America, SE: Southwestern Europe

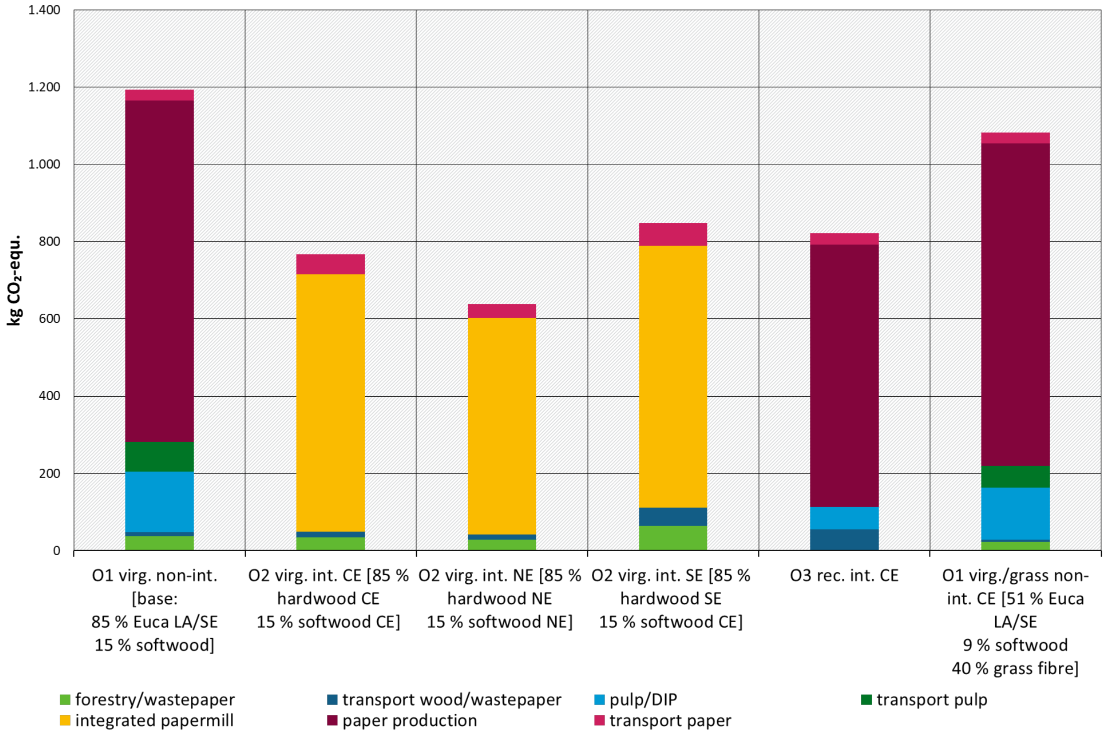
Source: (Own depiction 2021, ifeu)

3.1.2 Office paper grass paper scenario results

3.1.2.1 Office paper grass paper scenario results: Climate Change, Non-renewable Primary Energy Demand & Total Primary Energy Demand

Overall, non-integrated grass papers with 40 % grass fibre content are associated with around 10 % lower greenhouse gas emissions and primary non-renewable energy demand than other non-integrated virgin fibre based paper production. Nevertheless, the overall result also shows the same comparison to integrated and recycled office papers as described for base scenarios, regardless the fibre composition.

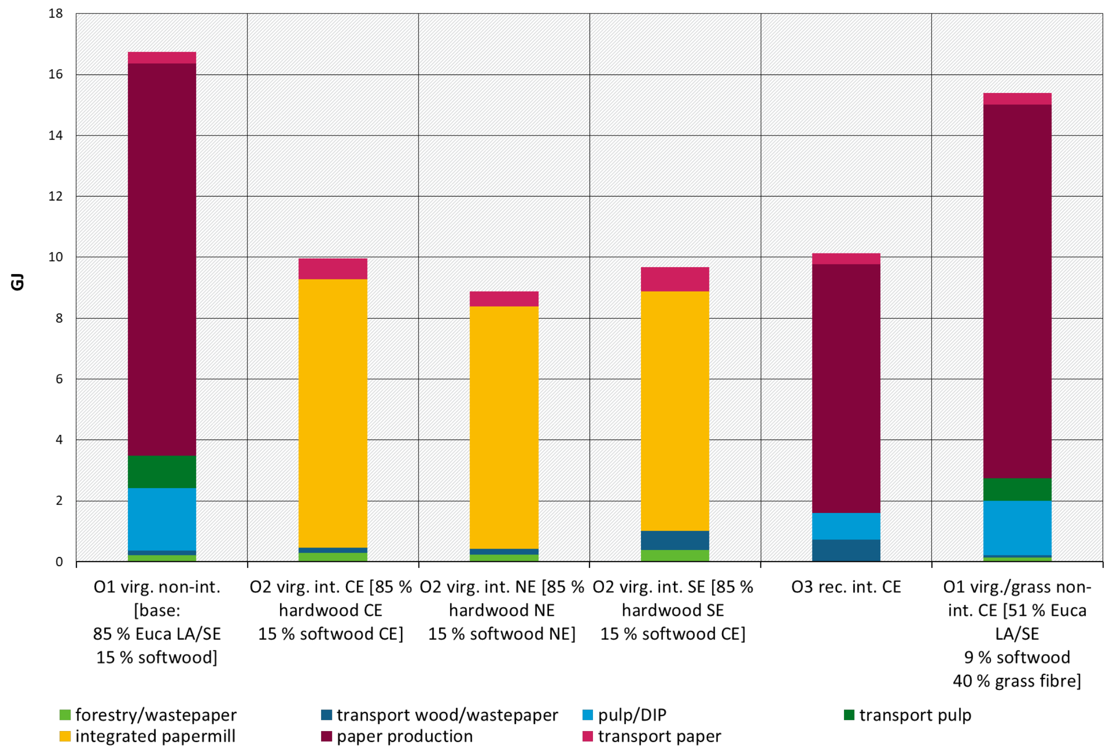
Figure 18: Climate Change, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 19: Cumulative Energy Demand (CED) non-renewable, 1000 kg office paper base scenarios, incl. grass paper



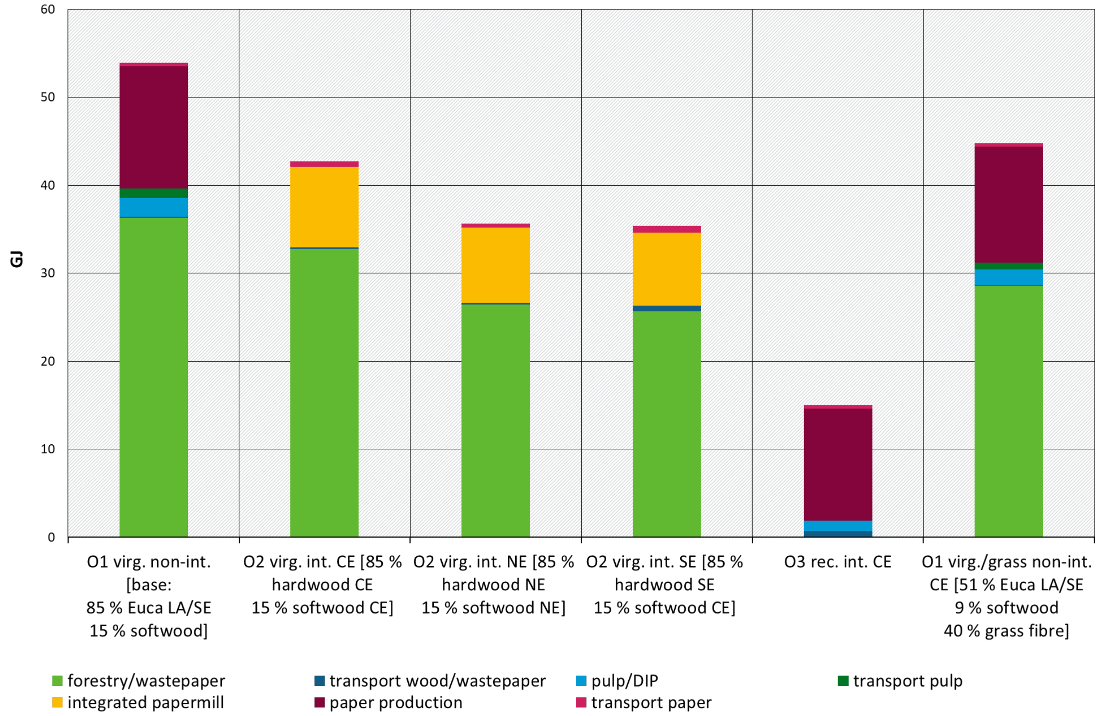
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 43 in this section shows the results of the inventory category Cumulative Primary Energy Demand (total).

Non-integrated grass paper shows a lower total primary energy demand than non-integrated virgin office papers, due to a less contribution from forestry. Its total CED is still higher than that of virgin and recycled papers from integrated production, though.

Figure 20: Total CED, 1000 kg office paper base scenarios, incl. grass paper



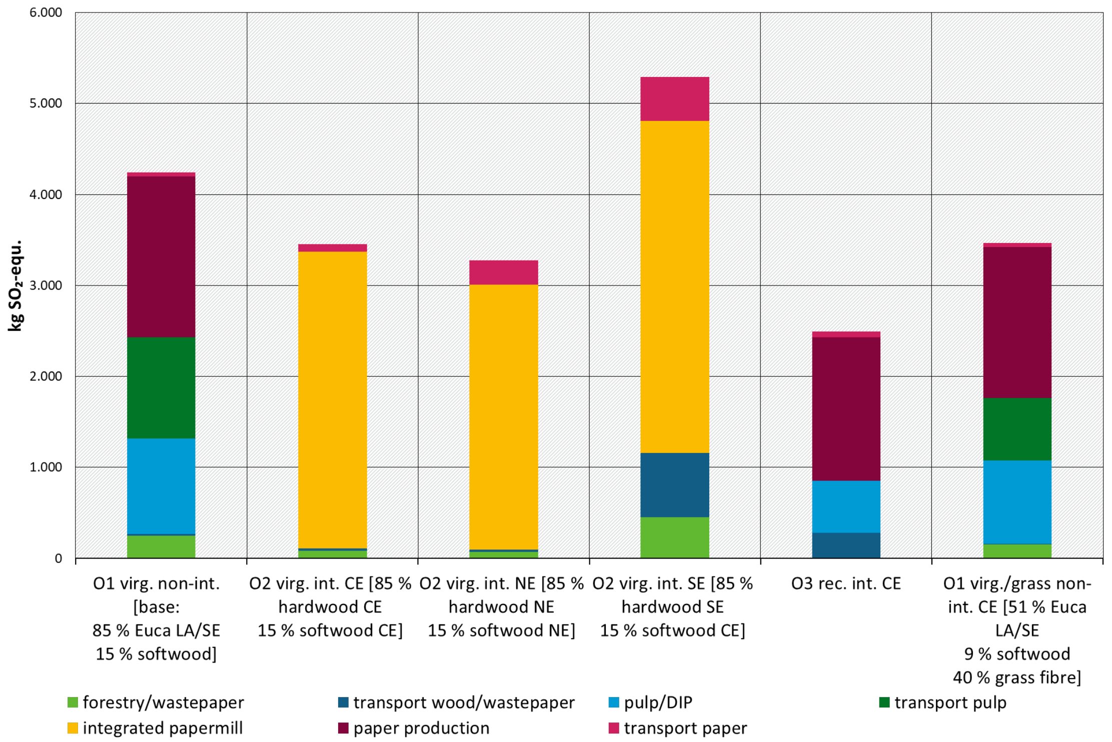
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.2.2 Office paper grass paper scenario results: Acidification & Terrestrial Eutrophication

Non-integrated grass papers perform for acidification and terrestrial eutrophication lower than the base scenario. Reductions are related to savings in forestry, as well as reduced contributions from pulping and pulp transports.

As a result, non-integrated grass papers are in the same order of magnitude regarding acidification and terrestrial eutrophication as Central and Northern European papers from integrated production, but still higher if compared to recycled office papers (the latter especially due to the remaining 60 % of virgin fibre).

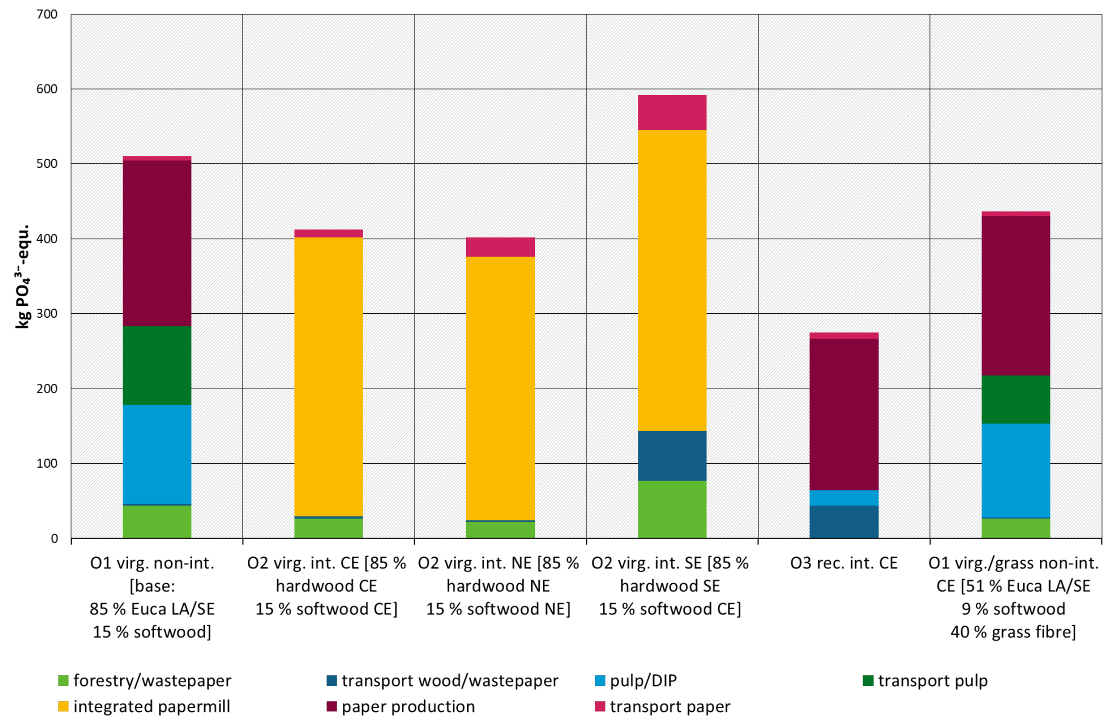
Figure 21: Acidification, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 22: Terrestrial Eutrophication, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

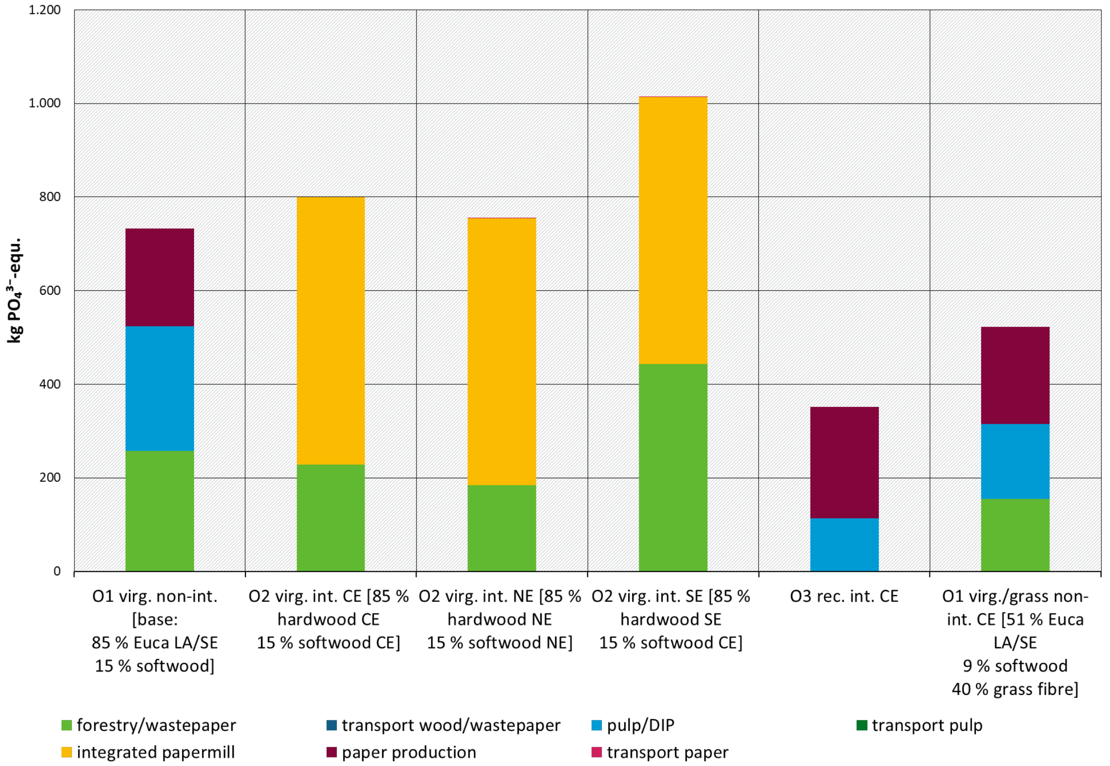
Source: (Own depiction 2021, ifeu)

3.1.2.3 Office paper grass paper scenario results: Water-related results

Non-integrated grass paper (40 % grass fibre content) shows reductions around more than 25 % in all water-related indicators results aquatic eutrophication, process water and AOX emissions to water relative to base non-integrated virgin office papers. Here the grass pellet process is a relatively simple processing relative to the demanding pulping process. In case of Aquatic Eutrophication, also nutrient-rich water emissions such as nitrogen and phosphorus compounds are reduced by use of non-fertilised grass pellets relative to virgin pulpwood forestry.

In a comparison with other office papers examined, grass paper ends up in between virgin non-integrated office paper and recycled office paper in all water-related indicators.

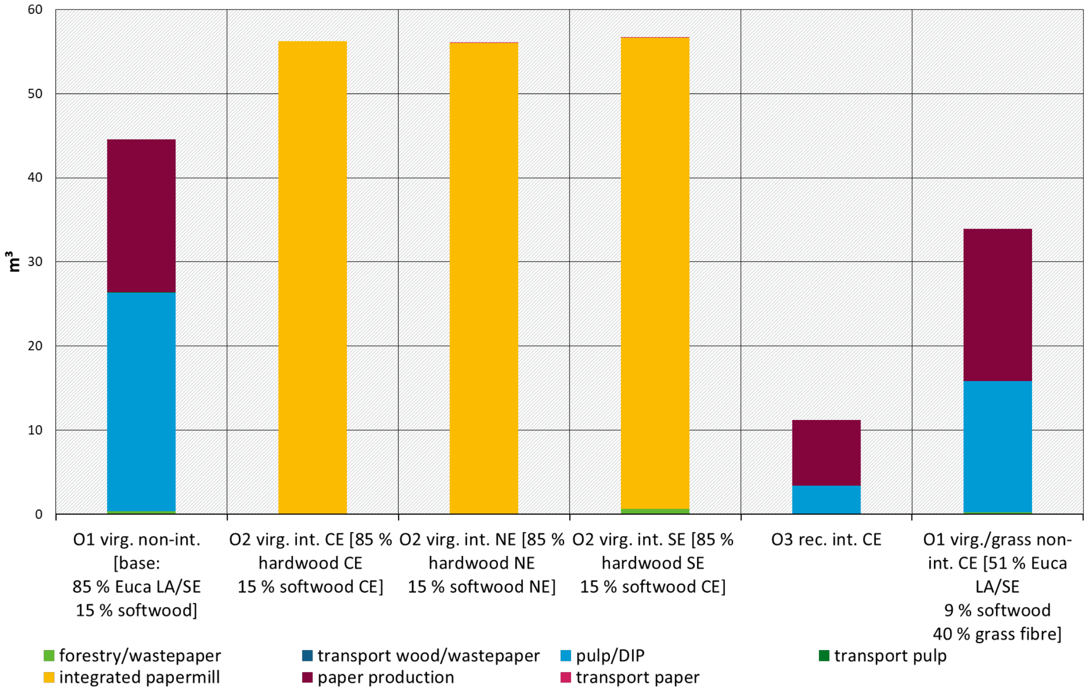
Figure 23: Aquatic Eutrophication, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

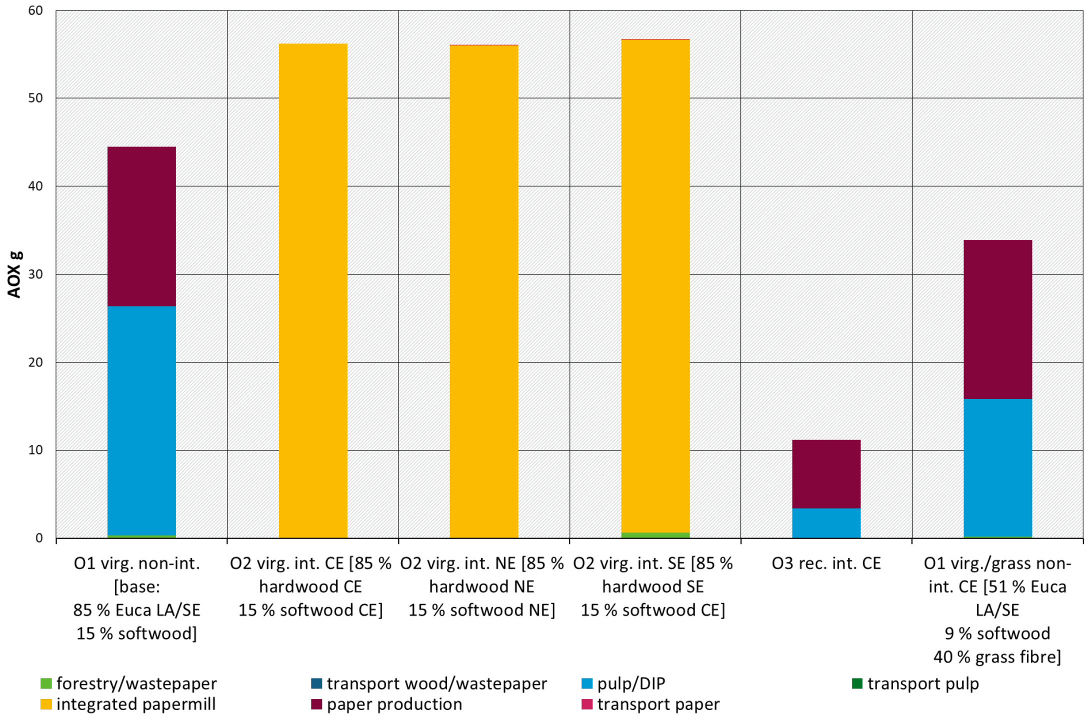
Source: (Own depiction 2021, ifeu)

Figure 24: Freshwater Demand, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 25: Adsorbable Organic Halogenated Compounds (AOX), 1000 kg office paper base scenarios, incl. grass paper



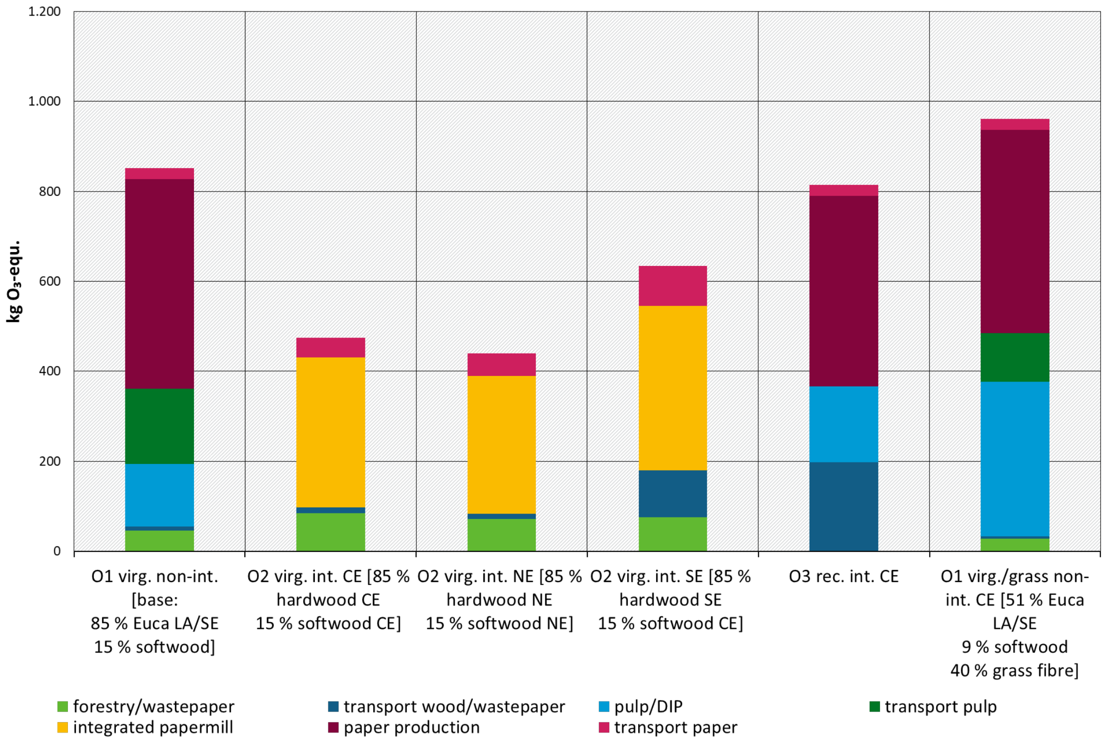
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.2.4 Office paper grass paper scenario results: Human Health-related results

Non-integrated grass paper is associated with higher Photo-oxidant formation and lower fine particulate matter (PM 2.5) than virgin non-integrated office paper. The increase in Photo-oxidant formation is related to fuel-based organic emissions as a result of the machine use for mechanical processing of grass (e.g. pelletizing and collection of grass from the land). The savings in nitrogen and sulfur oxides (key secondary fine particles) are related to reductions in virgin fibre that needs several combustion processes (including bio based).

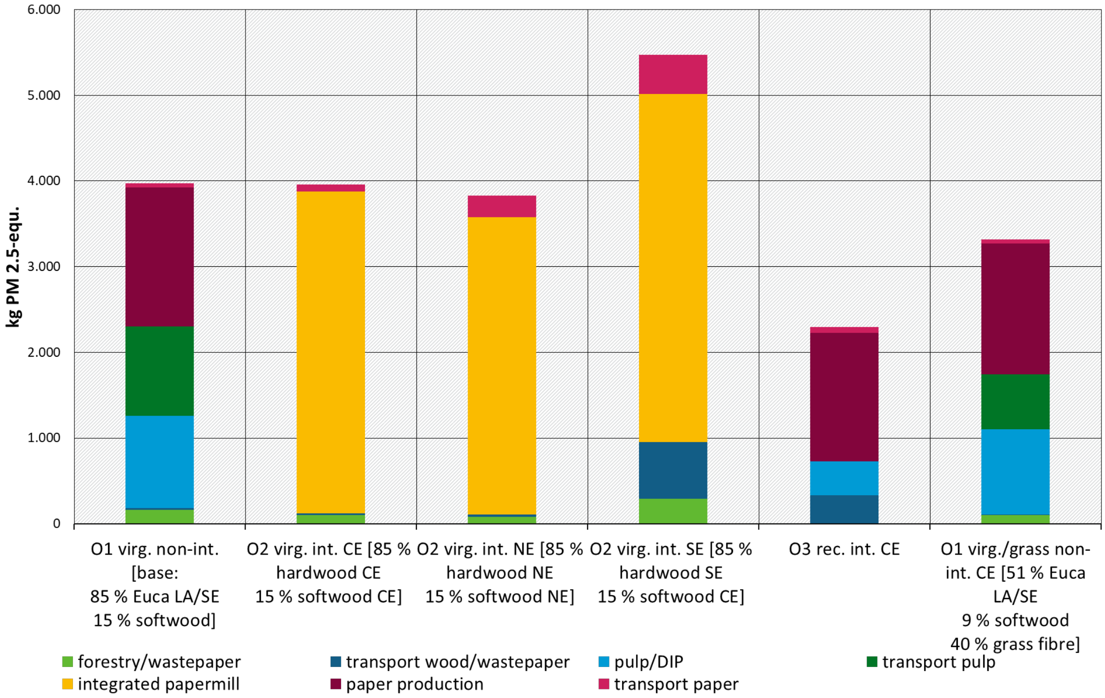
In comparison with both virgin and recycled office papers, grass paper is highest in Photo-oxidant formation. **However, comparative findings in this aspect have to be handled with care, as data symmetry within the various individual datasets contributing to this result may not be fully given based on the inventory data currently available.** As for fine particulate matter (PM 2.5), grass paper is associated with lower impact than virgin office papers, but remains higher than recycled office papers.

Figure 26: Photo-oxidant formation, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 27: Particulate Matter (PM 2.5), 1000 kg office paper base scenarios, incl. grass paper



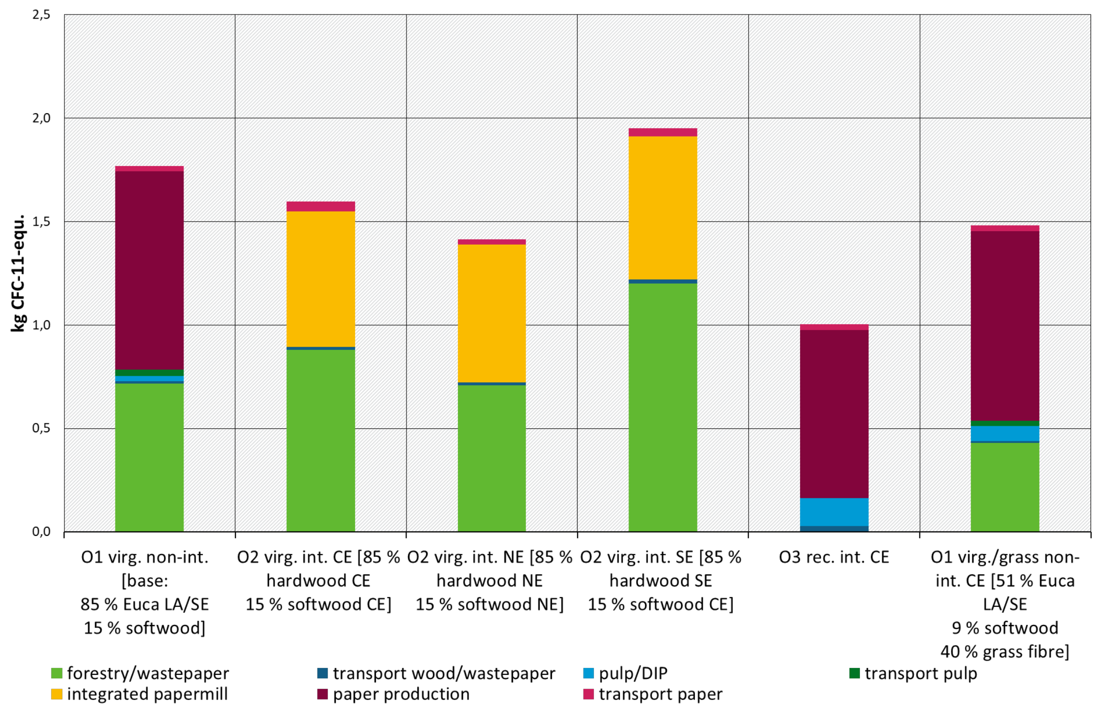
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

3.1.2.5 Office paper grass paper scenario results: Ozone Depletion

Non-integrated grass paper is associated with less ozone depletion than virgin non-integrated office papers, mainly due to savings in nitrous oxide emissions from forestry. As a result, grass paper is in the same order of magnitude as Northern European virgin integrated office papers, but remains higher than recycled office papers.

Figure 28: Ozone Depletion, 1000 kg office paper base scenarios, incl. grass paper



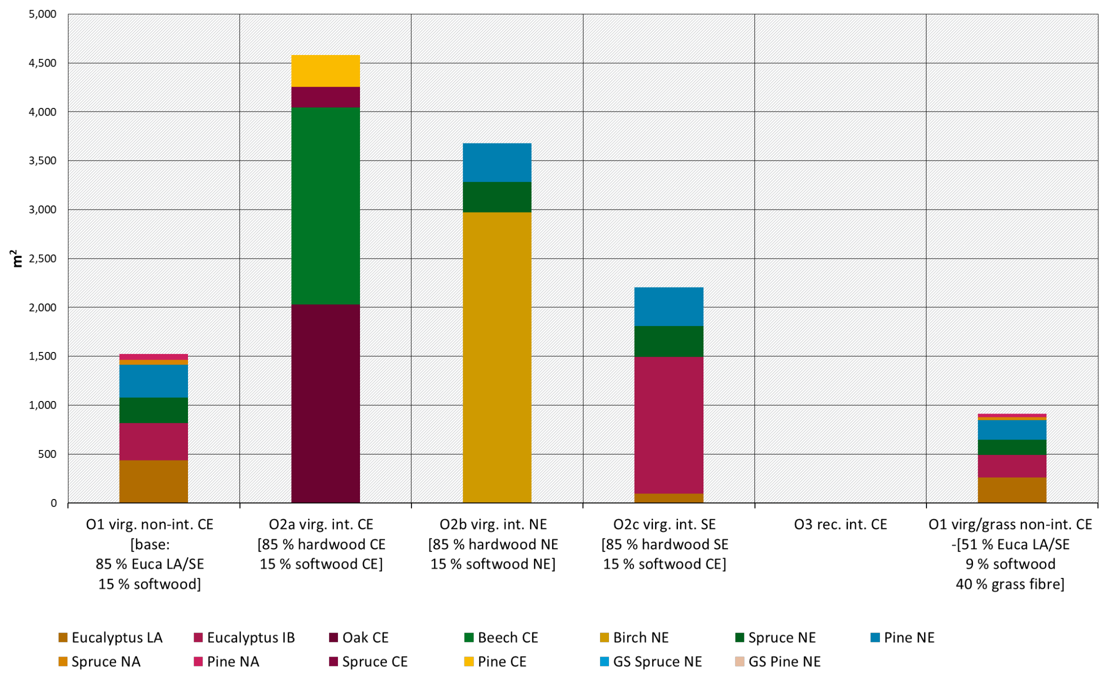
CE: Central Europe, LA: Latin America, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.1.2.6 Office paper grass paper scenario results: Forest Area

Required forest area strongly depends on tree types and geographic origin of pulp and thus wood origin, as harvesting yields of forestry operations differ due to e.g. different forest management types, local soil and climate conditions etc. Overall, the range in forest area required is up to 3 fold (with the maximum difference between non-integrated and Central European papers from integrated production). However, it has to be kept in mind that this indicator provides insight at the inventory level, so that assessment of further aspects, such as quality aspects related e.g. to biodiversity, are not taken into account at this stage yet. At this inventory level, especially eucalyptus with the highest yields in a comparison of pulpwood types examined here requires forest area at the lower end of the range. For a large part those high yields are related to the typical short rotation plantation practices in Eucalyptus forestry.

Grass paper requires in total less forest area than the non-integrated virgin office papers, as the virgin fibre input is reduced. Distribution over tree types and geographies remains, as it is assumed that virgin fibre is replaced by grass pellets as in the average pulp mix for non-integrated office papers. Hence overall, grass paper requires more forest area than recycled office papers, but less than virgin non-integrated office papers.

Figure 29: Forest Area, 1000 kg office paper base scenarios, incl. grass paper



CE: Central Europe, IB: Iberia, LA: Latin America, NA: North America, NE: Northern EuropeSource: (Own depiction 2021, ifeu)

3.2 Results tissue paper

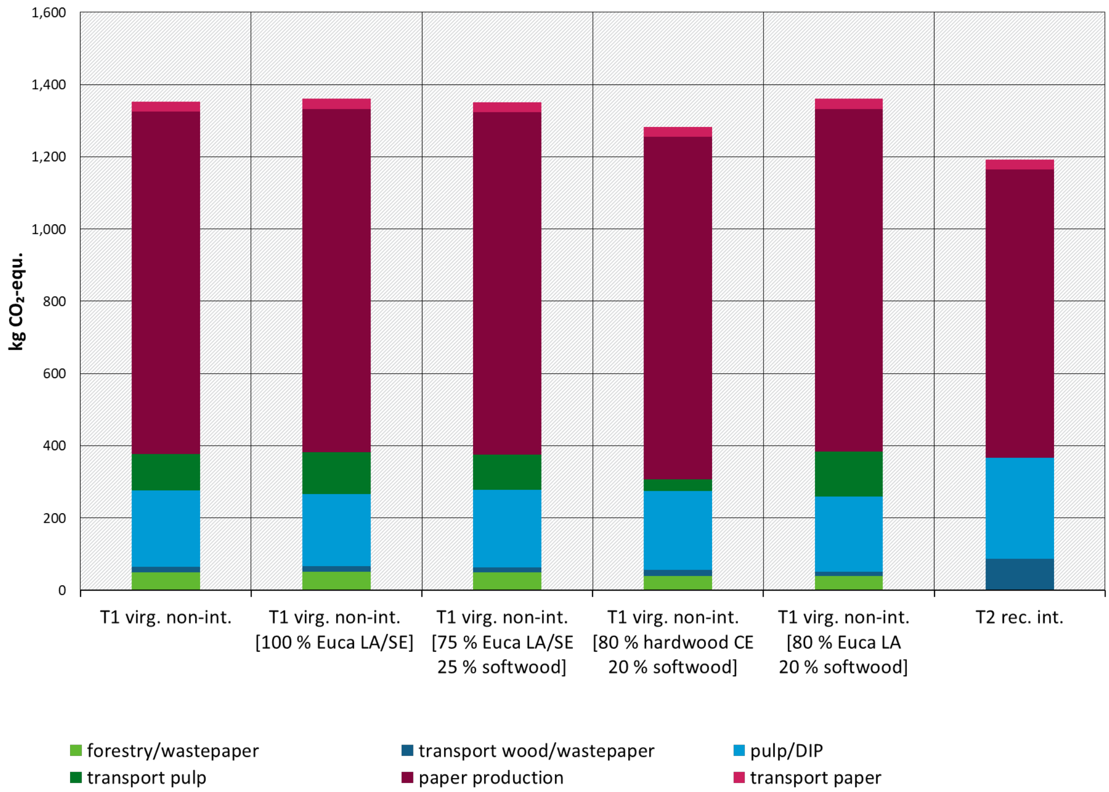
3.2.1 Tissue paper variant scenario results

Results of tissue paper variant scenarios are shown in the following Figure 30 to Figure 41, next to the tissue paper base scenarios as presented in the spotlight report. The individual sections point out specific observations related to paper variants examined.

3.2.1.1 Tissue paper variant scenario results: Climate Change, Non-renewable Primary Energy Demand & Total Primary Energy Demand

Overall, tissue papers with maximum and minimum short fibre content show very similar results regarding greenhouse gas emissions and primary non-renewable energy demand. Despite small differences in pulp production and pulp transport contributions, the overall result also shows the same comparison to recycled tissue papers as described for the base scenario, regardless the fibre composition. This is also largely true for variations in pulp origin, where only a pure pulp origin from Central Europe leads to slightly lower overall result (associated with savings in pulp transports), but still the comparative picture to recycled tissue remains stable.

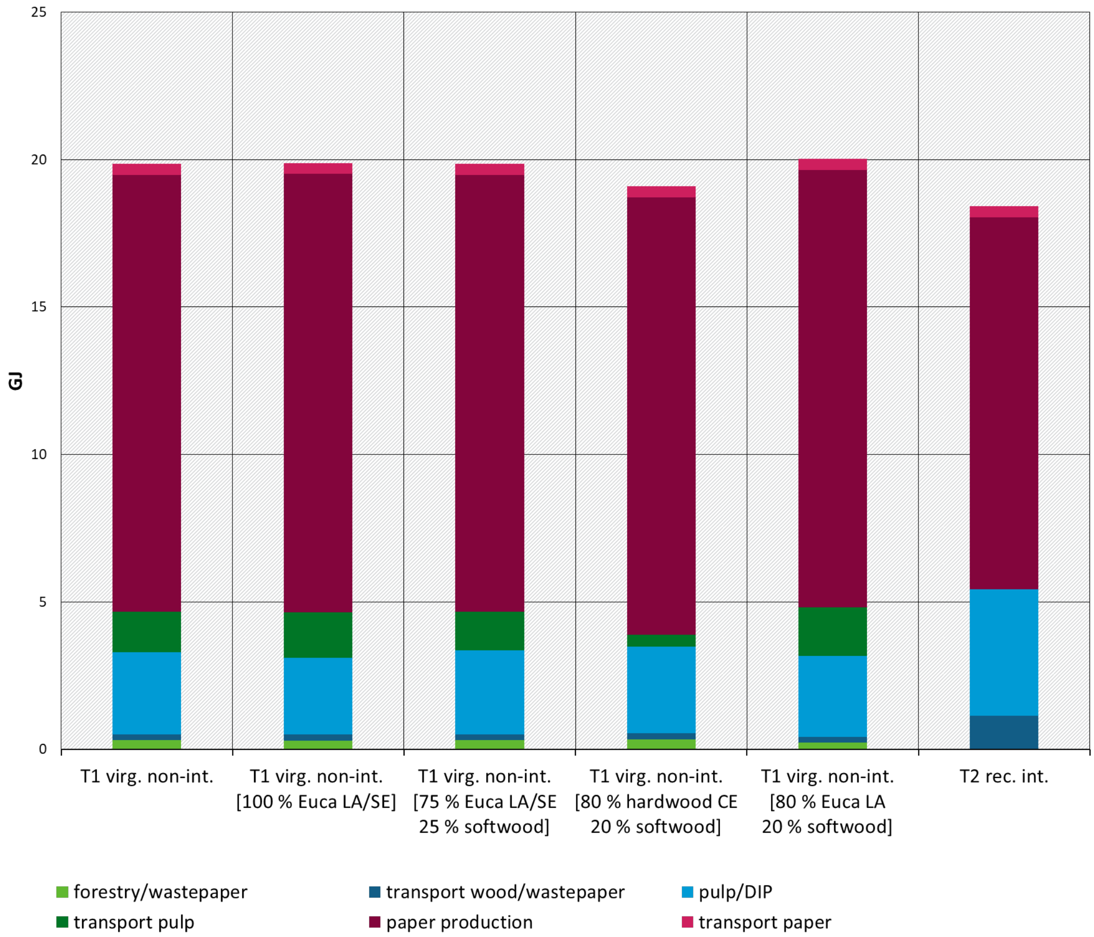
Figure 30: Climate Change, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 31: Cumulative Energy Demand (CED) non-renewable, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

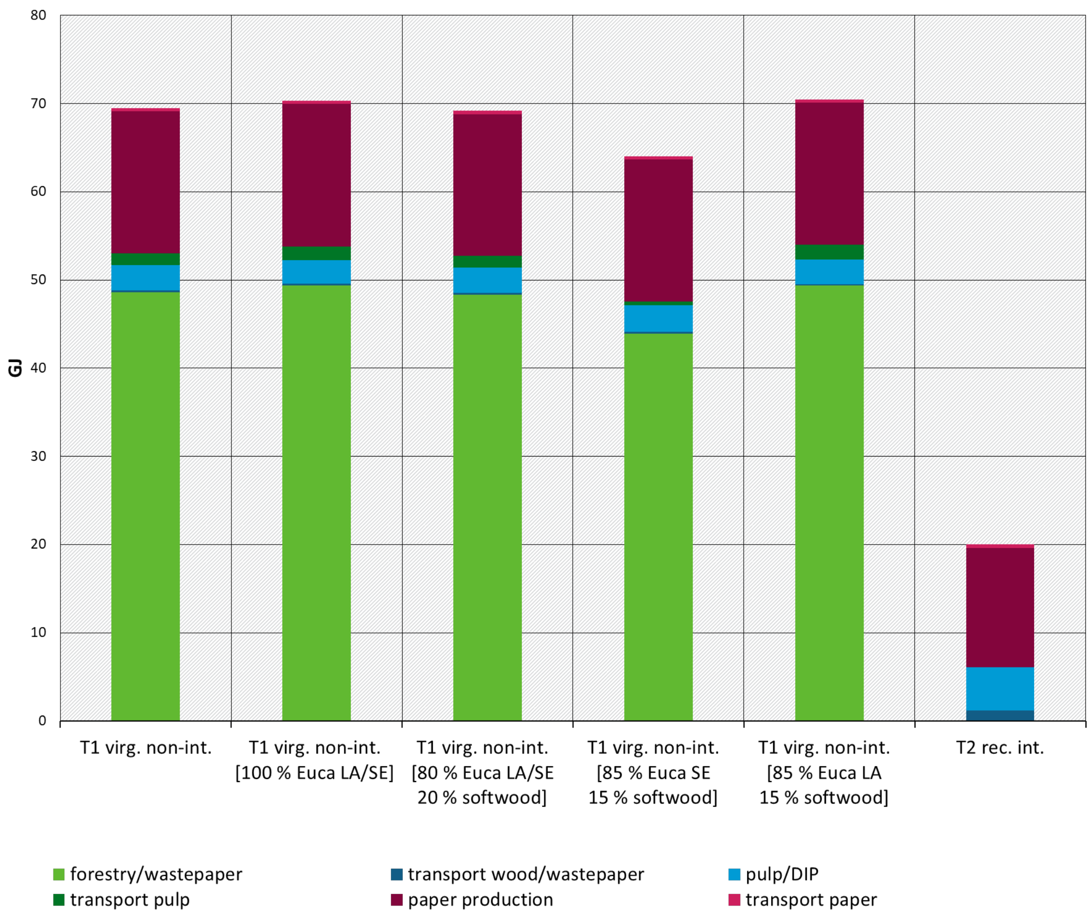
Figure 32 in this section shows the results of the inventory category Cumulative Primary Energy Demand (total).

Non-integrated grass paper shows a lower total primary energy demand than non-integrated virgin office papers, due to a less contribution from forestry. Its total CED is still higher than that of virgin and recycled papers from integrated production, though.

Figure 67 in this section shows the results of the inventory category Cumulative Primary Energy Demand (total).

Integrated recycled tissue paper is associated with a lower total primary energy demand than non-integrated virgin tissue papers. Although total primary energy demand is higher for the deinking process than for the production of virgin pulp, the high energy demand of the forestry life cycle step dominates the overall results. Differences due to different origins of virgin fibres are small.

Figure 32: Total CED, 1000 kg tissue paper, variant scenarios



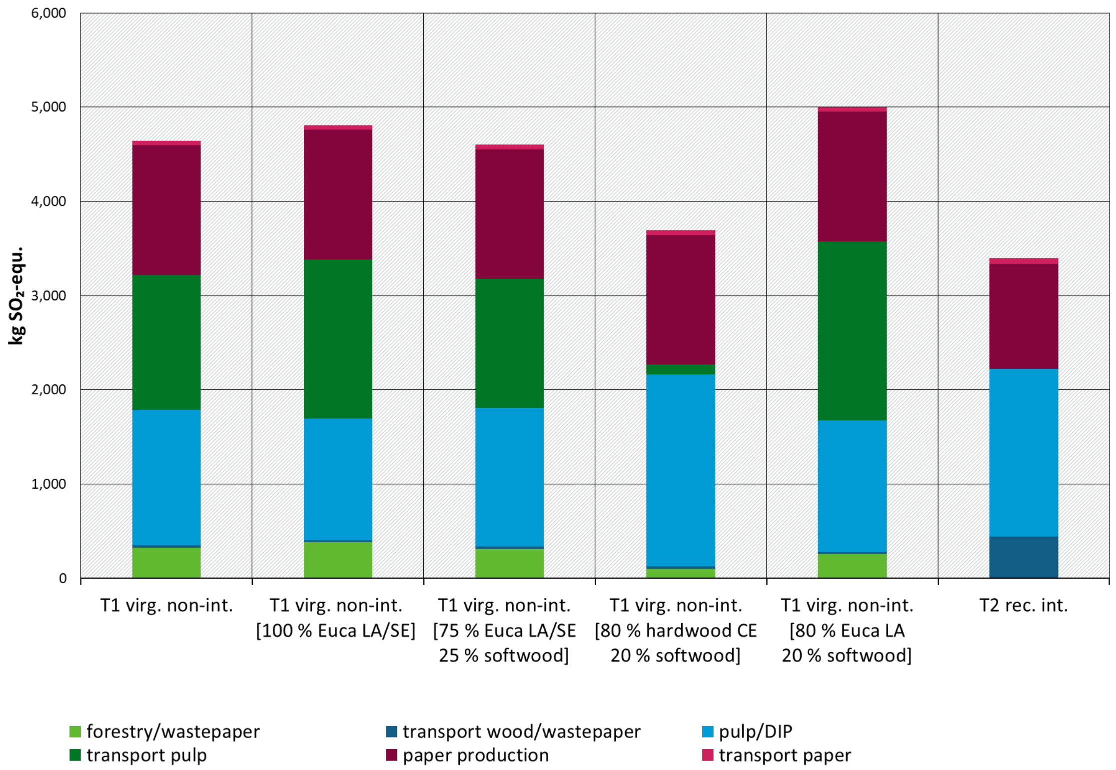
CE: Central Europe, LA: Latin America, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.2.1.2 Tissue paper variant scenario results: Acidification & Terrestrial Eutrophication

Tissue paper variants with minimum and maximum short fibre content are for acidification and terrestrial eutrophication very close to the base scenario. Fibre origin fully from Central Europe (short fibres based on European oak and beech pulpwood) is associated with lower acidification and terrestrial eutrophication impacts than the average pulp origin mix that is characterised by a high share of imported eucalyptus pulp.

As a result, tissue papers fully based on Central European fibres are associated with lower acidification and terrestrial eutrophication, but remain still higher if compared to recycled tissue papers.

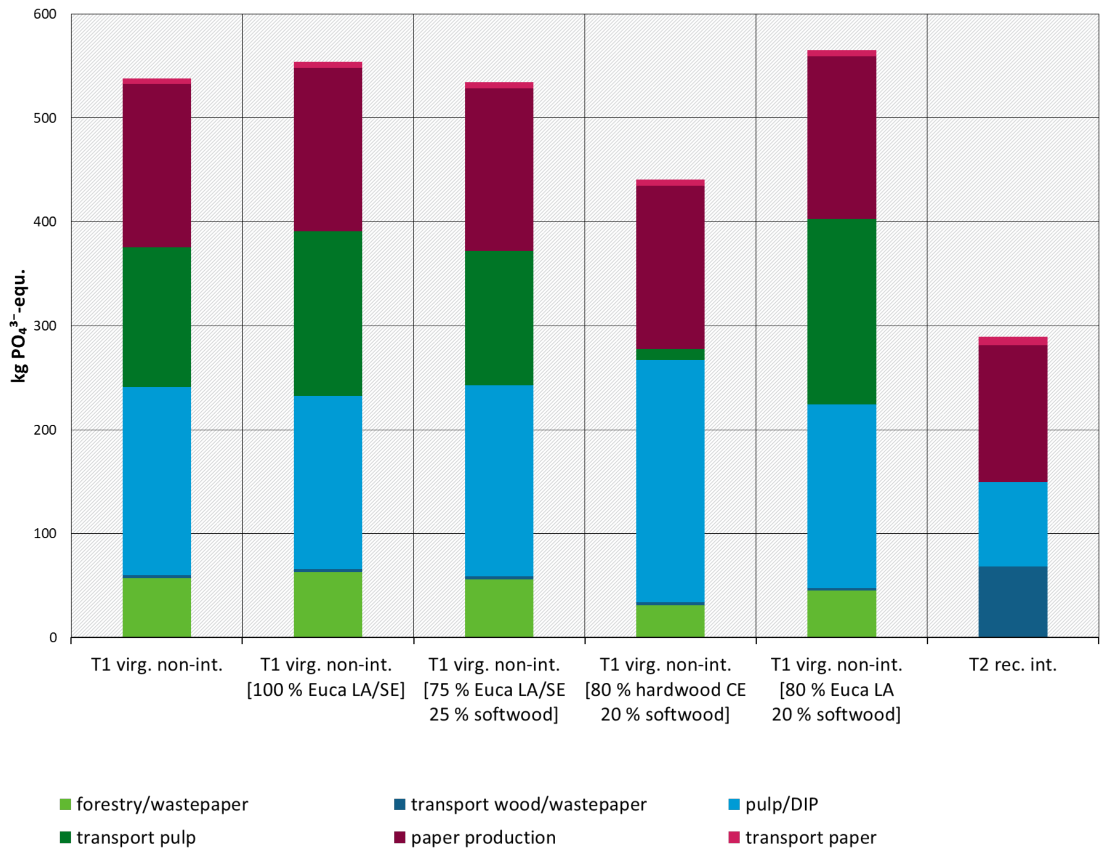
Figure 33: Acidification, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 34: Terrestrial Eutrophication, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

3.2.1.3 Tissue paper variant scenario results: Water-related results

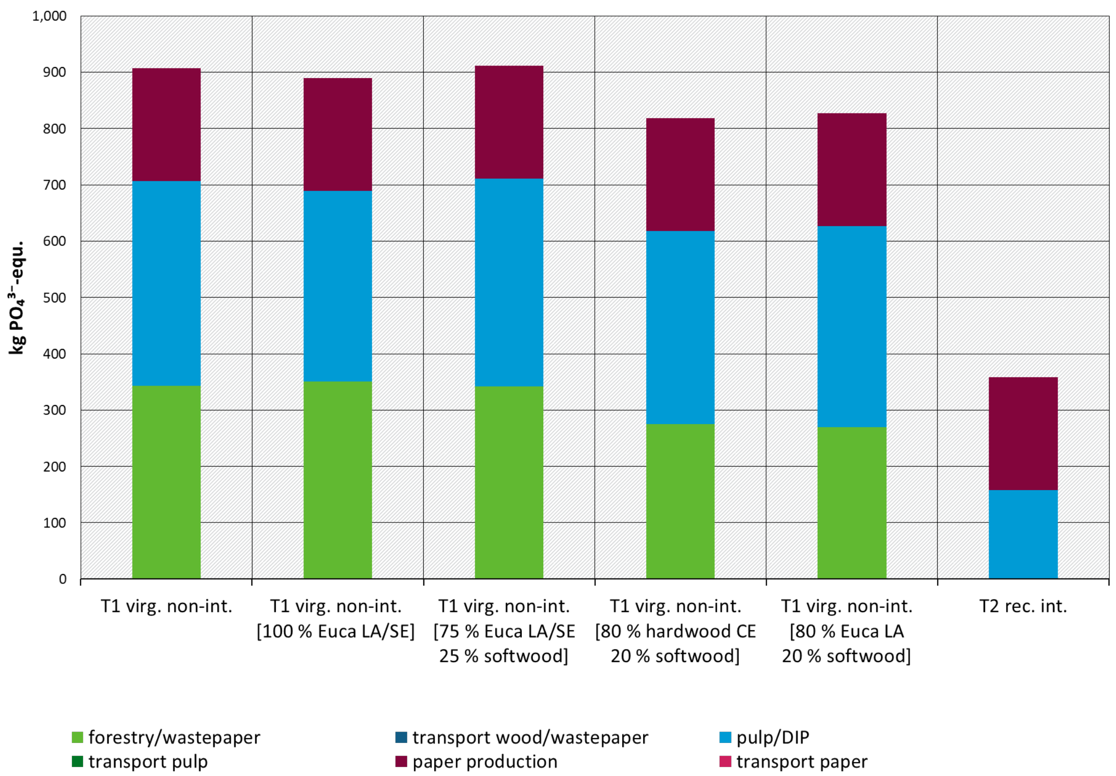
Tissue papers with variations in short and long fibre contents largely remain in the same order of magnitude than those with the base fibre composition for the water-related indicators results aquatic eutrophication, process water and AOX emissions to water.

Tissue papers based on pure Central European pulp remain also stable in Aquatic Eutrophication, but the picture changes with regards to process water demand and AOX emissions to water. Here the Central European pulp origin leads to higher demand in process water as well as AOX.

Inventory datasets available indicate higher inputs of both process water as well as chlorine-containing bleaching chemicals for Central European hardwood pulp than for Latin American Eucalyptus pulp. Overall process water demand strongly depends on the implementation of water recirculation within the pulp mill, and thus also on local conditions, if water savings are either in focus or outside the general awareness.

Required bleaching chemicals are clearly related to applied pulp bleaching sequences and technology as well as individual wood properties (e.g. lignin content). As eucalypt fibres are easier to bleach, and based on the chlorine-based bleaching chemicals input, Latin American Eucalyptus pulp is associated with lower AOX emissions than Central European hardwood pulp. This is the reason for lower AOX emissions associated with the base case tissue paper based on Eucalyptus pulp compared to a fully European hardwood-based tissue paper variant. As a result, AOX emissions to water are overall higher for a pure Central European fibre-based tissue paper than for both virgin and recycled tissue papers.

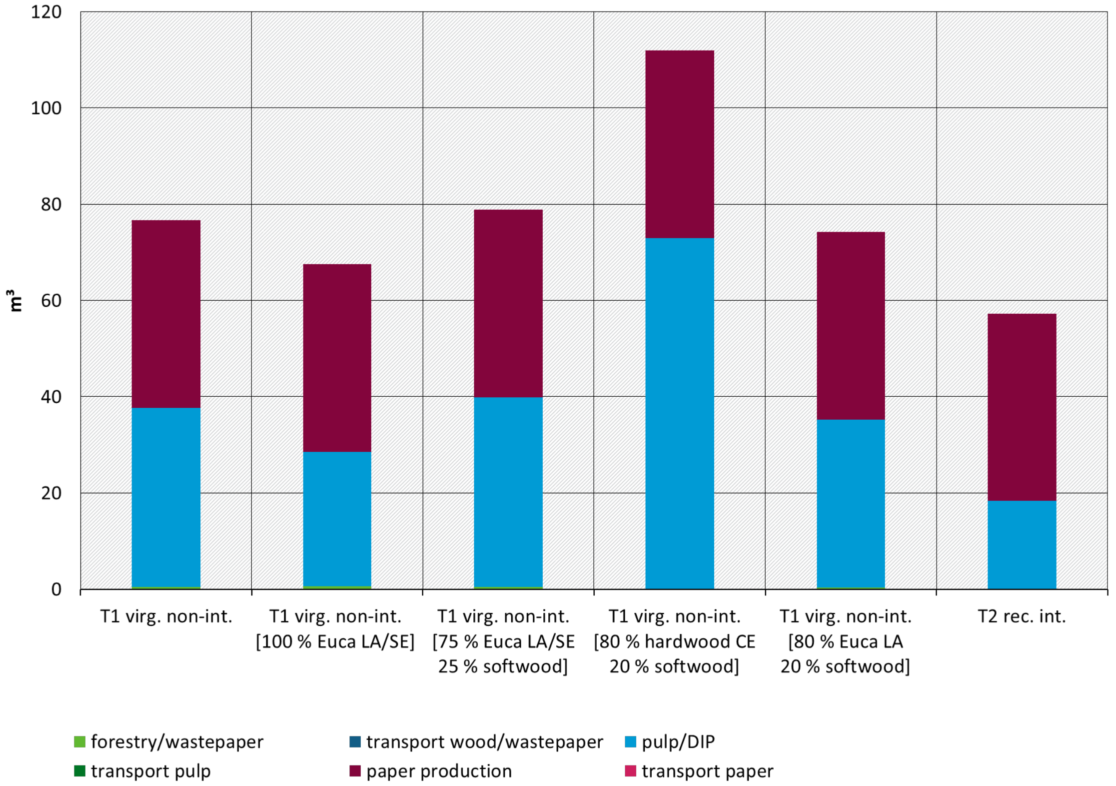
Figure 35: Aquatic Eutrophication, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

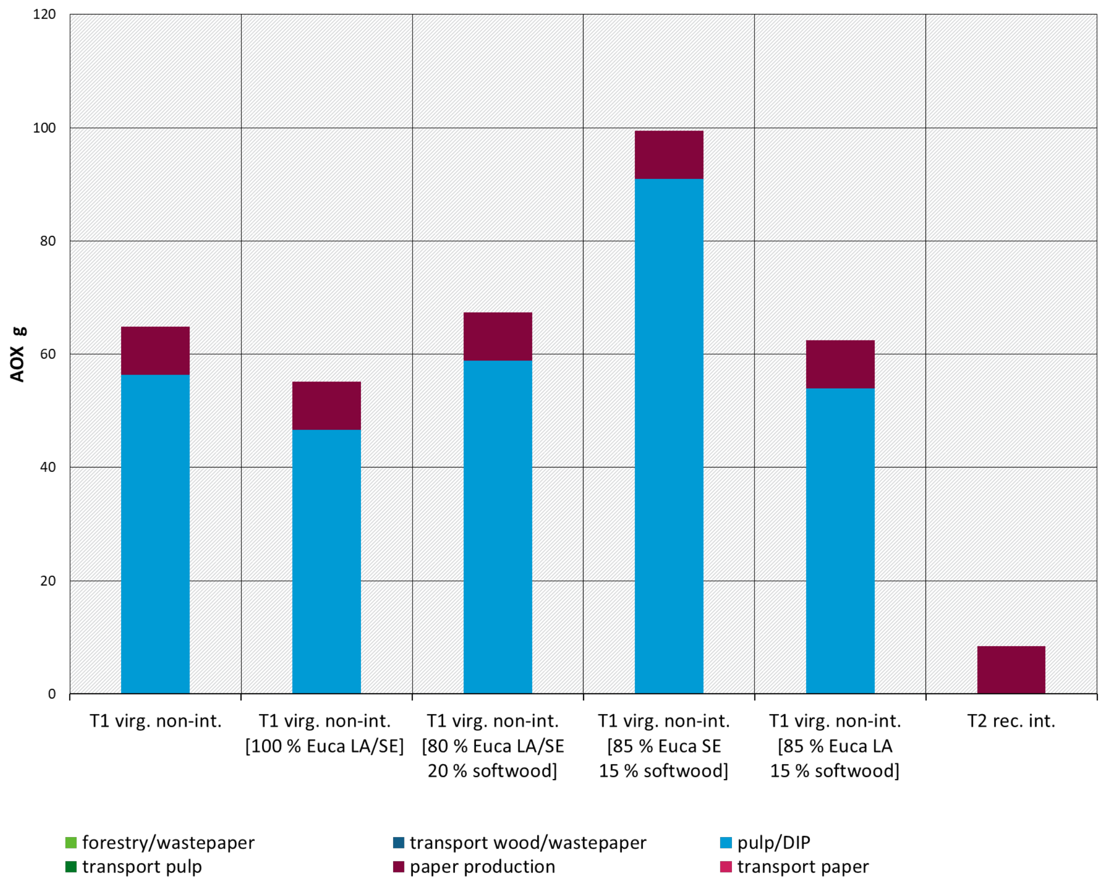
Figure 36: Freshwater Demand, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 37: Adsorbable Organic Halogenated Compounds (AOX), 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

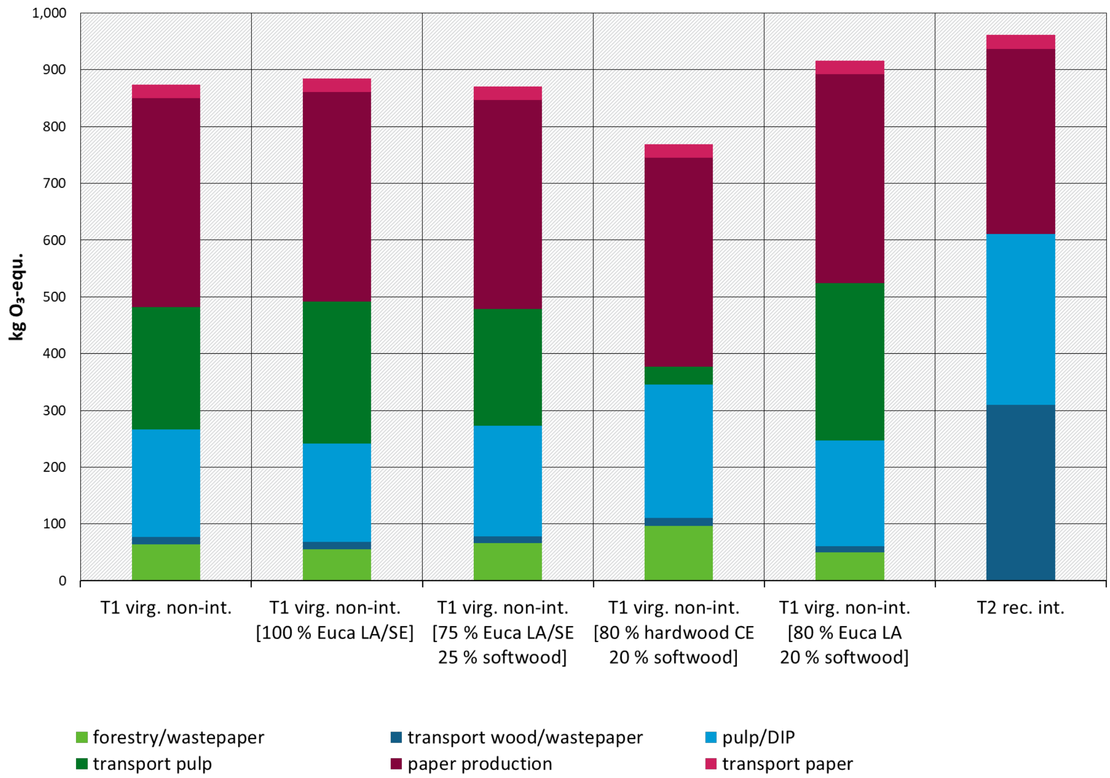
Source: (Own depiction 2021, ifeu)

3.2.1.4 Tissue paper variant scenario results: Human Health-related results

Tissue papers with variations in short and long fibre contents largely remain in the same order of magnitude than those with the base fibre composition for the health-related indicators results photochemical ozone formation and fine particulate matter (PM 2.5).

Tissue papers based on pure Central European pulp are associated with lower photochemical ozone formation and fine particulate matter (PM 2.5) than those with average pulp composition in the base scenarios. As a result, Central European tissue papers show comparable photochemical ozone formation than recycled counterparts. On the other hand, fine particulate matter (PM 2.5) is lower for pure Central European pulp-based tissue papers than base tissue papers, but nevertheless remains higher than for recycled tissue papers due to secondary fine particles such as nitrogen and sulfur oxides.

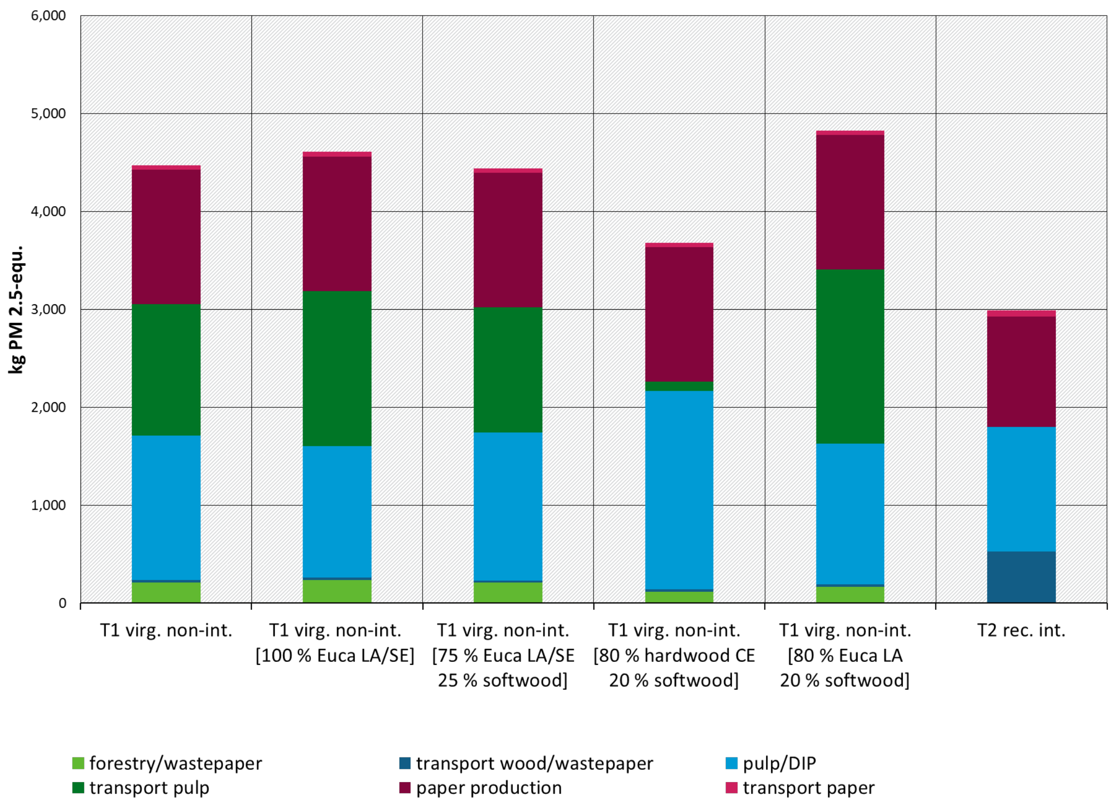
Figure 38: Photochemical Ozone Formation, 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

Source: (Own depiction 2021, ifeu)

Figure 39: Particulate Matter (PM 2.5), 1000 kg tissue paper, variant scenarios



CE: Central Europe, LA: Latin America, SE: Southwestern Europe

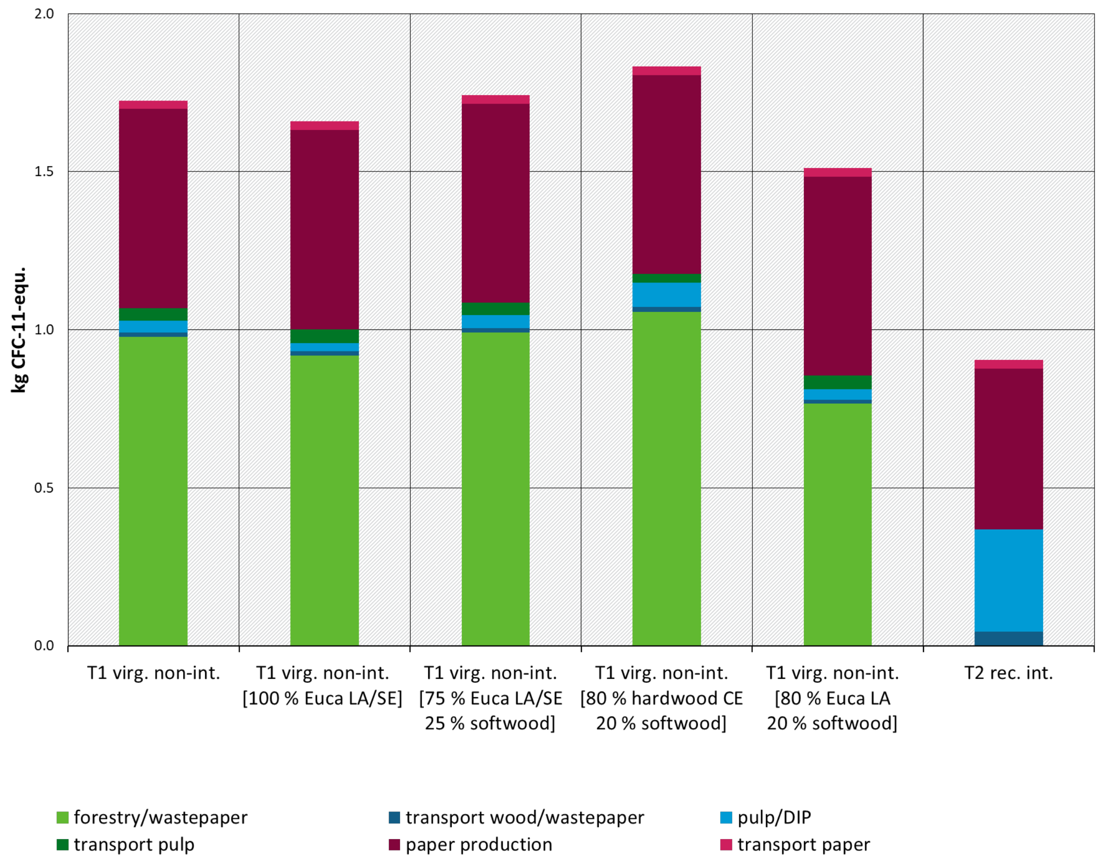
Source: (Own depiction 2021, ifeu)

3.2.1.5 Tissue paper variant scenario results: Ozone Depletion

Tissue papers with variations in short and long fibre contents as well as based on pure Central European pulp largely remain in the same order of magnitude than those with the base fibre composition regarding ozone depletion.

Tissue papers based on pure Latin American eucalyptus pulp lead to lower ozone depletion than virgin non-integrated tissue papers with average short fibre mix. This is related to the reduced nitrous oxide emissions from eucalyptus forestry, due to relatively high pulpwood harvesting yields in Latin America (Eucalyptus Latin America 33 m^3/ha versus Eucalyptus Iberia 15 m^3/ha).

Figure 40: Ozone Depletion, 1000 kg tissue paper, variant scenarios



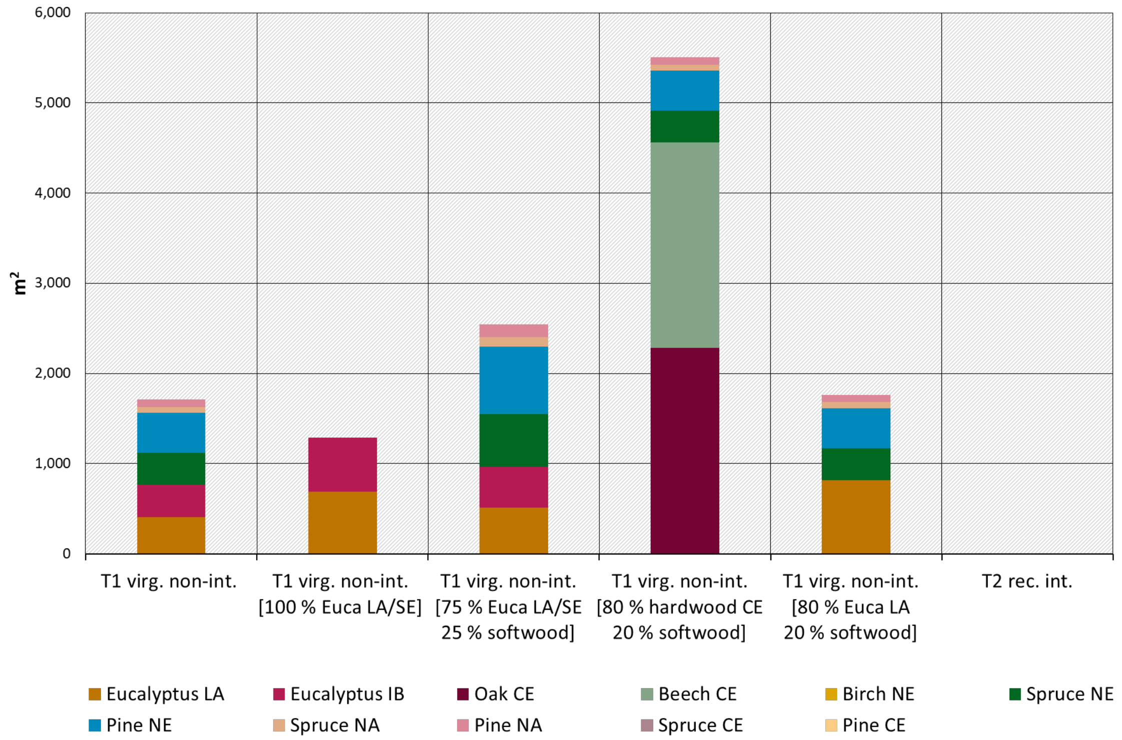
CE: Central Europe, LA: Latin America, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.2.1.6 Tissue paper variant scenario results: Forest Area

Tissue papers with variations in short and long fibre contents and different pulp origin and pulpwood species are associated with a quite different demand in Forest Area compared to the base pulp composition. Only the variant with slightly reduced short fibre content (01 Min) remains very close to the base forest area.

Clearly, demand in Forest Area directly depends on pulpwood yields, which differ between different forestry regions as well as between different tree types. Hence, minimum forest area (around 5.500 m^2 per t tissue paper) is required for pure eucalyptus-based tissue papers, due to high yields of pulpwood in eucalyptus short rotation forestry. On the other hand, forest area required for pure Central European pulp-based tissue papers is around 4.000 m2 per t tissue paper. The underlying yield per hectare is based on annual forest growth rates and includes round wood as well as thinning wood harvested during the rotation period. As the share of thinning wood for Central European paper production is potentially higher than assumed in the present study, the forest area needed for Central European paper production might be overestimated. However, it has to be kept in mind regarding those findings that those numbers do not include any qualitative forest area aspects, such as biodiversity etc., therefore comparative statements have to be handled with care regarding forest area demand.

Figure 41: Forest Area, 1000 kg tissue paper, variant scenarios



CE: Central Europe, IB: Iberia, LA: Latin America, NA: North America, NE: Northern Europe
Source: (Own depiction 2021, ifeu)

3.3 Results exercise book

3.3.1 Exercise book base scenario results

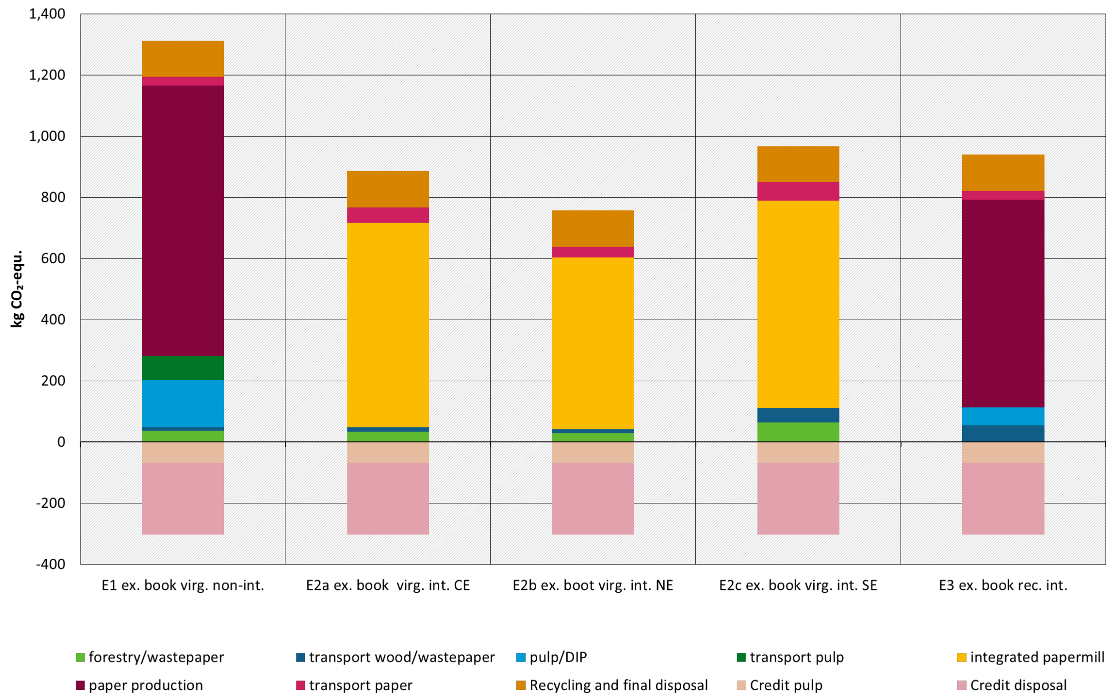
3.3.1.1 Exercise book base scenario results: Climate Change, Non-renewable Primary Energy Demand & Total Primary Energy Demand

First, the environmental indicators associated primarily with the provision of energy, namely the *CED non-renewable* and *climate change* will be considered.

Integrated recycled exercise books are associated with a lower non-renewable primary energy demand than non-integrated virgin exercise books. In a comparison with integrated exercise books, primary energy demand of recycled exercise books is very close to Southwest and Central European integrated exercise books. Correspondingly, greenhouse gas emissions associated with exercise book production are lower for recycled papers than for non-integrated virgin papers, but in the same order of magnitude than integrated Southwest and Central European exercise books. For a good part, the latter finding is related to the very high share of biomass-based process energy in integrated paper production through the use of black liquor, bark as well as wood chips as energy sources. In a comparison with Northern European integrated exercise books, this even leads to slightly higher indicator results of recycled papers versus Northern European papers from integrated production. To some extent, this is also related to the purchased electricity generation, where the share of Swedish grid electricity is associated with relatively low greenhouse gas emissions.

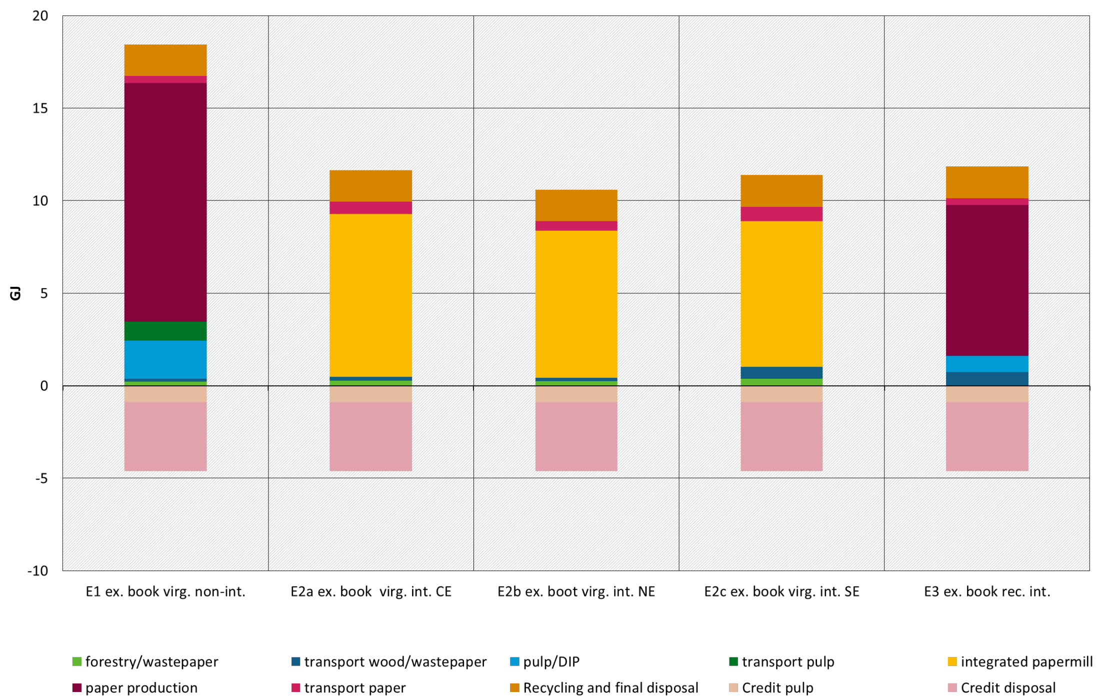
As the key contributions to the two indicators that are described in detail for the office paper, and those results are also valid for the exercise book results, it is observed here that further life cycle steps that become visible are related to incineration of exercise books after the use phase, if they don't end up in a recycling stream. Correspondingly, some credits are obtained by recovered energy from incineration plants, which replace electricity and thermal energy based on e.g. fossil fuels.

Figure 42: Climate Change, 1000 kg exercise book base scenarios



CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 43: Cumulative Energy Demand (CED) non-renewable, 1000 kg exercise book base scenarios

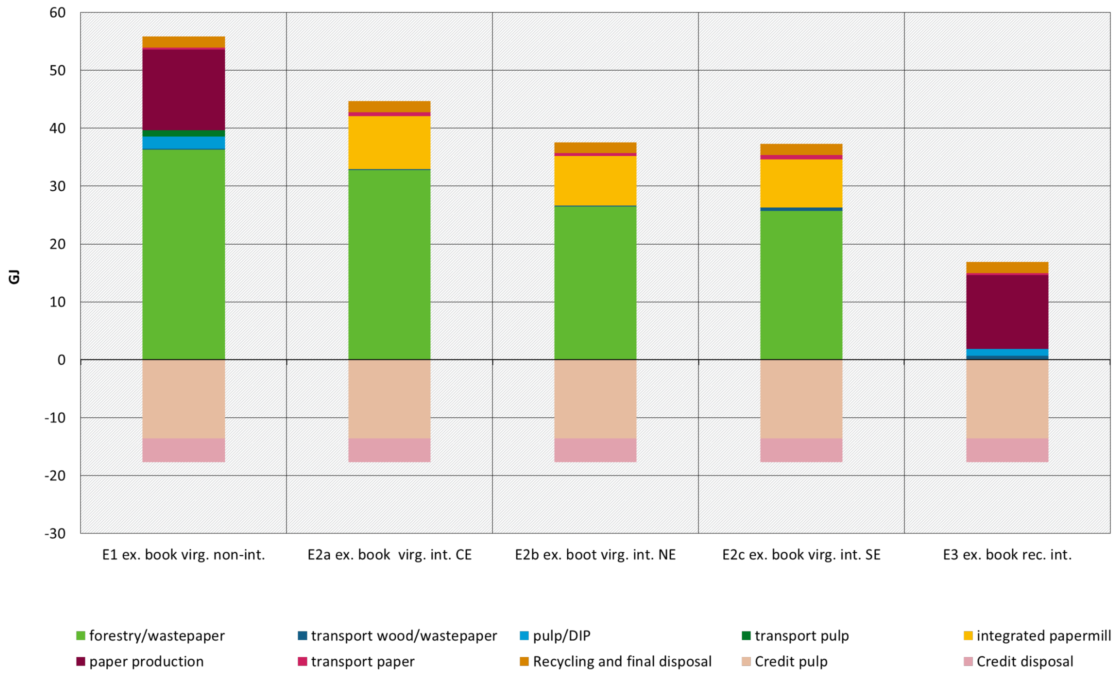


CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 44 in this section shows the results of the inventory category Cumulative Primary Energy Demand (total).

The result pattern for the comparison of exercise books mirrors the one for the corresponding intermediate paper products, as the additional life cycle steps like recycling and final disposal as well as the credits given are the same for all regarded scenarios.

Figure 44: Total CED, 1000 kg exercise book base scenarios



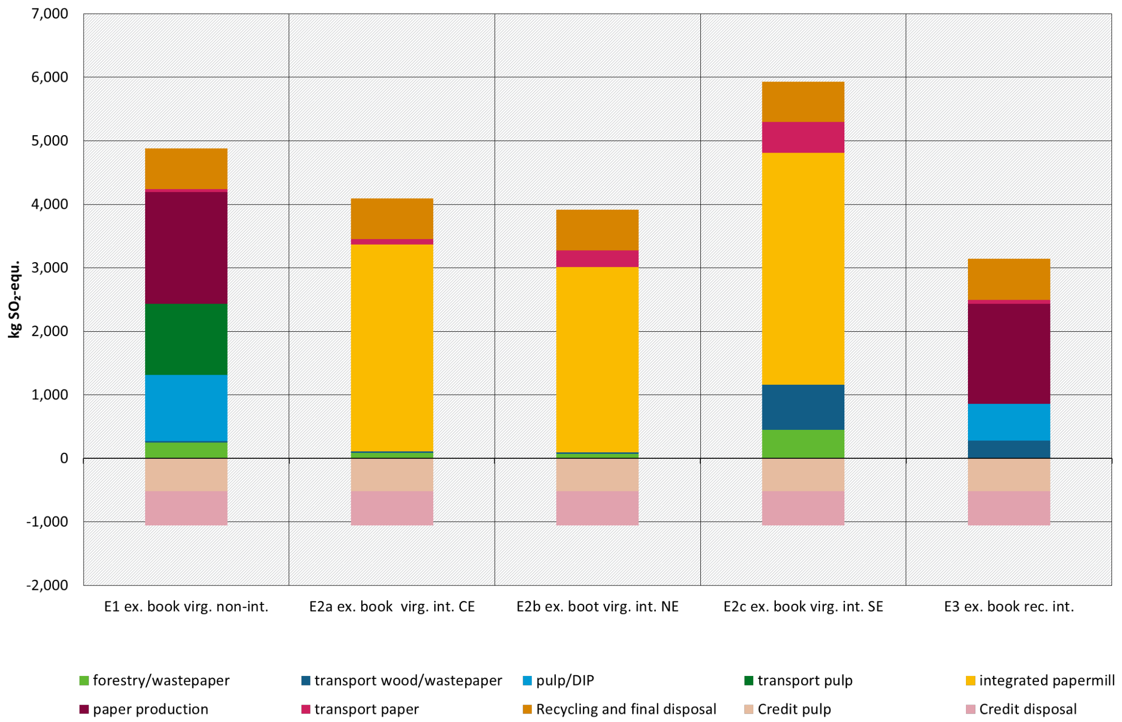
CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.3.1.2 Exercise book base scenario results: Acidification & Terrestrial Eutrophication

In this section, the environmental indicators related to non-carbon dioxide air emissions, but related to nitrogen and sulfur compounds, *Acidification* and *Terrestrial Eutrophication*, are considered. Those compounds are both typically associated with transports as well as combustion processes.

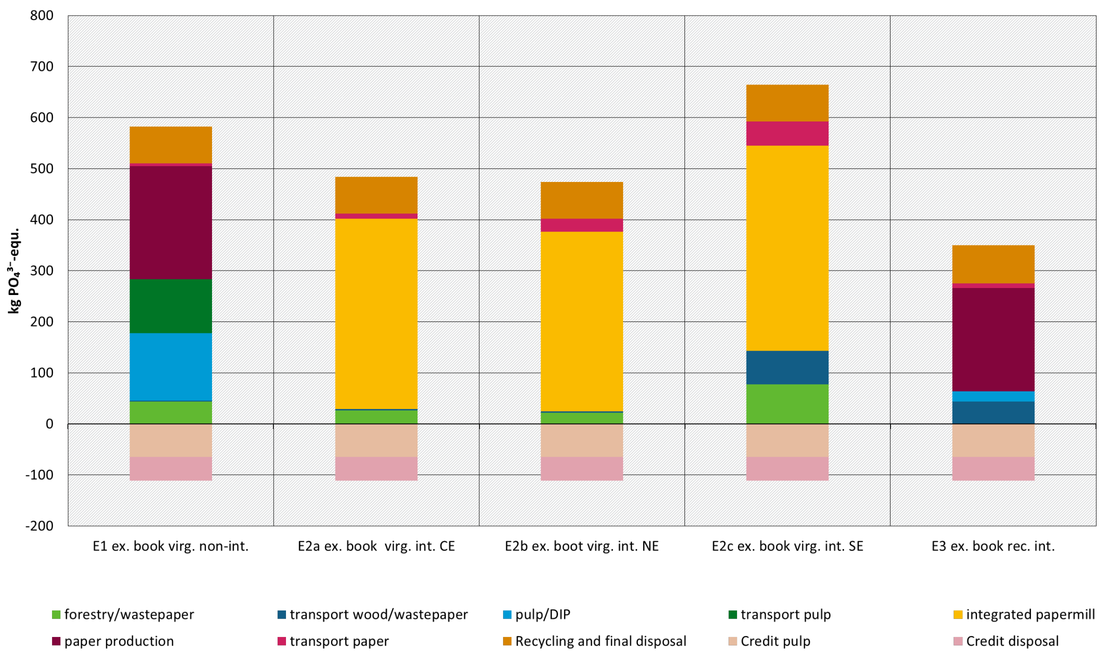
Integrated recycled exercise books are associated with lower (Acidification and Terrestrial Eutrophication, respectively) environmental impacts than non-integrated and integrated virgin office papers in the named indicators. This is still true for the Northern European integrated virgin paper that is characterised by lowest environmental impacts out of the group of virgin exercise books. For a good part, this is related to the high share of biomass-based process energy required at the paper mills for integrated paper production, due to the release of sulfur and nitrogen content originating from biomass and the thermal nitrogen oxide generation during combustion processes for energy generation. In case of non-integrated exercise book production, considerable transport processes contribute to both sulfur and nitrogen compounds emitted to air, especially in case of non-integrated virgin papers (pulp transports e.g. from Iberia and Latin America) and in case of Southwestern European papers from integrated production (eucalyptus wood transports from Latin America). In case of Southwestern European papers from integrated production, Iberian eucalyptus forestry shows up in addition, largely related to lower yields of Iberian eucalyptus plantations (15 m³/ha) if compared with Latin American plantations (33 m³/ha).

Figure 45: Acidification, 1000 kg exercise book base scenarios



CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 46: Terrestrial Eutrophication, 1000 kg exercise book base scenarios



CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.3.1.3 Exercise book base scenario results: Water-related results

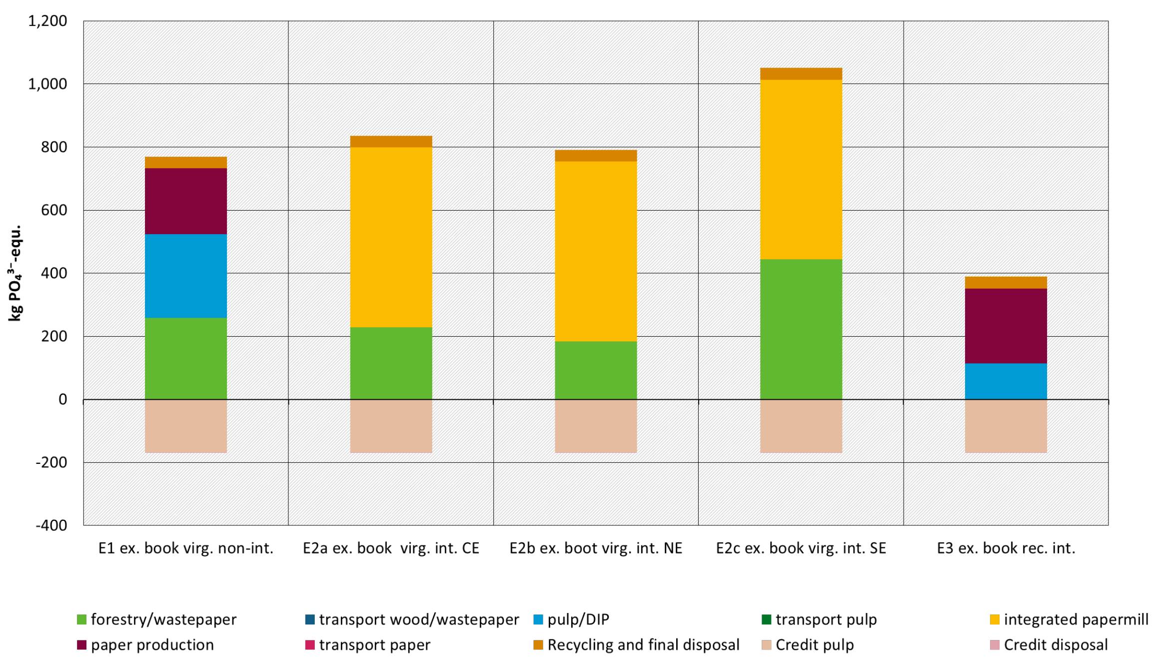
Looking at water-related environmental impacts and water-related environmental indicators provides additional insight into of the environmental performance of paper production. This includes *aquatic eutrophication*, *adsorbable organic halogenated compounds (AOX)*, and *process water demand (freshwater)*.

For the three environmental indicators in the focus here, recycled exercise book results are considerably lower (at least 50 % lower or more in aquatic eutrophication, and even higher for the other two water-related indicators) than all virgin papers examined.

As for the virgin papers, their contribution to aquatic eutrophication is of a similar order of magnitude regardless their production type integrated or non-integrated. As underlying emissions to water (such as COD) are largely related to the use of process chemicals, aquatic eutrophication related to overall paper production processes (i.e. integrated mill versus sum of pulping and papermaking in case of non-integrated production) is somewhat comparable per equal amount of virgin fibres. On the other hand, forestry does contribute as well due to nitrogen and phosphor compounds emitted to water, thus e.g. depending on different wood harvesting yields, differences according to pulpwood types are observed in aquatic eutrophication.

The picture is different for process water demand (freshwater), here the non-integrated production is associated with lower freshwater demand than the papers from integrated production This however may also be associated with the fact that in Northern European countries such as Sweden and Finland, where underlying process data on water inputs originate from, freshwater is not scarce and thus incentives for process water reductions do not exist. As primary data for Southwest European papers from integrated production are lacking, a robust statement on comparative freshwater demand versus other examined papers is not possible for data quality reasons.

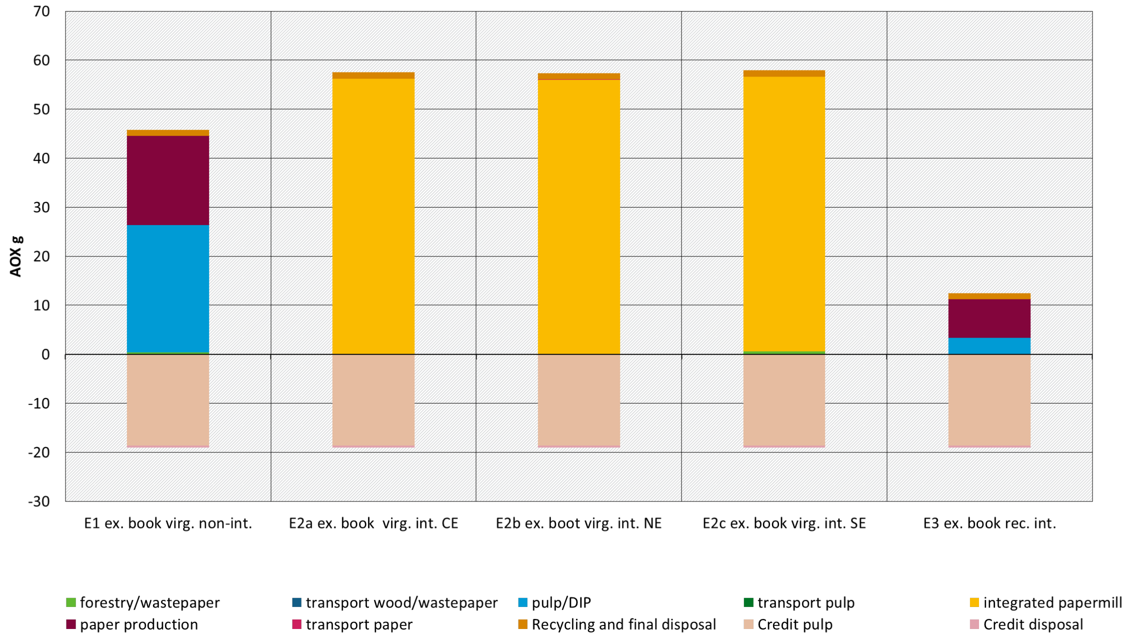
Figure 47: Aquatic Eutrophication, 1000 kg exercise book base scenarios



CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe

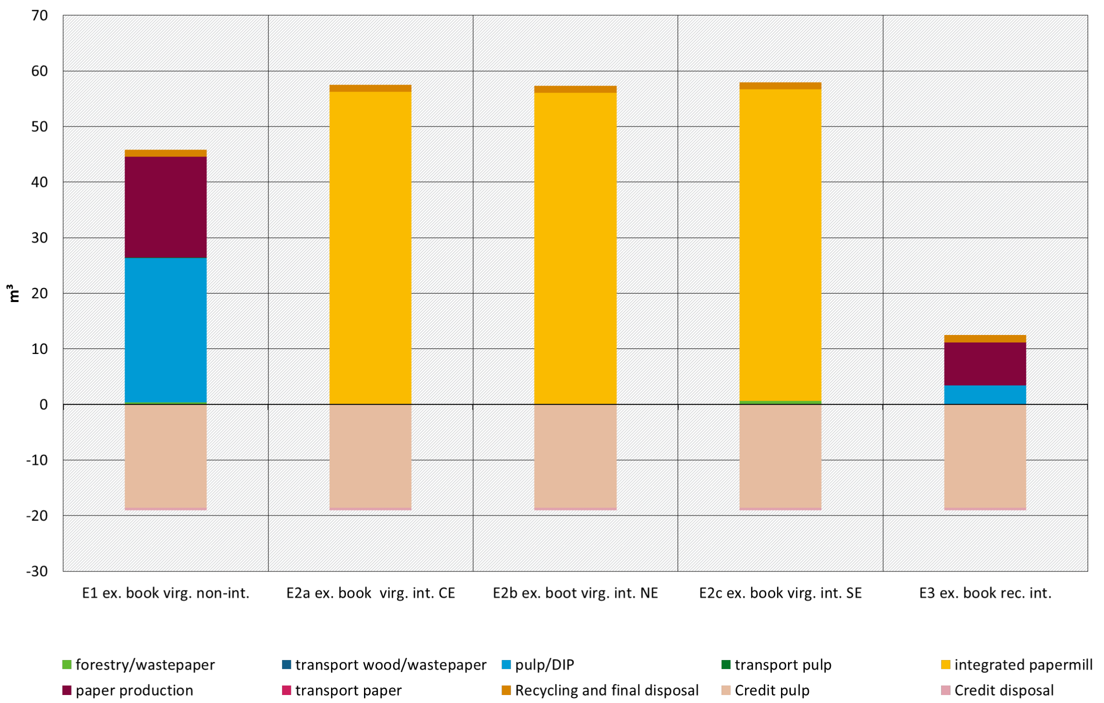
Source: (Own depiction 2021, ifeu)

Figure 48: Adsorbable Organic Halogenated Compounds (AOX), 1000 kg exercise book base scenarios



CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 49: Freshwater Demand, 1000 kg exercise book base scenarios



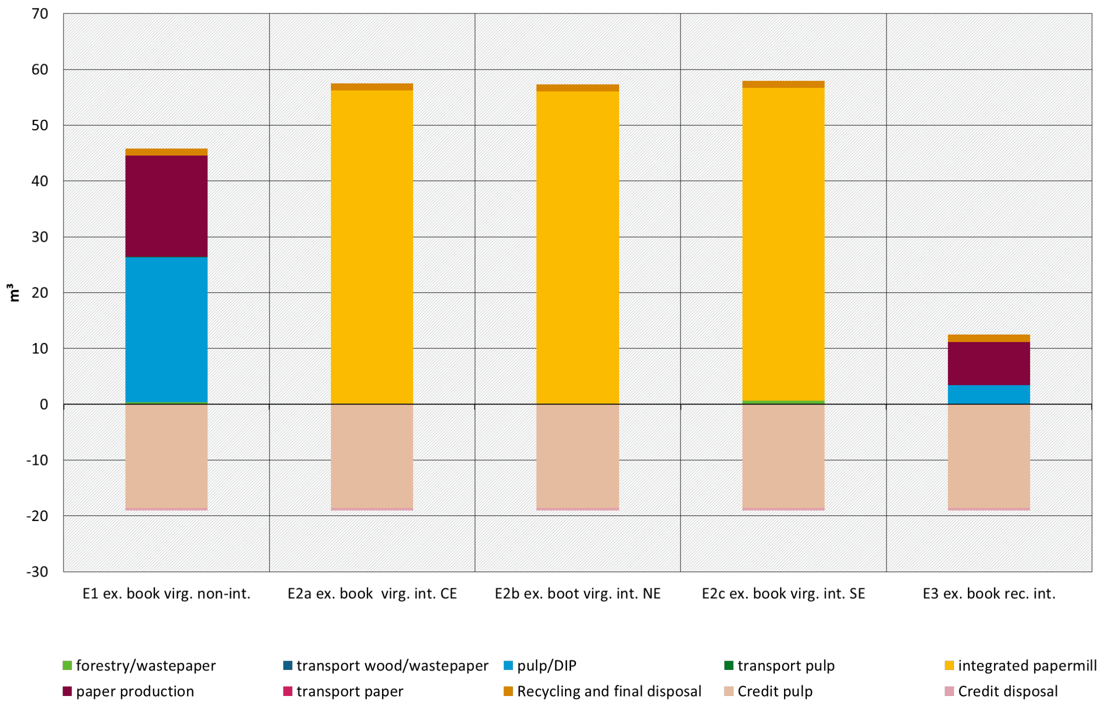
CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.3.1.4 Exercise book base scenario results: Human Health-related results

Environmental impact indicators *Photo-oxidant formation* and *fine particulate matter (PM 2.5)* are environmental indicators that are also health-related. This section provides a closer look into the environmental performance of office papers regarding those aspects.

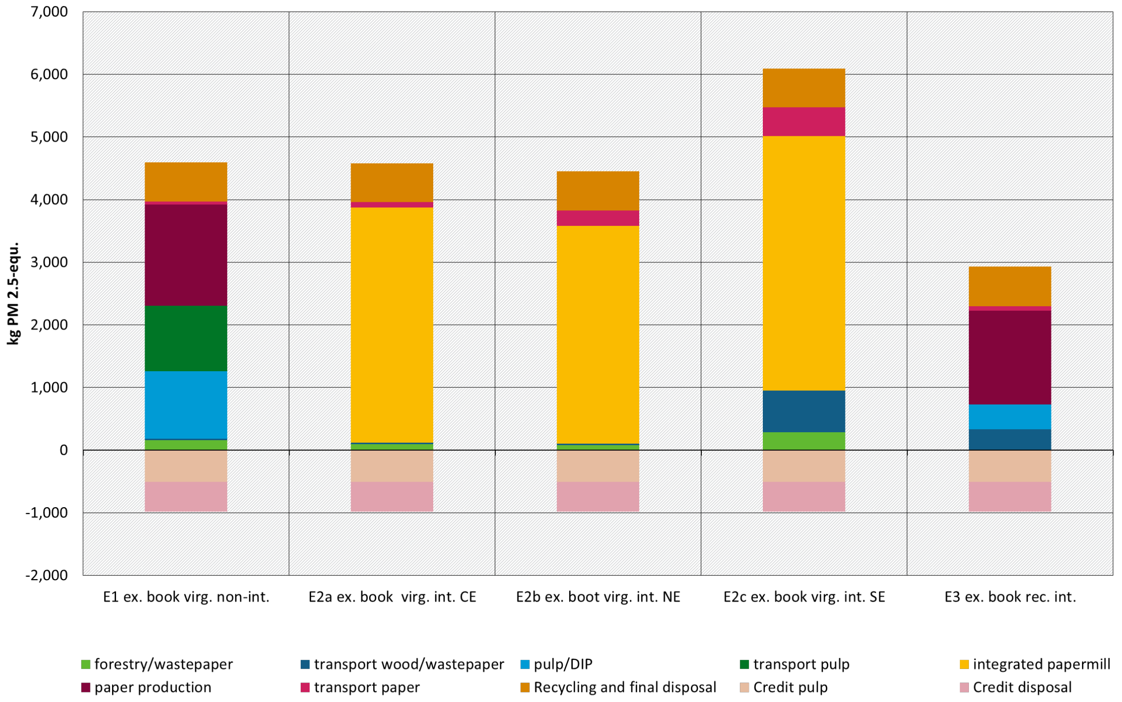
Integrated exercise books are associated with lower photochemical oxidant formation than non-integrated both virgin papers and recycled papers- based exercise books. This finding is related to organic air emissions (VOC and NMVOC) associated with combustion processes / energy prechains in general. Some of those air emissions are also transport-related, thus besides the energy-intensive processing steps of pulping and papermaking and integrated paper mills, also pulpwood/wastepaper/pulp transports show contributions. However, comparative findings in this aspect have to be handled with care, as data symmetry within the various individual datasets contributing to this result may not be fully given based on the inventory data currently available.

Figure 50: Photo-oxidant formation, 1000 kg exercise book base scenarios



CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

Figure 51: Particulate Matter (PM 2.5), 1000 kg exercise book base scenarios



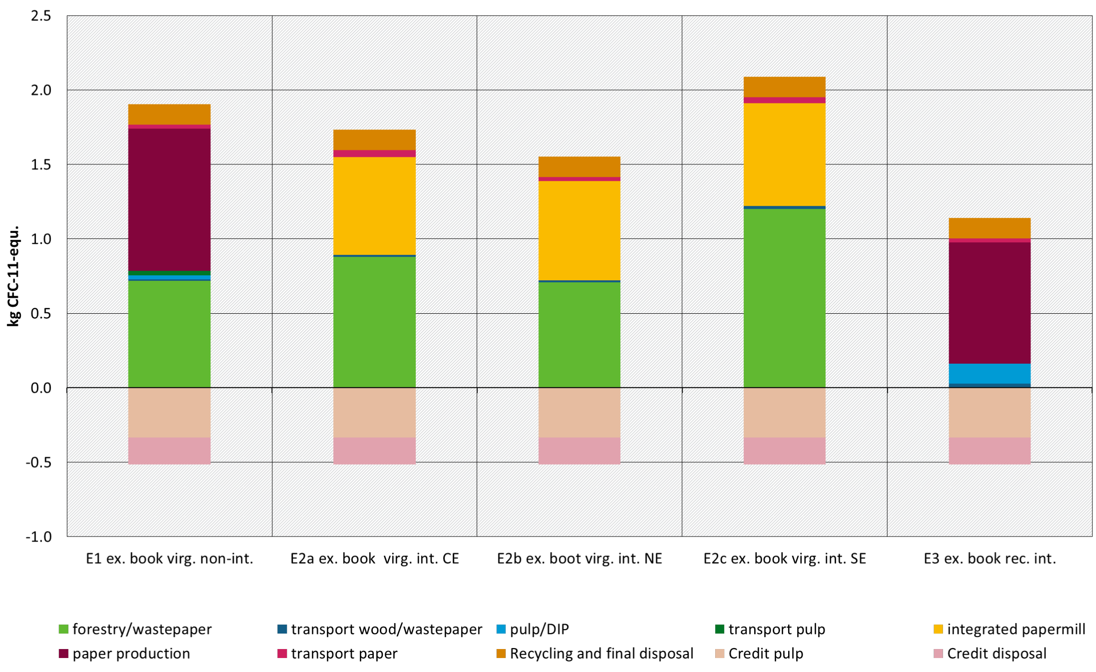
CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.3.1.5 Exercise book base scenario results: Ozone Depletion

Recycled exercise books are associated with clearly lower ozone depletion impacts than both integrated and non-integrated virgin paper-based exercise books examined. In case of papers from integrated production, the largest contributing emission to ozone depletion is nitrous oxide (N_2O) emitted to air from forestry operations. In case of non-integrated paper production, the nitrous oxide emission is not the largest but the second largest contribution.

Recycled exercise books on the other hand show the highest contribution related to energy generation processes, where also nitrous oxide is emitted as a result of combustion processes (both biogenic and fossil fuels).

Figure 52: Ozone Depletion, 1000 kg exercise book base scenarios



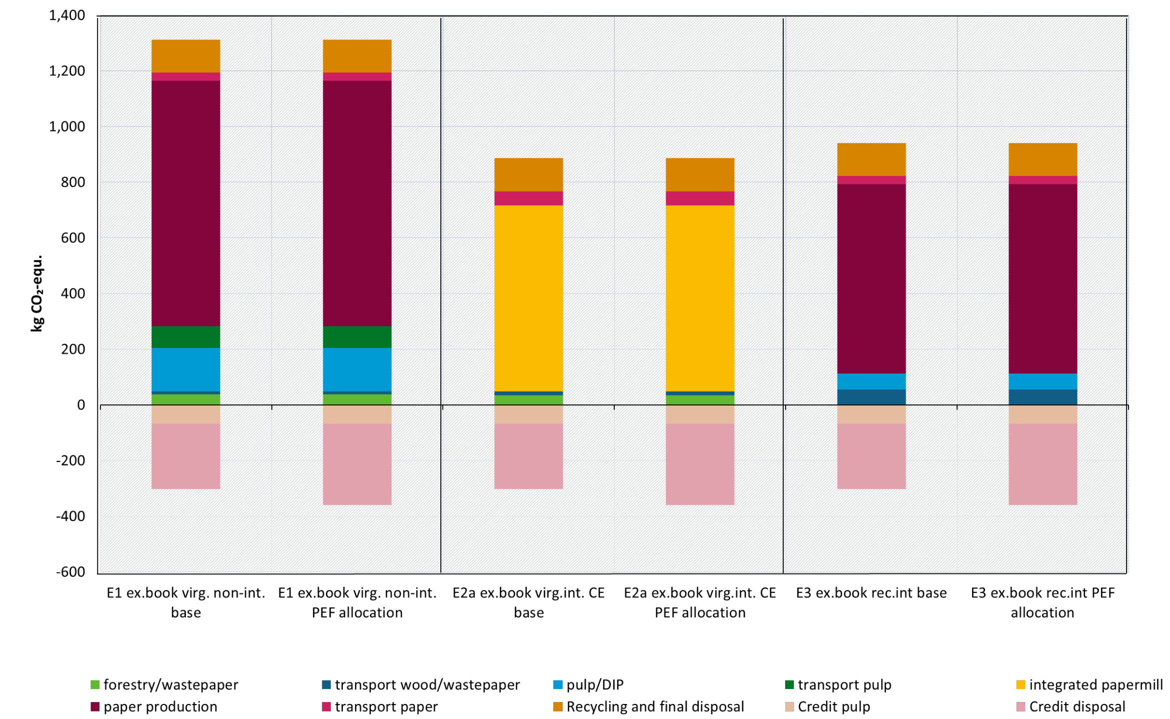
CE: Central Europe, NE: Northern Europe, SE: Southwestern Europe
Source: (Own depiction 2021, ifeu)

3.3.2 Exercise book sensitivity scenario results PEF Allocation

3.3.2.1 Exercise book sensitivity scenario results PEF: Climate Change, Non-renewable Primary Energy Demand & Total Primary Energy Demand

Integrated recycled exercise books are associated with lower non-renewable primary energy demand compared to non-integrated virgin exercise books. This is true for both PEF allocation methodology as well as for the UBA-based allocation approach that is applied for the base scenarios. Correspondingly, integrated recycled exercise books show lower greenhouse gas emissions than virgin non-integrated exercise books, also if the alternative PEF allocation methodology is applied as illustrated in this sensitivity analysis.

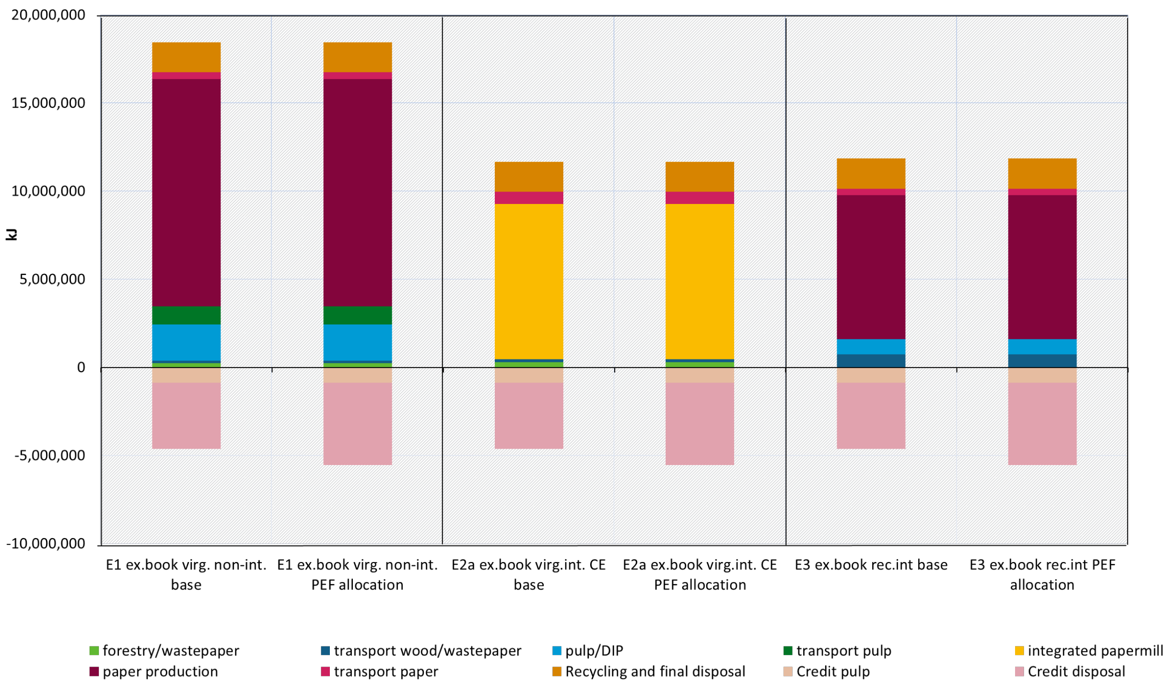
Figure 53: Climate Change, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe

Source: (Own depiction 2021, ifeu)

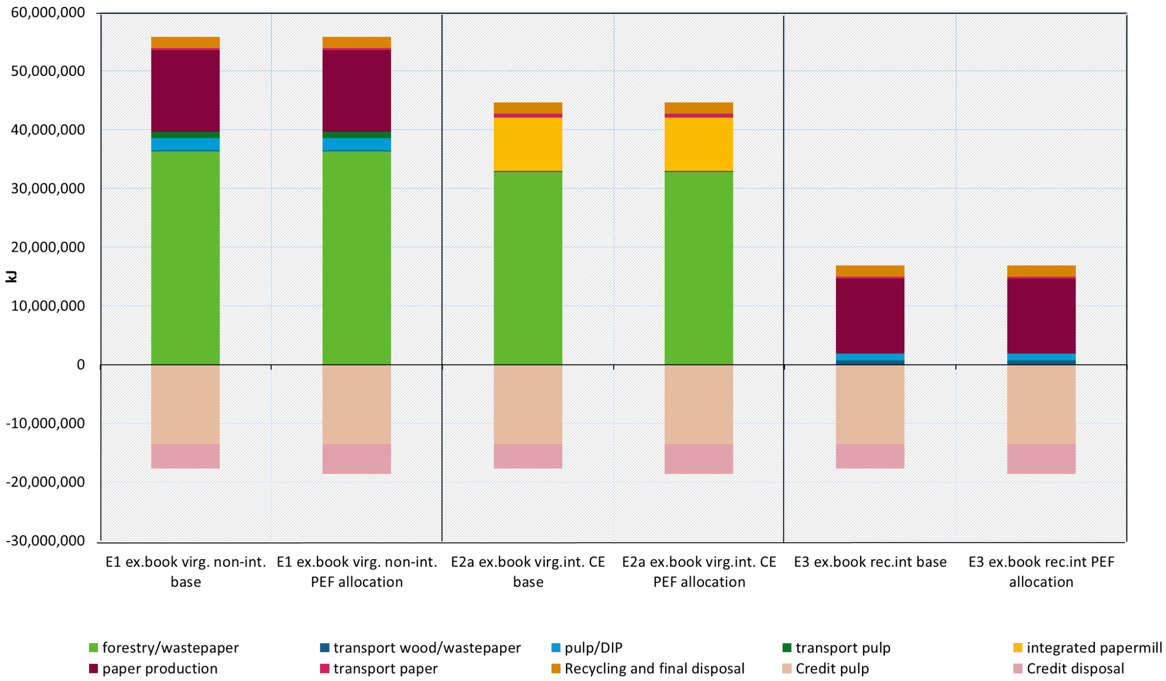
Figure 54: Cumulative Energy Demand (CED) non-renewable, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe

Source: (Own depiction 2021, ifeu)

Figure 55: Total CED, 1000 kg exercise book sensitivity scenarios, PEF



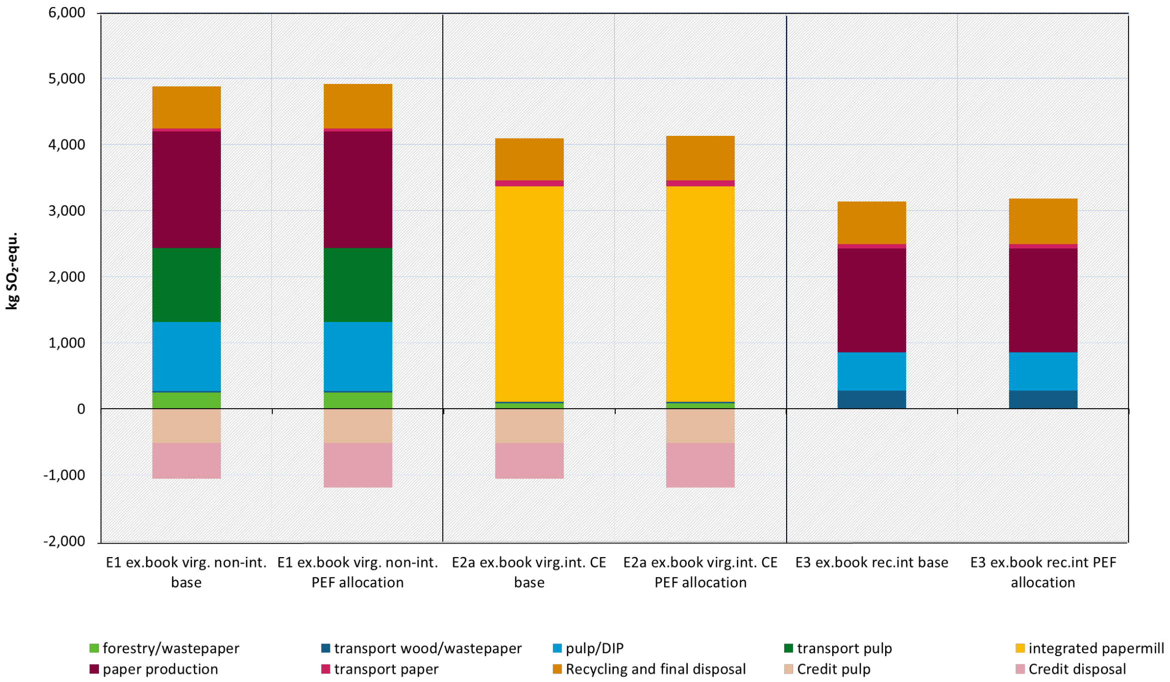
CE: Central Europe

Source: (Own depiction 2021, ifeu)

3.3.2.2 Exercise book sensitivity scenario results PEF: Acidification & Terrestrial Eutrophication

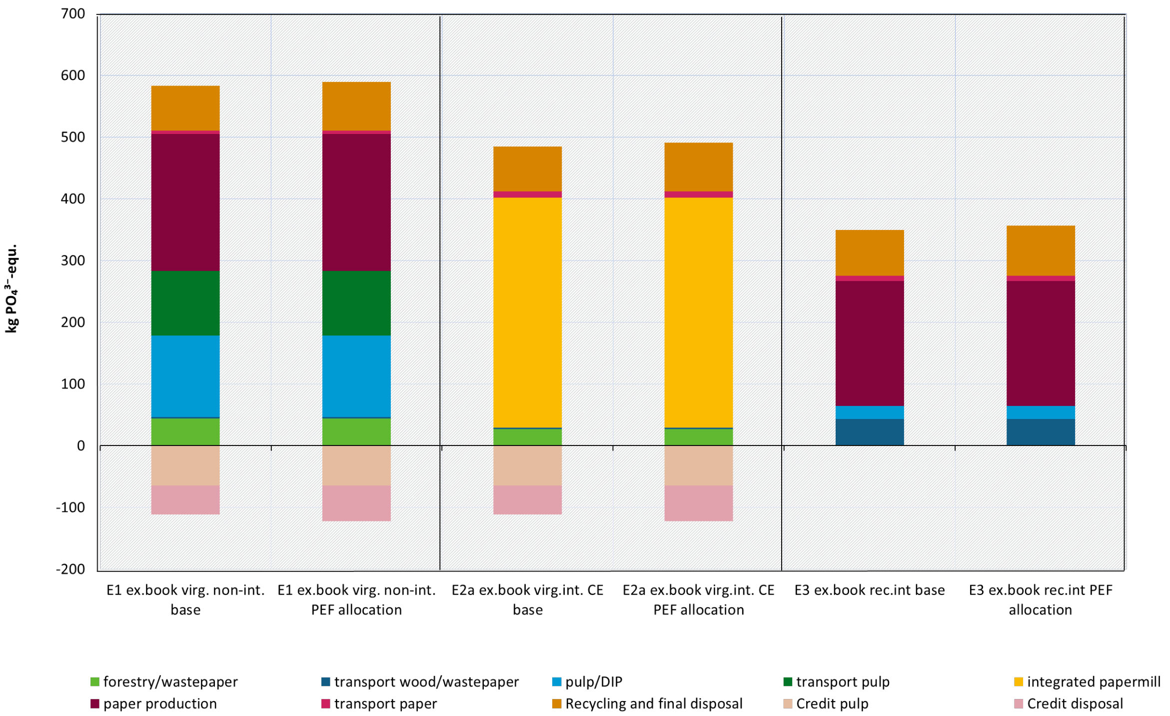
Integrated recycled exercise books are associated with lower (Acidification and Terrestrial Eutrophication, respectively) environmental impacts than virgin non-integrated exercise books. This is true for both, PEF allocation methodology as well as for the UBA-based allocation approach that is applied for the base scenarios.

Figure 56: Acidification, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe
Source: (Own depiction 2021, ifeu)

Figure 57: Terrestrial Eutrophication, 1000 kg exercise book sensitivity scenarios, PEF

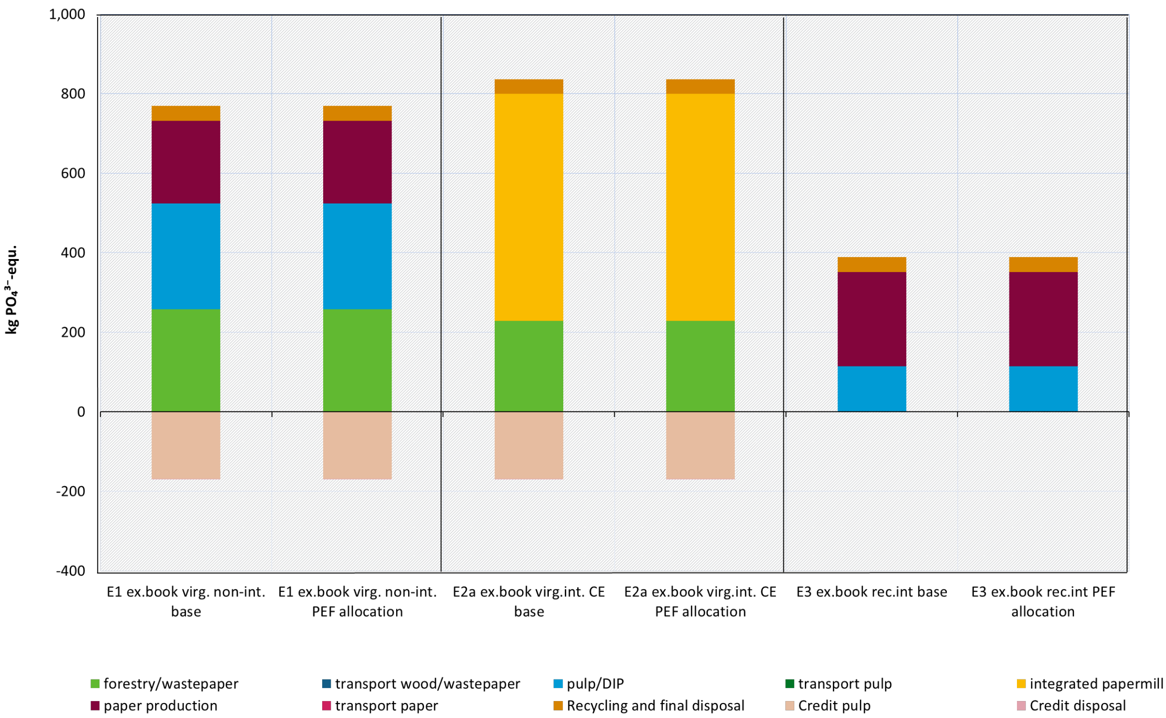


CE: Central Europe
Source: (Own depiction 2021, ifeu)

3.3.2.3 Exercise book sensitivity scenario results PEF: Water-related results

For the three water-related environmental indicators in the focus here, recycled exercise book results are considerably lower than non-integrated exercise books. These findings remain stable also if the PEF allocation methodology is applied, thus the result pattern does not change even with the overall net results of both exercise books is different.

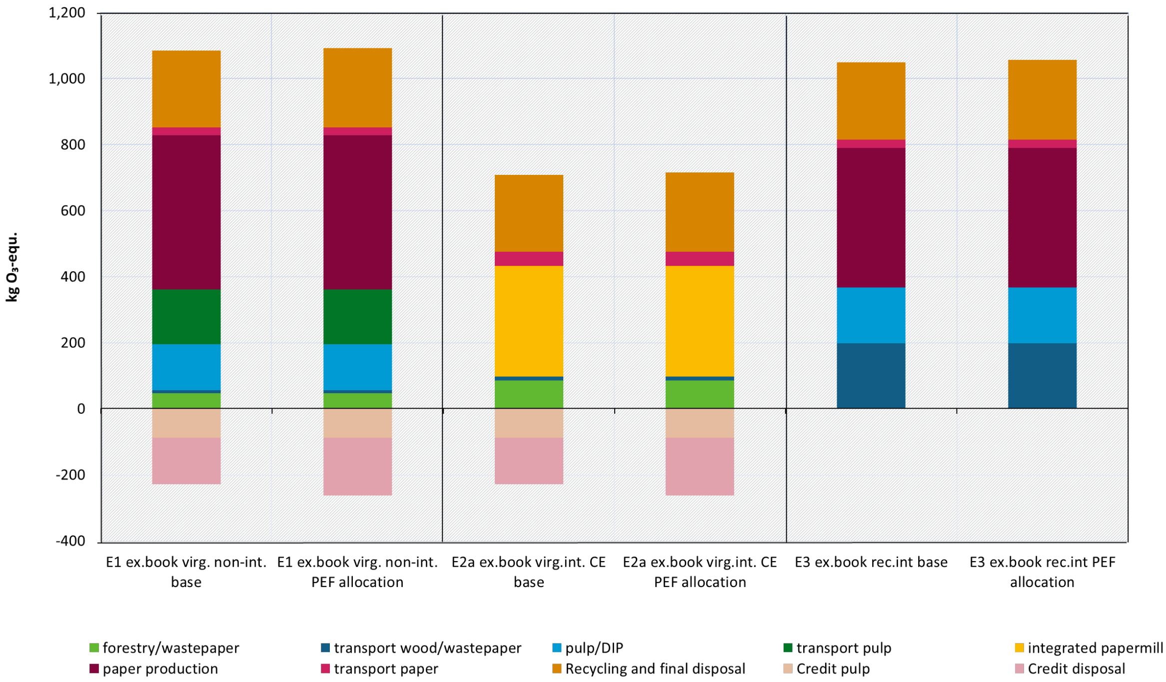
Figure 58: Aquatic Eutrophication, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe

Source: (Own depiction 2021, ifeu)

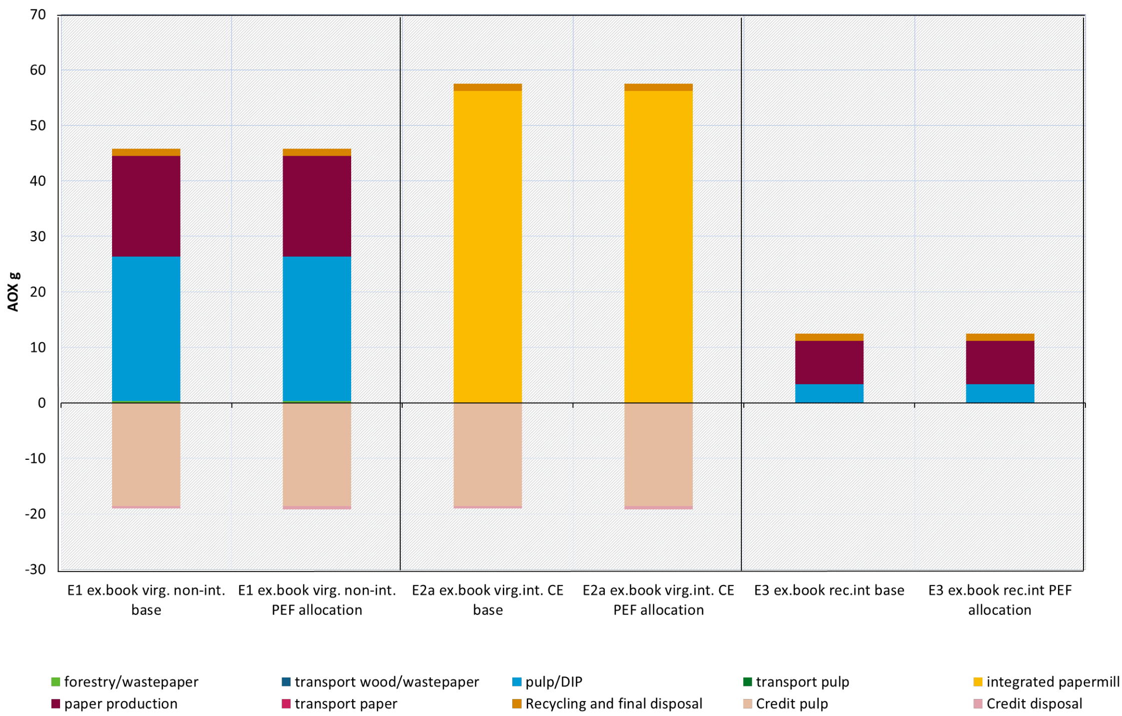
Figure 59: Freshwater Demand, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe

Source: (Own depiction 2021, ifeu)

Figure 60: Adsorbable Organic Halogenated Compounds (AOX), 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe

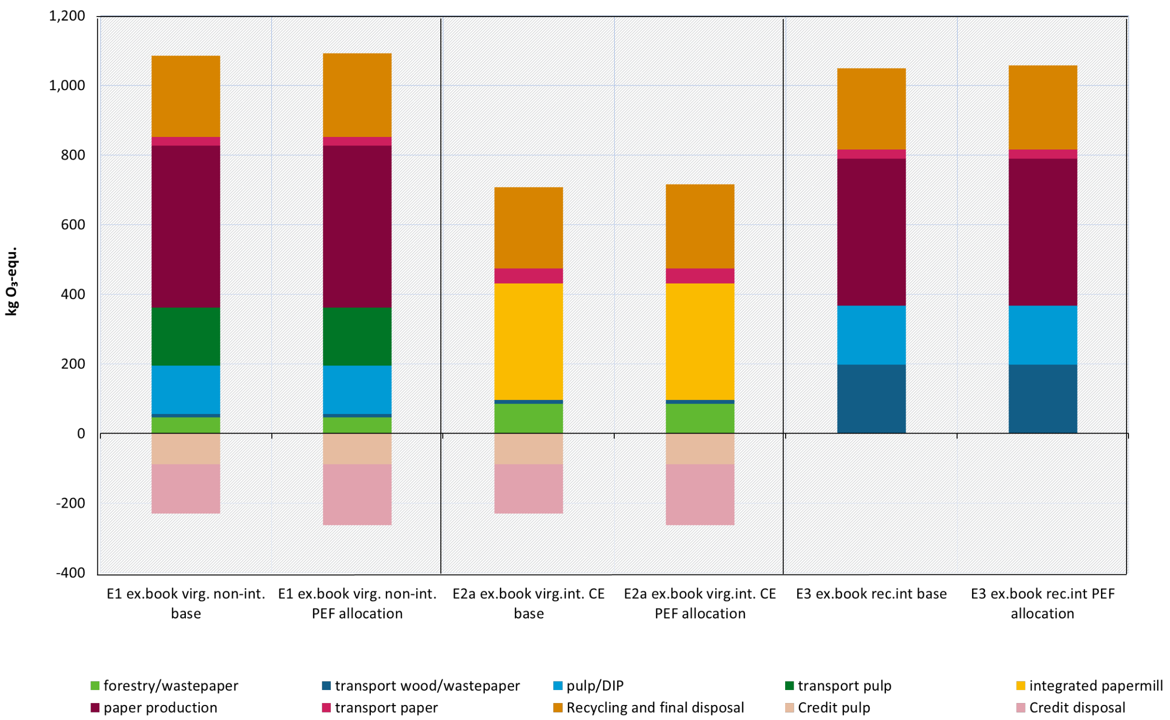
Source: (Own depiction 2021, ifeu)

3.3.2.4 Exercise book sensitivity scenario results PEF: Human Health-related results

If PEF allocation methodology is applied instead of the standard UBA approach as applied in the base scenarios, non-integrated recycled exercise books are in the same order of magnitude as non-integrated virgin exercise books regarding Photo-oxidant formation. **However, comparative findings in this aspect have to be handled with care, as data symmetry within the various individual datasets contributing to this result may not be fully given based on the inventory data currently available.**

Recycled exercise books are associated with lower fine particulate matter impact (PM 2.5) than virgin non-integrated exercise books. This result pattern remains stable also if PEF allocation methodology is applied instead of the standard UBA approach as in the exercise book base scenarios.

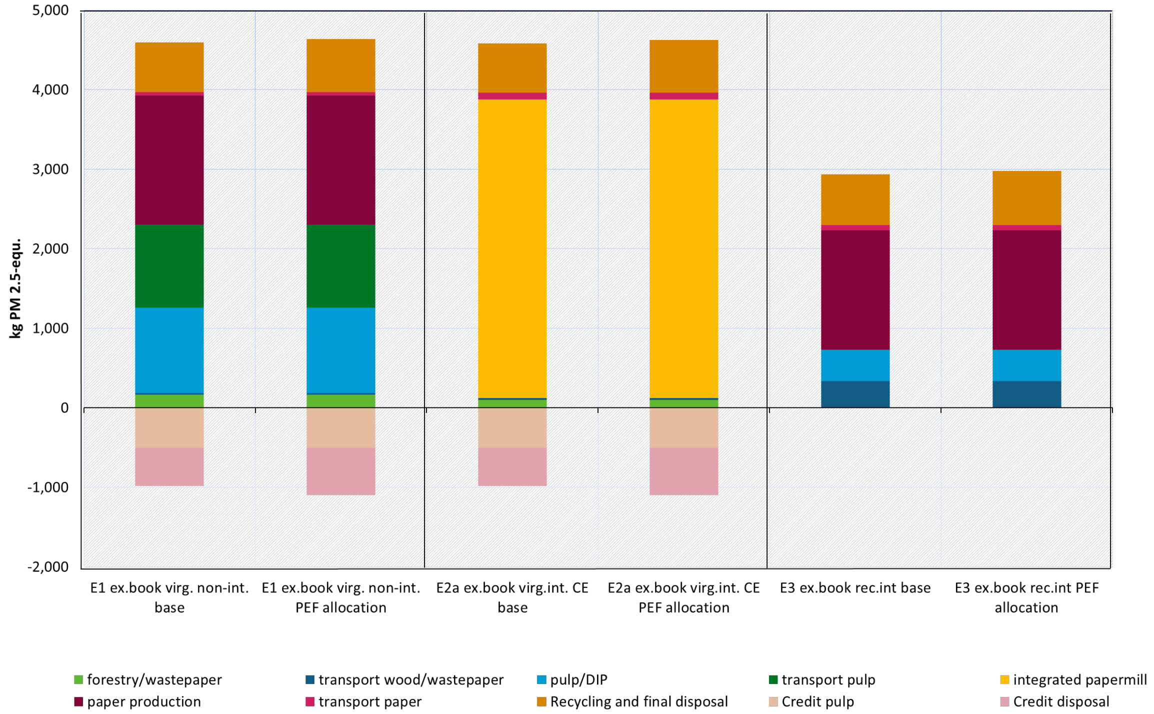
Figure 61: Photo-oxidant formation, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe

Source: (Own depiction 2021, ifeu)

Figure 62: Particulate Matter (PM 2.5), 1000 kg exercise book sensitivity scenarios, PEF



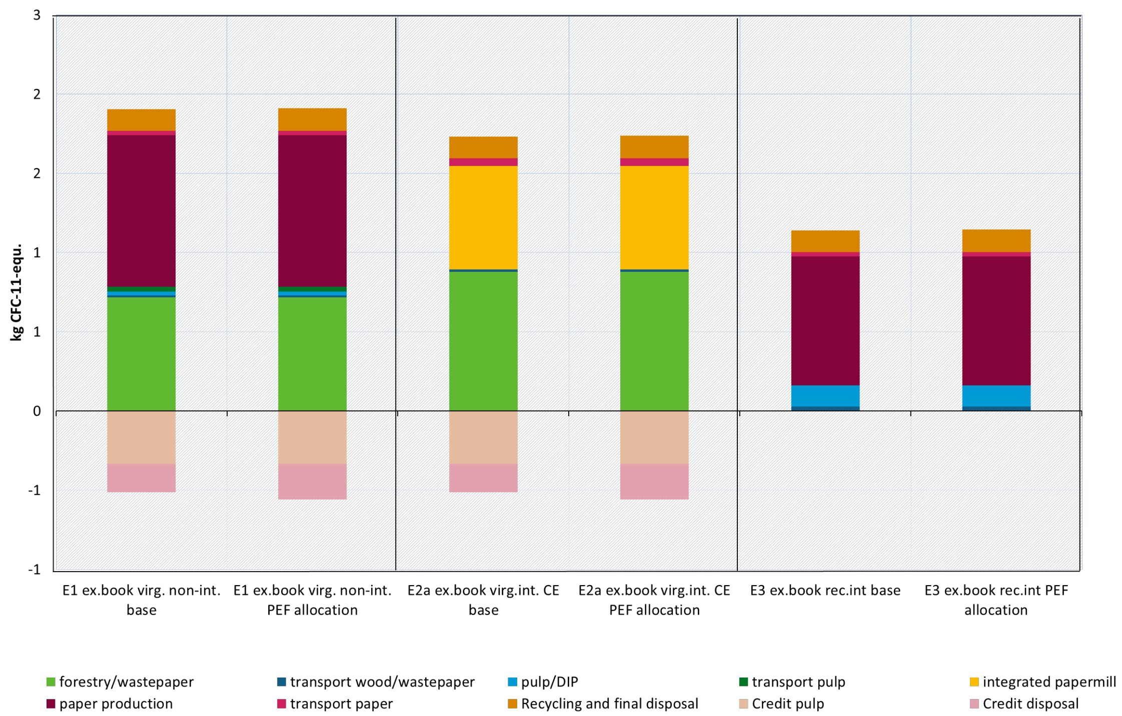
CE: Central Europe

Source: (Own depiction 2021, ifeu)

3.3.2.5 Exercise book sensitivity scenario results PEF: Ozone Depletion

Integrated recycled exercise books are associated with lower Ozone Depletion than virgin non-integrated exercise books. This is true for both, PEF allocation methodology as well as for the UBA-based allocation approach that is applied for the base scenarios. Hence the result pattern of the comparative result remains stable regardless the choice of allocation methodology.

Figure 63: Ozone Depletion, 1000 kg exercise book sensitivity scenarios, PEF



CE: Central Europe
Source: (Own depiction 2021, ifeu)

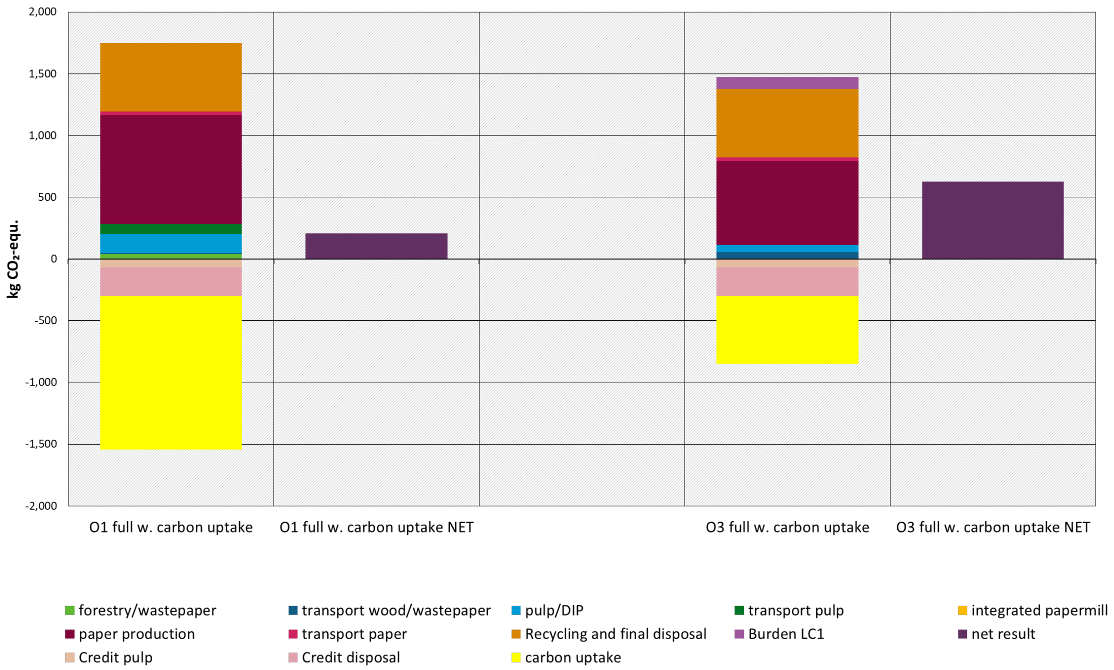
3.3.3 Exercise book sensitivity scenario "carbon fixation" approach

If the carbon fixation during the tree growth phase is taken into account as a negative entry at the beginning of the life cycle, and at the same time both biogenic and fossil carbon dioxide emissions are accounted for as greenhouse gases, the overall net result of the virgin non-integrated full lifecycle exercise book is considerably lower than in the base case. The carbon fixation is in the order of magnitude of climate change impact for the complete production chain of the exercise book.

In case of the recycled exercise book, the sum of greenhouse gas impacts up to the use phase and recycling/incineration burdens is lower than for the virgin non-integrated exercise books. However, as in the case of the recycled exercise books, only a part of the carbon fixation is assigned to the recycled paper product, so the overall net result of recycled exercise books is higher than for virgin non-integrated exercise books (net results are shown as separate violet bars in the stacked bar diagram in Figure 80).

Hence, both the overall net results of both virgin non-integrated as well as recycled integrated exercise books change considerably, and the comparative result changes the result pattern versus exercise book base scenarios.

Figure 64: Climate Change, 1000 kg exercise book sensitivity scenarios, PEF w. carbon uptake



Source: (Own depiction 2021, ifeu)

4 Limitations

The results of the analysed paper systems and the respective comparisons between them are valid within the framework conditions described in 2. The following limitations must be taken into account however.

Limitations arising from the selection of product types:

The results are valid only for the product types (i.e. office paper and tissue) selected.

Limitations concerning the chosen environmental impacts and applied assessment method:

The selection of the environmental impact and inventory categories applied in this study covers impact categories that are widely accepted within the LCA practitioner community. It should be noted that the use of other impact assessment methods could lead to different results. The results are valid only for the specific characterisation model used for the step from inventory data to impact assessment.

Limitations concerning geographic boundaries:

The results are valid only for the German market and cannot be assumed to be valid in geographic regions other than Germany.

This applies particularly for the end-of-life settings as the mix of waste treatment routes (recycling and incineration) and specific technologies used within these routes may differ, e.g. in other countries.

Limitations concerning data:

The results are valid only for the data used and described in this report: To the knowledge of the authors the data mentioned in 2.2.6 represents the best available and most appropriate data for the purpose of this study.

As primary data for Southwest European integrated produced office papers are lacking, a robust statement on comparative freshwater demand versus other examined papers is not possible for data quality reasons.

Comparative findings for photochemical oxidant formation of all paper products examined have to be handled with care, as data symmetry within the various individual datasets contributing to this result may not be fully given based on the inventory data currently available.

5 Discussion and conclusions

The comparison of paper production (within a cradle-to-gate scope) made of virgin versus recycled fibres is included in the spotlight report of this study.

5.1 Type and origin of used fibres

The additional cradle-to-gate scenarios included in this background report provide further insights regarding the type and origin of the fibres used:

- paper with different fibre origins

The geographic origin of pulp for virgin office and tissue papers does not significantly influence the environmental impacts in most of the examined impact categories. Only the scenario of a paper made purely from pulp originating from Central Europe leads to slightly lower overall results in most emission-related impact categories (associated with savings in pulp transports) as compared to the scenarios with pulp from mixed geographic origins. A notable exception is the category Adsorbable Organic Halogenated Compounds (AOX), where the pulp from Central European hardwood shows higher results than pulps made from Eucalyptus. This is due to the fact that Eucalyptus has a lower lignin content and therefore needs a lower chemical input which again causes lower AOX emissions than Central European hardwood pulp.

- share of hardwood and softwood

Office and tissue papers with higher and smaller short fibre content show very similar results regarding most environmental impact categories. A variation of fibre composition regarding hardwood and softwood origin within the technically feasible boundaries is therefore not a suitable determining factor for the environmental performance of paper.

- grass paper

Non-integrated grass paper with 40 % grass fibre content is associated with around 10 % lower greenhouse gas emissions and primary non-renewable energy demand than other non-integrated virgin fibre based paper production. Similar or even bigger reductions are shown for the other environmental impact categories. The exception is Photo-oxidant formation in which non-integrated grass paper is associated with higher impacts than virgin non-integrated office paper. This is related to fuel-based emissions of volatile organic compounds as a result of the machine use for mechanical processing of grass (e.g. pelletizing and collection of grass from the land).

As this comparison only looks at grass paper in a cradle-to-gate context, the potential difficulties of recycling a paper product with a 40% share of grass fibres has not been considered in this assessment. According to (CREAPAPER 2020), grass paper is considered as recycable. A higher amount of dirt or other colored specks in paper made from used grass paper is to be expected though. In fact a report from Papiertechnische Stiftung (PTS 2019) concludes that the recyclability of grass paper is limted due to the optical inhomogeneities in the recyled stock.

5.2 Exercise book as a paper product at the consumer level

The LCA scenarios for the exercise book basically show similar results for the base scenario and the (in regard to the modeling approach very similar) PEF scenario. However, when going beyond a technology comparison and looking at a final consumer product it is debatable if such a comparison serves to deliver meaningful results that could be used for recommendations to consumers. As there are always fibre losses associated with the recycling process there will always be a need to supplement the paper market with virgin fibres even if recycling rates would be maximised and recycling losses minimised.

Therefore, in order to provide a holistic assessment of the environmental performance at the consumer product level, it is necessary to take into account the two product subsegments “virgin fibre product” and “recycled fibre product” by looking at the product system (the product system exercise book is selected to serve as the example in the present study) as a complete system, where both the virgin subsegment as well as the recycled subsegment show their contributions. In other words, the complete product system of the exercise book takes into account that a certain share of fibres in real mass flows will be virgin and another share will be recycled fibres. For the assessment of the environmental performance of paper products at the final consumer level, is aimed to answer the question if an increase of recycling would be beneficial to the environmental performance of the product system.

For this purpose two different scenarios, both composed of both the “virgin fibre” subsegment as well as “recycled fibre subsegment are modeled. Here the aspect of the lifetime of the fibre (quantitatively expressed as the number of uses of the fibre) is a criterion to be taken into account, as it has a direct influence on real mass flows on the market of examined paper product systems.

The first scenario (scenario A) represents the current situation by considering the average number of uses of a fibre. The total average number of uses of a fibre for office paper is based on the European Fibre Flow Model (Meinl 2016), which lists a number of 3.15 uses for graphic paper other than newsprint. This has been rounded up to 3,2 uses as the original number is given for 2014 and the prediction for the year 2020 is 3,28 uses.

The second scenario (scenario B) provides insight into a potential future situation that represents an increased recycling activity on the paper market. For this purpose it is based on a very conservatively assumed technical maximum number of uses of a fibre. As according to (EU COM PPP BREF 2015) the fibre losses at each recycling process for office paper amount to at least 20%, the maximum number of uses is set to 5 for this scenario. The technically possible recyclability of fibres has been shown to be significantly higher than that by (Putz et al. 2018). In laboratory tests up to 25 cycles are possible with only slight losses in quality,

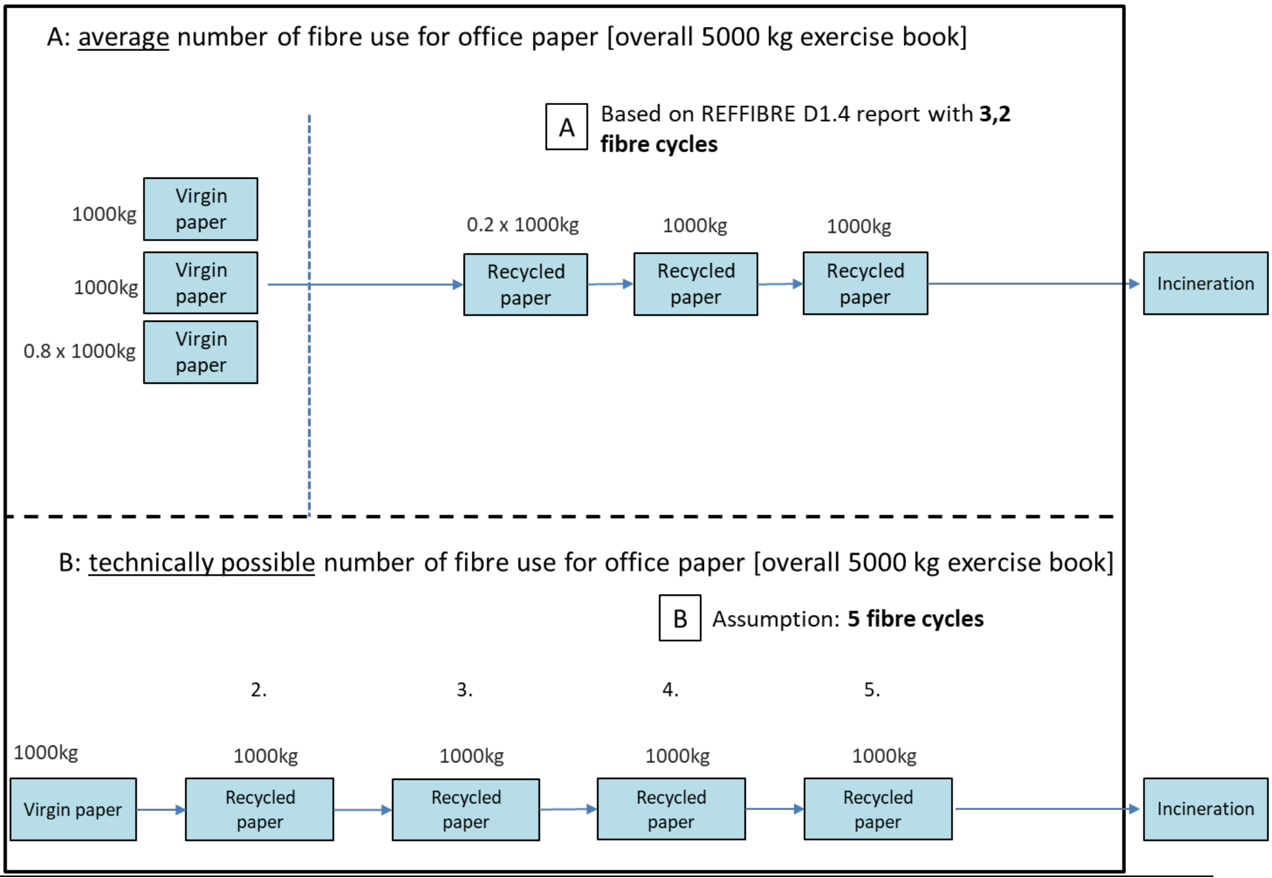
Figure 65 shows a schematic illustration of the two scenarios (scenario A – upper part of the figure, scenario B – lower part of the figure).

An overall number of 5 uses of fibres in scenario B mean that an originally virgin fibre could be used in up to 5 batches of exercise books in total. If one starts from the functional unit as examined in the present LCA, 1.000 kg paper product that means the fibres of those 1.000 kg virgin paper can be used for seven further 1.000 kg recycled paper products. So in this case, 5*1.000 kg paper is delivered.

If this is compared to the current status scenario A, scenario A has to supply a higher amount of virgin fibres in order to achieve the same production amount (5* 1.000 kg paper) within the regarded product system. No supplemental virgin fibres are added to the single recycling steps as the focus lies on the specific fibre and the losses at recycling processes are already represented by its limited total number of uses.

Figure 65shows a schematic illustration of the two scenarios. As 5 uses of fibres in scenario B mean that an originally virgin fibre could be used in up to 5 batches of exercise books, scenario A has to supply a higher amount of virgin fibres to achieve the same production amount within the regarded product system. No supplemental virgin fibres are added to the single recycling steps as the focus lies on the specific recycled fibre and the losses at recycling processes are already represented by its limited total number of uses.

Figure 65: Schematic illustration – recycling scenarios



Source: own depiction 2021, ifeu

Table 9 shows the LCA results of the two scenarios, which are calculated with an allocation factor of 50%. It shows that a higher number of uses of fibres leads to lower environmental impacts in most categories. The only exception being Photochemical Oxidant Formation, where the increased recycling leads to higher impacts. Regarding Climate Change the difference of just 2 % should not be considered as a significant difference though as the inevitable uncertainties within the underlying modeling data do not allow clear assertions on results that close to each other.

Table 9: Overview LCA results – product system comparison (Allocation factor 50%)

Impact Priority*	Indicators	5000 kg exercise book with 3,2 uses of fibre	5000 kg exercise book with 5 uses of fibre	8 uses vs 3,2 uses
Very high	Climate Change	3,53 t CO_2-eq.	3,48 t CO_2-eq.	2% lower
High	Acidification,	15,23 kg SO_2-eq	12,75 kg SO_2-eq	16 % lower
	Terrestrial Eutrophication,	1,83 kg PO_4-eq-	1,49 kg PO_4-eq-	18 % lower
	Ozone Depletion,	6,37 kg CFC-11-eq.	5,20 kg CFC-11-eq.	18 % lower
	Photochemical Oxid. Formation	3,07 kg O_3-eq	3,50 kg O_3-eq	14 % higher
Medium	Aquatic Eutrophication	3,02 kg PO_4-eq	2,20 kg PO_4-eq	27 % lower
Without	Fine particulate matter (PM 2.5)	15,85 kg PM 2.5-eq	12,53 kg PM 2.5-eq	21 % lower
Without	CED non-renewable	43,28 GJ	41,21 GJ	5 % lower
	CED total	141,75 GJ	91,34 GJ	36 % lower
Without	Freshwater	173,98 m^3	98,04 m^3	61 % lower
Without	Forest Area	8395,15 m^2*a	2998,27 m^2*a	44 % lower
Without	AOX	219,38 g	81,57 g	63 % lower

*UBA priorities according to (Schmitz et al. 1999)Source: (Own depiction 2021, ifeu)

It can be concluded though, that an increase of use cycles of fibres not only reduces the amount of virgin fibres needed, but will also lead to overall benefits in the environmental performance of office paper products (Table 20). It should therefore be aimed to increase the use of recycled fibres.

As long as waste paper availability of paper for recycling is a limiting factor for that goal, it is especially important to put recycled fibres from waste paper into products with the least possible fibre losses in their recycling process. The highest losses occur at the recycling of paper for the production of tissue paper as the used fibres have to be free from ash and fines. According to (EU COM PPP BREF 2015) “the yield during processing paper for recycling goes down to 53 – 58 %”, while it is about 75 – 80 % for recycled fibres used for graphic paper.

If paper for recycling becomes available in line with market demand for recycled fibres to be used in products with minimum deinked pulp (DIP) fibre losses such as office papers, additional paper for recycling is recommended to be directed to a use as recycled fibre for other paper products such as tissue. Although tissue products are associated with higher fibre losses in the production of recycled fibres, they show a potential to reduce related environmental impacts, partly due to their predominant non-integrated production.

5.3 Sensitivity analyses regarding allocation and carbon uptake

Regarding the assessment of the exercise book two sensitivity analyses have also been modelled:

a) Allocation according to PEF

In the framework of the European PEF project the so-called circular footprint formula was developed that determines how the recycling allocation shall be modelled. As both approaches, the UBA-based and the PEF compliant allocation, use a 50% allocation factor - the results are almost the same. The main difference between the two approaches is the fact that in the UBA-based method the allocation factor is also applied to the energy recovery processes, while this is not the case in the circular footprint formula.

b) Carbon uptake

In this sensitivity analysis the carbon uptake during the tree growth phase is calculated as a negative carbon dioxide emission at the beginning of the life cycle, while biogenic (together with fossil) positive carbon dioxide emissions. As a consequence the overall net results for Climate Change are considerably lower than in the base cases of both variants of exercise books examined.

As in the case of the recycled exercise books, only a part of the carbon fixation is assigned to the recycled paper product, based on the average number of fibre uses, the overall net result of recycled exercise books is higher than that of virgin non-integrated exercise books.

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