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Towards Quantification of the Water Footprint of Paper: A First Estimate of its Consumptive Component

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Abstract For a hardcopy of this article, printed in the Netherlands, an estimated 100 l of water have been used. Most of the water is required in the forestry stage, due to evapotranspiration (green and blue water). In addition, the water footprint during the industrial stage, as accounted for in this study, consists of evaporation from water obtained from ground water and surface water (blue water). In this study estimates are made of water requirements for producing paper using different types of wood and in different parts of the world. The water footprint of printing and writing paper is estimated to be between 300 and 2600 m^3/t (~2-13 l for an A4 sheet). These estimates account for paper recovery rates in different countries. This study indicates that by using recovered paper for the production of paper the global average water footprint of paper is only 60% of what it would be if no recovered paper would be used at all. Further savings may be achieved by increasing the recovery percentages worldwide. In addition, the global water footprint of paper can be reduced by choosing production sites and wood types that are more water-efficient. The results of this study suggest that the use of recovered paper may be particularly effective in reducing water footprints. This study is a first step towards a better understanding of the significance of the water footprint of paper and the effect of using recovered paper.

Keywords Water footprint · Paper · Virtual water · Green water · Blue water · Recycling

1 Introduction

Forests are renewable resources that are key to the production of paper, since the main ingredient of paper is wood pulp (cellulose). Next to their importance for paper, forests are important for the production of other goods, such as timber and firewood, the conservation of biodiversity, the provision of socio-cultural services and carbon storage. Forests also play a vital role in catchment hydrology. Deforestation and afforestation affect hydrological processes in a way that may directly influence water availability. It is for instance well

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established that a reduction in runoff is expected with afforestation on grasslands and shrublands (e.g. Fahey and Jackson 1997; Wilk and Hughes 2002; Farley et al. 2005; Jackson et al. 2005).

Large amounts of freshwater are required throughout the supply chain of a product until the moment of consumption. For quantifying this amount, the water footprint concept can be used (Hoekstra and Chapagain 2007; 2008). The water footprint of a product is defined as the total amount of freshwater that is needed to produce it. The water footprint can contain green, blue and grey components. The green component is the volume of water evaporated from rainwater stored in or on the vegetation or stored in the soil as soil moisture. The blue component refers to evaporated surface and ground water. The grey component is the volume of polluted ground- and surface water. An increasing number of publications on virtual-water trade and water footprints of consumer products have been added to scientific literature recently. These include studies focussing on populations of countries or regions (e.g. Ge et al. 2011; Montesinos et al. 2011), specific consumer products (e.g. Ercin et al. 2011) and studies that discuss the way these concepts may be used (e.g. Aldaya et al. 2010; Wichelns 2010a; 2010b; Velázquez et al. 2011). So far, the water footprint of paper has not been studied in enough detail to reflect on its claims on water resources. This study is a first step towards a quantification of the water footprint of paper. In this study, a method for determining the water footprint of paper at the national level is proposed that takes into account both the forestry and the industrial stage of the production process. The scope is limited to a study of consumptive water use—considering both the green and blue water footprint. First, the water footprint of paper produced using pulp from the main pulp producing countries in the world is estimated, taking into account the use of recovered paper. To show the significance of the water footprint of paper, the results are applied to the case of the Netherlands.

2 Method

2.1 Estimating the Water Footprint of Paper

The water footprint during the forestry stage contains both a green and blue component. These two components cannot easily be determined separately as trees use rainfall water and tap from groundwater resources simultaneously. Therefore, in the scope of this study, we estimate the green and blue water footprint of paper as a total sum. During the industrial stage there is only a blue water footprint. The water footprint of a unit of paper p (expressed in m^3/t) is estimated as follows:

$$WF[p] = WF_{forestry}[p] + WF_{industry}[p]$$

The water footprint of a unit of paper p for the forestry stage is estimated as follows:

$$WF_{forestry}[p] = \left(\frac{ET_a + (Y_{wood} \times f_{water})}{Y_{wood}}\right) \cdot f_{paper} \times f_{value} \times \left(1 - f_{recycling}\right)$$

in which ET_a is the actual evapotranspiration from a forest/woodland (m^3/ha/year), Y_{wood} the wood yield from a forest/woodland (m^3/ha/year), f_{water} the volumetric fraction of water in freshly harvested wood (m^3/m^3), f_{paper} the wood-to-paper conversion factor (i.e. the harvested volume needed to produce a metric ton of paper(m^3/t), f_{value} the fraction of total value of the forest which is associated with paper production (dimensionless) and $f_{recycling}$

the fraction of pulp derived from recycled paper (dimensionless). Note that the wood-to-paper conversion factor relates to the so-called product fraction (f_p, *mass/mass*) that is used in the standard calculation of a product water footprint (Hoekstra et al. 2009). The two parameters relate as follows:

$$f_{paper} = \frac{1}{f_p \times \rho}$$

with ρ being the density of harvested wood (ton/m^3).

The water footprint of a unit of paper p for the industrial stage is estimated as follows:

$$WF_{industry}[p] = E + R + P$$

in which E is the evaporation in the production process (m^3/t), R the water contained in solid residuals (m^3/t) and P the water contained in products (m^3/t).

2.1.1 Step 1: Estimating Evapotranspiration (ET_a) by Forest Type and by Country

There are several factors that influence evapotranspiration from forest biomes, including meteorological conditions, tree type and forest management. To get an overview of evapotranspiration from forests at the global level, use is made of two data sources that are both obtained from FAO GeoNetwork (Fig. 1):

- The World's Forests 2000 (FAO 2001): this dataset is based on 1992–93 and 1995–96 AVHRR data and gives global distribution of forest biomes at a resolution of 1 km. Five different forest types are distinguished: boreal (typical trees include pine, fir, and spruce), tropical (typical trees include eucalyptus), sub-tropical, temperate (typical trees include oak, beech and maple) and polar forest. Different forest types can be present in one country. For its low relevance, polar forests have been ignored.
- Annual actual evapotranspiration (FAO 2009b): this dataset contains annual average values for the period 1961–1990 at a resolution of 5 arc minutes.

With these data it is possible to obtain a rough estimate of annual evapotranspiration values for forests in most countries of the world. Country averages are determined by averaging all values of actual evapotranspiration in a country for all locations that are covered with closed forest. For calculating the water footprint of paper, evapotranspiration values for the 22 main global producers of pulp (FAO 2009a) are determined. Together, these countries produced 95% of globally produced pulp for the period 1998–2007. The locations from which wood is actually obtained remain unclear from statistics on pulp production. Therefore it is difficult to relate the right amount of evapotranspiration to the production of pulp. Due to a lack of detailed spatial information, in this study ranges of possible evapotranspiration values are presented, rather than estimates for actual forestry locations. Besides uncertainties on locations of origin within a producing country, also import from other countries may be important. Paper mills in Sweden, for example, use 75% of wood that originates from Sweden itself; the other 25% is imported from Latvia, Estonia and Lithuania (Gonzalez-Garcia et al. 2009). These pre-processing international trade flows are not taken into account in this study.

Table 1 shows the average annual evapotranspiration for the main pulp producing countries by forest type. If only one forest type exists in a country, only one value will be

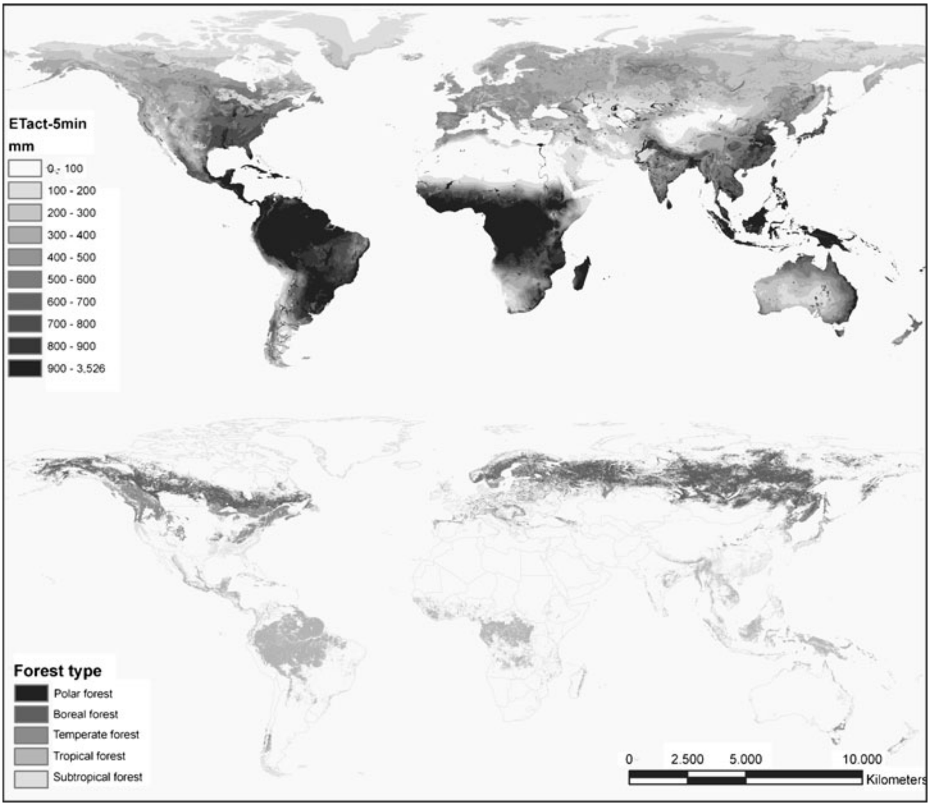

Fig. 1 Top: annual actual evapotranspiration (FAO 2009b). The dataset contains yearly values for global land areas for the period 1961–1990. Bottom: The World's Forests 2000 (FAO 2001) This database is based on 1992–93 and 1995–96 AVHRR data

considered. If more than one forest type exists, the values of all forest types are given. For large countries covering several climatic zones, such as the USA, values of evapotranspiration may vary considerably.

In this study, the green and blue water footprint requirements have been determined jointly. The difference between the use of green and the use of blue water is not as straightforward for forestry products as it is for other (agricultural) products. This difficulty is related to the process of water uptake by trees. The extent of the root zone of a full grown tree is generally well beyond the rainwater that is contained in the soil. Trees obtain water from the soil as well as from aquifers. In-depth studies on forest hydrology for specific cases would be required to come anywhere close to a reliable estimate of the ratio green/blue in the water footprint of forestry products.

2.1.2 Step 2: Estimating Wood Yield (Y_{wood})

For this study it has been assumed that the wood used for the production of wood pulp is harvested at a rate corresponding to the maximum sustainable annual yield from productive forests with wood production as its primary function. We will reflect

Table 1 Contribution to annual pulp production and estimates for average actual annual evapotranspiration by forest type in the main pulp-producing countries

Pulp producing country	Contribution to global pulp production[a]	Share of chemical pulp[a]	Average actual annual evapotranspiration by forest type (mm/year)[b]			
			Boreal	Temperate	Subtropical	Tropical
USA	29.5%	85%	278	516	635	1730
Canada	13.5%	52%	358	360	–	–
China	9.2%	11%	370	416	608	547
Finland	6.5%	60%	355	293	–	–
Sweden	6.3%	69%	345	318	–	–
Japan	5.9%	87%	–	637	725	–
Brazil	4.8%	93%	–	–	965	1048
Russia	3.3%	74%	310	362	–	–
Indonesia	2.4%	93%	–	–	–	1071
India	1.7%	37%	–	–	455	551
Chile	1.6%	86%	–	567	578	–
France	1.3%	67%	–	401	386	–
Germany	1.3%	44%	–	363	–	–
Norway	1.2%	26%	328	303	–	–
Portugal	1.0%	100%	–	512	502	–
Spain	1.0%	93%	–	547	527	–
South Africa	1.0%	72%	–	–	819	762
Austria	0.9%	76%	–	344	–	–
New Zealand	0.8%	45%	–	491	630	–
Australia	0.6%	50%	–	768	775	818
Poland	0.6%	76%	–	377	–	–
Thailand	0.5%	86%	–	–	–	636
Total	94.8%					

[a] Data source: annual averages for the period 1996–2005 based on FAOSTAT data (FAO 2009a)

[b] Data sources: national averages estimates based on grid data from FAO (2001; 2009b)

upon this approach in the discussion section. Data on wood products are obtained from the Global Forest Resources Assessment 2005 (FAO 2006). The estimates used in this study are presented in Table 2. Tree types are categorized into pine, eucalyptus and broadleaves. In this study the following assumptions are made for tree types in different forest biomes:

– Boreal forests yield pine
– Temperate forests yield broadleaves and pine
– Subtropical and tropical forests yield eucalyptus

2.1.3 Step 3: Fraction of Water in Harvested Wood (f_{water})

Generally this fraction is around 0.4 m^3 of water per m^3 of freshly harvested wood (e.g. Gonzalez-Garcia et al. 2009; NCASI 2009). A large part of the water may be returned to surface or ground water during the industrial manufacturing process. It is however removed

Table 2 Wood yield estimates for the main pulp-producing countries

Pulp producing country	Wood yield estimates (m^3/ha/year)[a]		
	Broadleaves	Eucalyptus	Pine
USA	7[c]	16[c]	6
Canada	7[c]		6[b]
China	6	6	4
Finland	7		6
Sweden	7[b]		8[b]
Japan	11	14	7[b]
Brazil	20	45	
Russia	7[c]		8[c]
Indonesia		19	
India		10	
Chile	22	26	19
France	7[b]	16[b]	9
Germany	7[b]		8[b]
Norway	7[b]		8[b]
Portugal	7[b]	16[b]	8[b]
Spain	7[b]	16[b]	8[b]
South Africa	11	23	
Austria	7[b]		8[b]
New Zealand	14	19[b]	15
Australia	14[b]	19	12
Poland	8		7
Thailand		14[b]	

[a] Data source: FAO (2006)

[b] Continental averages from available data are assumed

[c] European continental averages are used. In the case of Canada and the United States this is due to a lack of available data. For Russia, a European average is assumed to be more representative than the Asian continental average

from the forest area and should therefore be accounted for in the water footprint in the forestry stage.

2.1.4 Step 4: Wood-to-Paper Conversion Factors (f_{paper})

This is the amount of wood needed to produce a certain mass of paper (m^3/t). Estimates for important products are obtained from the UNECE conversion factors report (UNECE/FAO 2010). The main conversion factors are summarized in Table 3. The product categories used in this study are based on the categories as used in the ForestSTAT database (FAO 2009a). For different kinds (and qualities) of paper different types of pulp are used. The pulp differs according to the type of pulping technique that is applied. In this study no differences are made for different tree types.

2.1.5 Step 5: Estimating the Fraction of Total Value of the Forest Associated with Paper Production (f_{value})

Forests generally serve multiple functions, one of which may be the production of paper. Others may be the production of timber, biodiversity conservation and carbon storage. Therefore, not all evapotranspiration from a forest should necessarily be attributed to the production of paper. A value fraction (Hoekstra and Chapagain 2008) could be determined

Table 3 Wood-to-paper conversion factors

Product	FAO product code (FAO 2009a)	ITC product group codes used (ITC 2006)	Conversion factors based on UNECE/FAO (2010) (m^3/t)
Mechanical Wood Pulp	1654	2512	2.50
Semi-Chemical Wood Pulp	1655	25191	2.67
Chemical Wood Pulp	1656	2514, 2515, 2516	4.49
Dissolving Wood Pulp	1667	2513	5.65
Recovered Paper	1669	2511	
Newsprint	1671	6411	2.87
Printing & Writing Paper	1674	6412, 6413	3.51
Other Paper & Paperboard	1675	6414, 6415, 6416, 6417, 6419, 642	3.29

to allocate the amount of water to be allocated to the production of wood pulp for a forest with n functions, including the production of wood pulp:

$$f_{value}[pulp] = \frac{value[pulp]}{\sum_{i=1}^{n} value[i]}$$

In this study it is assumed that paper is produced from forests that have wood/pulp production as the primary function and for which annual growth is equal to annual harvest, so we assume the value fraction to be equal to 1. We will come back to this issue in the discussion section.

2.1.6 Step 6: Estimating the Fraction of Pulp Derived From Recovered Paper ($f_{recycling}$)

Recycling is an important factor for the water footprint, because fully recycled paper avoids the use of fresh wood and thus nullifies the water footprint in the forestry stage. When more recovered paper is used, the overall water footprint will decrease. On average an estimated 41% of all produced pulp is obtained from recycled paper (FAO/CEPI 2007; UNECE/FAO 2010), with large differences between producers using no recycled paper at all to producers that achieve relatively high percentages. We obtained the 'recovered paper utilization rates' for the main pulp producing countries from (FAO/CEPI 2007). The 'recovered paper utilization rate' is the amount of recovered paper used for paper and paperboard as a percentage of paper and paperboard production. Losses in repulping of recovered paper are estimated to be between 10 and 20% (FAO/CEPI 2007). In this study, 15% is used for all countries. The values used in this study are summarized in Table 4. The product categories for which recycling is taken into account are only the consumer product categories (i.e. newsprint, 'printing & writing paper' and 'other paper & paperboard'), since these are the only categories for which it is actually used.

2.1.7 Step 7: Estimating the Water Footprint of Paper in the Forestry Stage

For a quantification of the water footprint of paper in the forestry stage, estimates for the main pulp producing countries are made, as listed in Table 1.

Table 4 Recovered paper utilization rates and $f_{recycling}$ for the main pulp-producing countries

Country	Recovered paper utilization rate[a]	Fraction of pulp derived from recycled paper ($f_{recycling}$)[b]
USA	0.37	0.31
Canada	0.24	0.20
China	0.42[a]	0.36
Finland	0.05	0.04
Sweden	0.17	0.14
Japan	0.61	0.52
Brazil	0.40	0.34
Russia	0.42[c]	0.36
Indonesia	0.42[c]	0.36
India	0.42[c]	0.36
Chile	0.42	0.36
France	0.60	0.51
Germany	0.67	0.57
Norway	0.22	0.19
Portugal	0.21	0.18
Spain	0.85	0.72
South Africa	0.42[c]	0.36
Austria	0.46	0.39
New Zealand	0.25	0.21
Australia	0.64	0.54
Poland	0.36	0.31
Thailand	0.59	0.50
Average of main pulp producing countries	0.42	0.36
Netherlands	0.70	0.60

[a] Data source: (FAO/CEPI 2007)

[b] 85% of recovered paper utilization rate assumed due to loss in processing

[c] When no data are available for the individual country, the average of the other countries is used

2.1.8 Step 8: Estimating the Water Footprint of Paper in the Industrial Stage

The water footprint of paper in the industrial stage of production is estimated based on the case of the USA, considering the country's paper and pulp production sector as a whole (NCASI 2009). The USA is the largest producer of paper pulp and is assumed to be representative for the global paper industry. In this study no comparison is made between different techniques and processes that may be used in producing pulp.

In this study a number of processes with potentially significant contributions to the water footprint of paper have been ignored. These processes include: finalizing paper product and getting it to the consumer. In this process machines, several materials and energy sources are used. Also transportation has not been accounted for. For transportation a variety of alternative sources of energy may be used, including fossil fuels and bioenergy. Particularly when bioenergy is involved, the water footprint in transportation may be substantial (Gerbens-Leenes et al. 2009).

2.2 Estimating the Water Footprint of Paper Consumption in a Country

Many countries strongly depend on imports of pulp and paper. For those countries it is relevant to know the water footprints of the imported products and where these water footprints are located. This will be shown in a case study for the Netherlands. As a basis, we use data on the annual production, import, export and consumption of paper for the Netherlands as shown in Table 5.

A weighted average for all import partners is made for a few different paper products, similar to the way it is done by van Oel et al. (2009) and Hoekstra et al. (2009). Data on imports specified by trade partner are used from the International Trade Centre (ITC 2006). Table 3 shows the product categories used for estimating the water footprints of imported paper products. The average water footprint WF^* of a paper product p consumed in the Netherlands (NL) is estimated by assuming that:

$$WF^*[NL,p] = \frac{P[NL] \times WF[NL,p] + \sum_{c=1}^{m} (I[c] \times WF[c,p])}{P[NL] + \sum_{c=1}^{m} I[c]}$$

in which $WF[NL,p]$ is the water footprint of paper product p produced in the Netherlands using Dutch pulp; $WF[c,p]$ the water footprint of paper product p produced in the Netherlands using pulp from country c; $P[NL]$ the production of wood equivalents in the Netherlands, and $I[c]$ the import of wood equivalents into the Netherlands from country c. The various sorts of pulp produced in and imported into the Netherlands are expressed in wood equivalents using the conversion factors as shown in Table 3. The assumption here is that paper products are based on domestic and imported pulp according to the ratio of domestic pulp production to pulp import. On the Dutch market, in the period 1996–2005, 6% of the available pulp (expressed in terms of wood equivalents) had domestic origin; the remaining 94% was imported.

3 Results

3.1 The Water Footprint of Paper

The evapotranspiration per volume of harvested wood for the main pulp producing countries is shown in Table 6. The water footprint of paper is shown in Tables 7, 8 and 9. Country-specific recycling percentages are incorporated in these values. The lowest estimate for printing & writing paper is 321 m^3/t (eucalyptus from subtropical biome in Spain) and the highest value is 2602 m^3/t (eucalyptus from tropical biome in the USA), corresponding to 2 and 13 l per sheet of standard A4 copy paper respectively. If no recovered paper would have been used, these values would become 753 m^3/t (eucalyptus

Table 5 Annual production, import, export and consumption for the Netherlands for the period 1996–2005

Product	Pulp	Newsprint	Printing & writing paper	Other paper & paperboard
FAO code	1654–56, 1667	1671	1674	1675
Production (ton/year)[a]	125350	387700	895400	1987200
Import quantity (ton/year)[a]	1132860	476540	1267890	1498200
Export quantity (ton/year)[a]	322340	259480	1143450	1417900
Consumed (ton/year)	935870	604760	1019840	2067500

[a] Source: ForestStat (FAO 2009a)

Table 6 Water footprint of harvested wood for the main pulp-producing countries

Pulp producing country	Water footprint for different trees and places of origin (m^3/m^3)				
	Pines from Boreal biome	Pines from Temperate biome	Broadleaves from Temperate biome	Eucalyptus from Subtropical biome	Eucalyptus from Tropical biome
USA	463	860	752	397	1081
Canada	597	600	525		
China	891	1001	693	1105	995
Finland	592	488	451		
Sweden	413	381	463		
Japan		859	571	527	
Brazil				214	233
Russia	371	434	528		
Indonesia					564
India				455	551
Chile		298	262	222	
France		446	584	241	
Germany		435	529		
Norway	393	363	442		
Portugal		613	746	314	
Spain		655	797	329	
South Africa				356	331
Austria		412	501		
New Zealand		335	351	338	
Australia		662	549	415	438
Poland		539	459		
Thailand					463

from subtropical biome in Brazil) for the lower estimate and the higher estimate would be 3880 m^3/t (eucalyptus from subtropical biome in China). For one sheet of A4 copy paper this means 4 and 19 l respectively.

3.1.1 *Water Footprint of Paper in Industrial Stage—Example USA*

In the USA, annual industrial production of paper is around 97×10^6 t/year. The total water use for the main water consumption categories is: $E=507 \times 10^6$ m^3, $R=19 \times 10^6$ m^3, $P=10 \times 10^6$ m^3 (Fig. 2). A rough estimate then gives an average value of 5.5 m^3/t.

3.2 The Water Footprint of Paper Consumption in the Netherlands

The Dutch water footprint related to the consumption of paper is significant if compared to the footprint related to the consumption of other products. The water footprint of paper is estimated to constitute 8–11% of the total water footprint of Dutch consumption (Van Oel et al. 2009). Figure 3 gives a summary of the water footprint accounts for the Netherlands insofar related to paper consumption, production and trade. Minimum and maximum estimates are given to account for the fact that paper can have a low or high water footprint depending on the biome from which the wood is derived (Tables 7, 8 and 9).

Table 7 Water footprint of newsprint (m^3/t), taking into account country-specific recovered paper utilization rates

Country	Pine from boreal biome	Pine from temperate biome	Broadleaf from temperate biome	Eucalyptus from subtropical biome	Eucalyptus from tropical biome
USA	912	1692	1479	781	2127
Canada	1363	1371	1199		
China	1648	1852	1282	2045	1840
Finland	1626	1342	1239		
Sweden	1015	935	1138		
Japan		1187	789	729	
Brazil				406	441
Russia	687	802	976		
Indonesia					1043
India				842	1019
Chile		551	483	410	
France		627	822	339	
Germany		537	654		
Norway	917	847	1030		
Portugal		1446	1759	740	
Spain		522	635	262	
South Africa				659	613
Austria		720	876		
New Zealand		757	793	763	
Australia		866	718	543	573
Poland		1073	914		
Thailand					662

Table 10 shows the water footprint of paper in the Netherlands, whereby a distinction is made between: (i) paper produced from trees grown in the Netherlands, (ii) imported paper to the Netherlands or paper produced from imported pulp, and (iii) the weighted average. The water footprint of paper produced from trees grown in the Netherlands is substantially lower (two to three times) than that of imported paper or paper produced from imported pulp. Most of the imported pulp originates from other European countries (85%), followed by North America (12%) (Fig. 4).

If countries from which the Netherlands imports pulp and paper would not recover paper as they currently do (Table 4) and if also the Netherlands itself would not recover paper, the water footprint of paper products consumed in the Netherlands would be 4.9–7.1 Gm^3/yr. Using recovered paper has thus resulted in a water saving of ~36%. For the Netherlands, the water footprint of a standard A4 copy paper (80 g/m^2) is between 5 and 7 l (7–10 l if no recovered paper is used).

4 Discussion and Conclusion

This numbers presented in this paper are only a first step towards a reliable estimate of the water footprint of paper. Nonetheless, this study shows that the water footprint of paper is highly significant and deserves to be studied in more detail.

Table 8 Water footprint of 'printing & writing paper' (m^3/t), taking into account country-specific recovered paper utilization rates

Country	Pine from boreal biome	Pine from temperate biome	Broadleaf from temperate biome	Eucalyptus from subtropical biome	Eucalyptus from tropical biome
USA	1115	2069	1809	955	2602
Canada	1667	1676	1466		
China	2015	2266	1568	2501	2250
Finland	1988	1641	1515		
Sweden	1241	1144	1392		
Japan		1452	965	891	
Brazil				497	540
Russia	840	981	1193		
Indonesia					1275
India				1029	1246
Chile		674	591	502	
France		766	1005	415	
Germany		657	799		
Norway	1121	1036	1260		
Portugal		1769	2151	905	
Spain		638	776	321	
South Africa				806	749
Austria		881	1072		
New Zealand		925	969	933	
Australia		1060	878	665	701
Poland		1312	1118		
Thailand					809

The water footprint of printing and writing paper is estimated to be between 300 and 2600 m^3/t (2–13 l for an A4 sheet). In these estimates paper recovery rates in different countries (Table 5) are accounted for.

This study indicates that by using recovered paper for the production of paper the global average water footprint of paper is only 60% of what it would be if no recovered paper would be used at all. Further savings may be achieved by increasing the recovery percentages worldwide. The global water footprint of paper can be reduced by choosing production sites and wood types that are more water-efficient. The results of this study suggest that the use of recovered paper may be particularly effective in reducing the water footprint of paper. In addition, the global water footprint of paper can be reduced by choosing production sites and wood types that are more water-efficient.

For countries with a low recovered paper utilization rate a lot of room for reduction of the water footprint remains. In some countries such as the Netherlands, Spain and Germany a lot of recovered paper is already used. For the Netherlands, the water footprint related to the consumption of paper is significant. The water footprint of paper products is estimated to constitute 8–11% of the total water footprint of Dutch consumption.

In this study only a first rough estimate for the water footprint of paper has been made. To arrive at this estimate several assumptions and simplifications have been made. Below, some important assumptions are described and commented upon briefly.

Table 9 Water footprint of 'other paper & paperboard' (m^3/t), taking into account country-specific recovered paper utilization rates

Country	Pine from boreal biome	Pine from temperate biome	Broadleaf from temperate biome	Eucalyptus from subtropical biome	Eucalyptus from tropical biome
USA	1045	1940	1696	895	2439
Canada	1563	1571	1374		
China	1889	2124	1470	2344	2109
Finland	1864	1538	1420		
Sweden	1163	1072	1304		
Japan		1361	904	835	
Brazil				466	506
Russia	787	920	1119		
Indonesia					1195
India				965	1168
Chile		631	554	470	
France		718	942	389	
Germany		616	749		
Norway	1051	971	1181		
Portugal		1658	2017	848	
Spain		598	728	301	
South Africa				755	702
Austria		826	1004		
New Zealand		867	909	874	
Australia		993	823	623	657
Poland		1230	1048		
Thailand					759

No detailed study was devoted to the differences between production systems for wood and wood pulp. Therefore, the uncertainty about the water footprint of paper is considerable and not accounted for in this study. Also, rather than accounting for evapotranspiration for the whole period between planting and harvesting, the average annual evapotranspiration from an extended area of forest has been used for the estimates presented. This implies

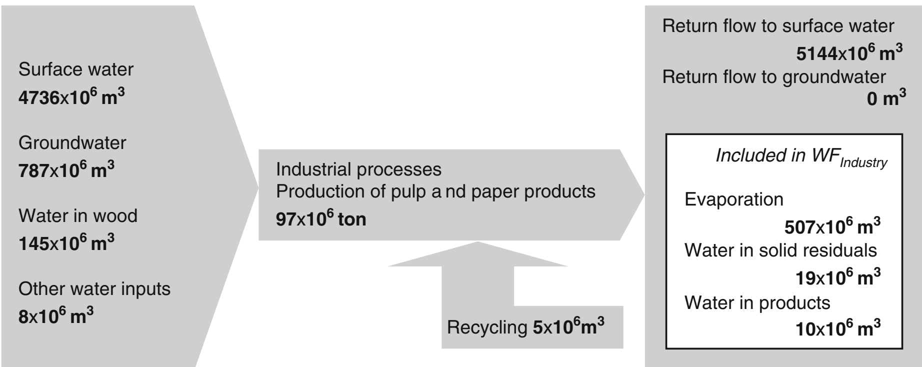

Fig. 2 Water flows in the paper and pulp industry in the USA (NCASI 2009)

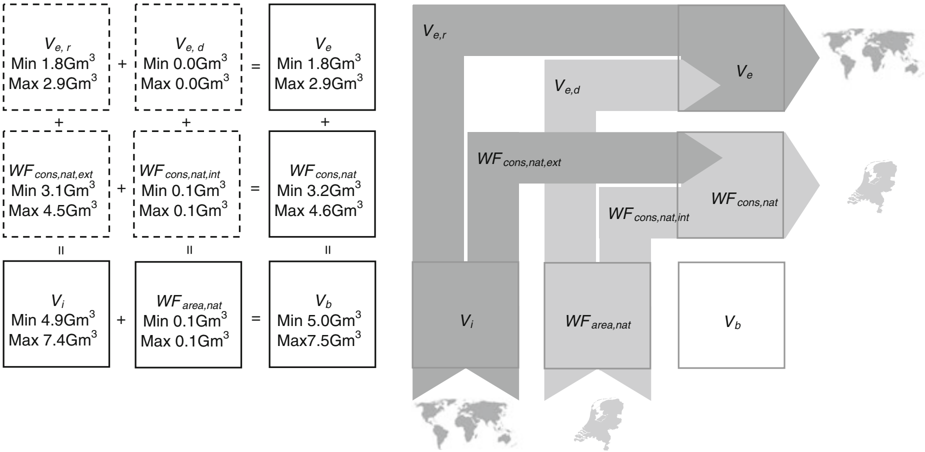

Fig. 3 Summary of the water footprint accounts for the Netherlands insofar related to paper consumption, production and trade: virtual-water import (V_i), virtual-water export (V_e), the water footprint within the area of the nation ($WF_{area,nat}$) the water footprint related to national consumption ($WF_{cons,nat}$), the external water footprint ($WF_{cons,nat,ext}$), the internal water footprint ($WF_{cons,nat.int}$), the virtual-water re-export ($V_{e,r}$) and the virtual-water export from domestic production ($V_{e,d}$). The numbers in the boxes are minimum and maximum estimates for the period 1996–2005

gradual harvesting over a long period of time. This may very well be far from what is happening in reality. Moreover, in estimating the water footprints of paper, annual meteorological variations or changes over longer periods of time have not been accounted for. For evapotranspiration, climate averages have been used (for the period 1961–1990).

For the data on wood yield used in this study (FAO 2006), the maximum sustainable annual yield has been assumed. This may again deviate considerably from actual maximum sustainable annual yields for the woodlands and forests concerned. The maximum sustainable annual yield is the maximum annual yield that can be obtained from a forested

Table 10 Water footprint of paper products in the Netherlands

Origin		Water footprint (m^3/t)	
		Lower estimate	Higher estimate
Paper produced from trees grown in the Netherlands	Newsprint	369	410
	Printing & writing paper	451	501
	Other paper & paper board	423	470
Imported paper to the Netherlands or paper produced from imported pulp	Newsprint	829	1144
	Printing & writing paper	994	1402
	Other paper & paper board	848	1267
Average paper as on the Dutch market[a]	Newsprint	802	1101
	Printing & writing paper	962	1349
	Other paper & paper board	823	1221

[a] For the production of these products in the Netherlands it is assumed that pulp is used from imported and domestic sources in the same ratio as they are available (imported+produced). Around 94% of the available pulp in the Netherlands is imported

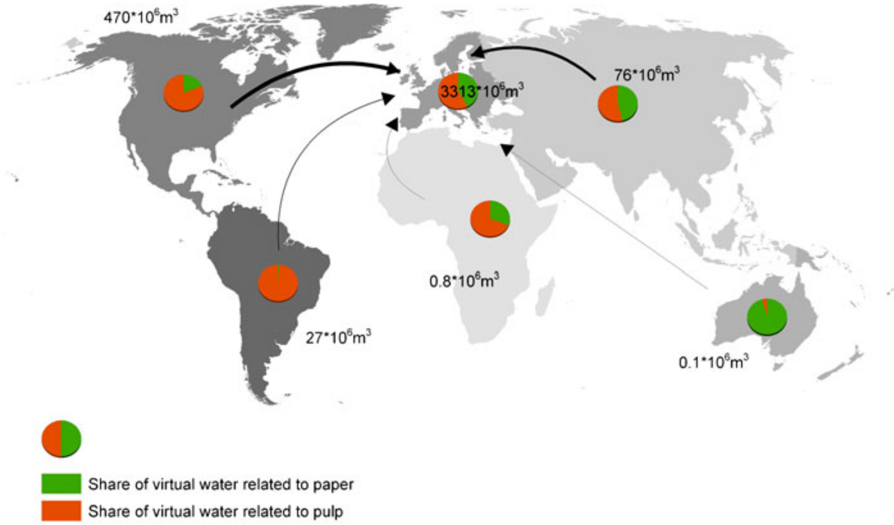

Fig. 4 Virtual-water imports to the Netherlands by continent related to the import of pulp and paper

area over an extended period of time. If the reported yield is less than this figure the water footprint estimate that is calculated for that forest in this study is an overestimation, since in that case not all of the forest (and the evapotranspiration of that forest) is actually used for production of wood for the paper industry. Per biome we have estimated the maximum sustainable annual yield by assuming one typical tree type. In reality, many forest biomes are mixed with regard to tree types. For a boreal forest biome, pine trees have been assumed when taking data for the maximum sustainable annual yield, which is not precisely the case for all areas that are classified as boreal biome. For temperate, subtropical and tropical biomes, tree diversity may be even higher. Since actual evapotranspiration estimates are used for biomes rather than for specific tree types, this may off course cause significant inaccuracies. By studying specific cases in more detail uncertainties may be reduced considerably.

Moreover, in this study the functions of a woodland or forest, other than the production of wood for the paper industry are not accounted for at all. Many planted forests are monocultures of introduced species, unlike the assumption of representative biomes as assumed in this study. Moreover, these introduced species are often not even found in the natural biome. When analyzing cases with specific species, more precise data should be studied to reduce uncertainty. Moreover, woodlands like semi-natural forests and plantations often serve purposes of considerable importance next to that of delivering wood for the production of paper. Next to the production of timber, important functions include biodiversity conservation and carbon storage. A possible way of accounting would be to allocate the forest-ET over the various forest functions according to their economic value (Hoekstra 2009). One would need estimates of the various values of forests, as for instance reported in Costanza et al. (1997).

When recovered paper is used for producing new paper one could decide to account for the water footprint in the forestry stage of the original wood that was used for producing the recovered paper. In this study that part of the water footprint is not accounted for. Thus, in this study the pulp from recycled paper has no forestry-related water footprint. If one would decide to do take into account this part of the water footprint then one still has to decide on the water footprint of the recovered paper that was used to produce the newly recovered paper and so on. Moreover, in theory one could decide to reduce the water footprint op paper if one assumes that this paper in the future will be recycled. However, beforehand it is not known how many times (if at all) a paper product will be recycled. If one would be able to precisely trace recycling flows, one could also allocate the water footprint in the first stage of wood production to the final paper products produced in the different recycling stages, so that (decreasing) fractions of the forestry-related water footprint are allocated to the paper products in the subsequent recycling stages. If one is interested in estimating the water footprint of a specific paper product produced in a particular paper mill using a specific mixture of wood pulp and recycled paper-pulp, one would need to study the process in much more detail than has been done in this study. The current study is a macro study, where the total annual water footprint in the forestry stage of paper production is allocated to the total annual paper production, whereby the latter is partly based on recycled paper. This study could serve as a first step towards understanding the significance of the water footprint of paper and exploring ways to reduce its negative impacts.

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