water footprint network

Water Footprint Assessment of polyester and viscose

and comparison to cotton

C&A

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Authors: Alexandra Freitas, Guoping Zhang, Ruth Mathews

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The results and findings of this report are based on scientific analysis done by Water Footprint Network. All the internal data from C&A are provided solely to be used in this report. The partners of the initiative consider it a living document that will be adapted to the circumstances based on new findings and concepts, future experiences and lessons learnt.

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Executive Summary

The production of manmade fibres, including polyester and viscose, has significantly increased in recent years. This is mainly in response to the textile market's growing demand, but also to limitations in expanding production of cotton and other natural fibres. Currently, manmade fibres account for almost 76% of all fibres produced worldwide and in 2015, world production was 68.9 million tonnes.

With the growing demand of manmade fibres, it becomes increasingly relevant to understand the environmental impacts associated with their production. This report presents the Water Footprint Assessment of polyester and viscose within the context of local water conditions.

This study is part of the support Water Footprint Network is providing C&A in developing a deep understanding of water consumption and pollution of raw materials production and garment processing used in their products. While it builds an understanding of the water footprint related to polyester and viscose, it also identifies strategic interventions that can be used and applied by the textile sector and concerned stakeholders to define a water strategy that addresses the sustainability issues associated with polyester and viscose fibres production.

In this study, the scope of analysis was defined by necessity, and limitations in data availability. Hence, the raw materials and production processes analysed in the water footprint calculations are limited and results need therefore to be carefully interpreted and not extrapolated as representative of all fibre production scenarios. However, the analysis undertaken allows a first glance on the most outstanding water sustainability issues in the production of polyester and viscose fibres, and identifies the actions required to move toward sustainable production of these materials.

The results of this study show that the water footprint of polyester can be as high as 71,000 cubic metres per tonne of fibre under the production scenario used in the analysis. The largest contributions to the water footprint come from the industrial production phases (i.e. refineries, petrochemicals and polyester fibre production) and water management practices applied during oil exploration. "Produced water" resulting from oil exploration is the largest by-product of this activity and contains toxic pollutants that are not always properly treated before disposal. Thus, the grey water footprint represents over 99% of the water footprint of polyester, which could be significantly reduced by applying adequate water management practices.

It is also evident that polyester has sustainability issues related to water due to the fact that, for all stages of production analysed in this study, operations are in locations with high water scarcity and/or water pollution problems. Ten out of 15 polyester production locations studied in this report are in water sustainability hotspots, i.e. locations with high water scarcity and/or pollution levels. They are mostly located in Asia, which accounts for approximately 92% of global polyester fibre production and 86% of global use in manufacturing textiles. China has the largest demand for polyester in the world and accounts for 65% of global polyester fibre consumption.

The dissolving wood pulp market has grown in recent years mainly due to the increasing demand for viscose fibres that are the leading user of dissolving wood pulp. In 2015, global dissolving wood pulp production was 6.15 million tonnes, with the USA responsible for 19%, followed by South Africa with 15% of global production. The water footprint assessment of viscose shows several similarities with that of polyester. The component of viscose that contributes most to the total water footprint is also the grey water footprint. This applies to all stages of production including the wood production stage. The largest contribution to the total water footprint calculated in this study is associated with the industrial processing of dissolving wood pulp and fibre production.

It is notable that the water footprint of viscose varies significantly depending on the fibre type and the processes involved. In the production processes analysed, the water footprint of viscose staple fibre is estimated at approximately 3,000 cubic meters per tonne of yarn. However, when produced through batch washing the footprint goes up to more than 30,000 cubic metres when produced through continuous washing due to higher demands for chemical inputs.

Similarly to polyester, production location matters in terms of the sustainability of viscose related to water. All locations across all stages of viscose production assessed in this study are in sustainability hotspots, indicating that either environmental flow requirements and/or water quality standards are being violated.

The results of this study also highlight the importance of the actual practices and technologies used in fibre production and their effect on the water footprint, similarly to what had been identified in previous studies on the water footprint of different agricultural practices in cotton production. It is important to note that the water footprint of polyester and viscose calculated in the current assessment is limited to publicly available data. Significant differences in the water footprint to what is reported here may arise if specific, detailed studies are undertaken for viscose and polyester, as was undertaken for cotton. Therefore, to fully understand the water footprint of these three fibre types and compare them properly, further research is needed.

To address the two key outcomes of this study, – the magnitude of the water footprint and the sustainability issues in the locations in which they occur – brands and retailers will need a two-pronged approach to water stewardship: working individually within their own company’s value chain and working collectively with other brands, retailers and stakeholders to transform the sector.

Both engagement with suppliers and brands and retailers’ collective engagement should aim at supporting improvements in producers’ water footprint performance: implementing best practices and investing in innovation and technology that reduce the water footprint, and that improve local water conditions.

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Note

Number is this study should be interpreted as follows:

- Commas are used as separators of thousands (1,000 = one thousand)
- Points are used as decimal separators (1.5 = one and half)

List of acronyms and abbreviations

AOX	Adsorbable organic halogens
BAT	Best available techniques
BOD	Biochemical Oxygen Demand
BREF	European Commission Reference Documents on Best Available Techniques
BWS	Blue water scarcity
COD	Chemical Oxygen Demand
Cm	Centimetre
DMT	Dimethyl terephthalate
DWP	Dissolving Wood Pulp
FAO	Food and Agriculture Organization of the United Nations
FENC	Far Eastern New Century
FY	Fiscal Year
Kg	Kilogram
m^3	Cubic metres
MEG	Monoethylene glycol
PET	Polyethylene terephthalate
REEL	Responsible Livelihood Enhanced Environment
t	Metric tonne
TPA	Terephthalic acid
USA	United States of America
WF	Water footprint
WFA	Water Footprint Assessment
WFN	Water Footprint Network
WPL	Water pollution levels
WS	Workstream

1 Introduction

Few industries have the impact that the textile sector has on the world. Globally, an average of almost 10,000 litres of water is necessary to produce 1 kilogram of cotton fabric, with approximately 2,500 litres needed for a standard 250 gram cotton t-shirt[1]. Water is a key natural resource for the textile sector as its supply chain is both dependent upon the availability and quality of water, and its use creates an impact on those water resources through consuming and polluting water. The textile sector increasingly faces water availability and quality issues in its global supply chain.

Reductions in the consumption and pollution of water resources in the textile sector will lead to greater water security for businesses and are necessary for water use to be sustainable, efficient and equitable.

The Water Footprint Network has been supporting C&A in developing a deeper understanding of water consumption and pollution arising from raw materials production and garment processing. This has been done through quantifying the water footprint of raw materials and processing, assessing the sustainability of these water footprints and recommending strategic response options which will reduce the water footprint and make it more sustainable. Three studies have been completed: "C&A's Water Footprint Strategy: Cotton Clothing Supply Chain'[2], 'Grey Water Footprint Indicator of Water Pollution in the Production of Organic vs. Conventional Cotton in India'[3] and "Toward sustainable water use in the cotton supply chain. A comparative assessment of the water footprint of agricultural practices in India"[4].

Polyester and viscose are the second and third most important raw materials for C&A, following cotton. Additionally, production of manmade fibres, including polyester and viscose, has significantly increased in recent years in response to the textile market's growing demand as well as to limitations in expanding production of cotton and other natural fibres. This heightens the importance of achieving sustainable production of manmade fibres in the supply-chain of the apparel sector.

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[1] Mekonnen and Hoekstra, 2010, 2011
[2] http://www.waterfootprint.org/Reports/CA_Strategy_Final_Report_Formatted%2006.08.2013.pdf
[3]http://www.waterfootprint.org/Reports/Grey%20WF%20Phase%20II%20Final%20Report_Formatted%2006.08.2013.pdf
[4] http://waterfootprint.org/media/downloads/Assessm_water_footprint_cotton_India.pdf

2 Method and data

This study follows the methodology for Water Footprint Assessment described in the *Water Footprint Assessment Manual: Setting the Global Standard* as developed by the Water Footprint Network (Hoekstra et al., 2011). The water footprint (WF) is an indicator of freshwater use that looks at both direct and indirect water use for any kind of productive activity, for the products consumed by an individual or group of individuals, or for the activities within a geographic area.

Data and specific approaches adopted for the current assessment are presented in the sections below. Details on the Water Footprint Assessment methodology are presented in Annex 1. Details on data used, their limitations and necessary assumptions for the current assessment are presented in Annex 2.

2.1 Data

Global information on trade in industrial products, and their production processes is very fragmented and in some cases, scarce. Therefore, in the current assessment, detailed research using the data available for the largest viscose and polyester producers was undertaken. This included data for raw materials, processes, production volumes and market prices.

These data were used to calculate water footprints and to map production locations and linkages between main producers. Relevant studies, company websites and annual reports (on sustainability, production and financial aspects) were analysed and all potentially useful information was compiled. This analysis included both online reports of major producers and a large number of third party reports, e.g., studies and guidance documents from international institutions, market reports, news and magazines on the textile market and textile retailers.

Not all data found through these methods is useful for water footprint calculations and water footprint sustainability assessments. A typical example is related to effluents, for which available data are usually expressed in pollutant concentrations. However without information on effluent volumes for the site, the pollutant load per production unit cannot be estimated and therefore the grey water footprint cannot be calculated. Therefore, not all data collected in the research for this report could be used in the current study (see Annex 2 for specifics on data used).

2.2 Method

Water Footprint Assessment is a four-phase process which uses water footprint accounting to answer specific questions of interest including whether the water footprint is sustainable and, if not, which response strategies will improve its sustainability.

Water Footprint Assessment places the water footprint within the context of local water conditions and identifies strategic interventions that can be used to develop a sustainable water strategy.

The four phases of Water Footprint Assessment are:

1. Setting goals and scope;
2. Water footprint accounting;
3. Water footprint sustainability assessment; and
4. Water footprint response strategies.

2.2.1 Goals and scope

The goals of the current assessment are to:

- Calculate the water footprints of polyester and viscose for specific raw materials and the related production processes included in this study;
- Assess global polyester and viscose water footprint sustainability;
- Compare global polyester and viscose water footprint sustainability with that of cotton; and
- Provide guidance for achieving sustainable water use in polyester and viscose supply chains.

The scope therefore includes:

- Identification of raw materials and processes involved in the production of polyester and viscose fibres for textile production;
- Global mapping of raw materials selected for the assessment and industrial processing locations of polyester and viscose fibres;
- Identification of hotspots and water sustainability issues; and
- Strategic recommendations on the way forward towards sustainable production of these raw materials.

Limitations

The scope of analysis for polyester and viscose, namely the phases and processes considered, is presented in Table 1. The scope was defined by:

- Necessity, as both polyester and viscose may derive from an array of raw materials; and
- Limitations in data availability.

Hence, results presented in this report need to be carefully interpreted and should not be used as applicable to any particular production scenario. Specifics on data sources and limitations are presented in Annex 2.

This study should be seen as a first analysis that provides insights into the water footprint and sustainability assessment of polyester and viscose fibres. It presents an initial picture of the issues that need further analysis and attention from those concerned with sustainable production and sourcing of these fibres.

Greater detail and specifics on raw materials and production processes of polyester and viscose are presented in sections 4 and 5, respectively.

Table 1 – Phases and processes of analysis for polyester and viscose

	Polyester	Viscose
Raw materials included in study	• Oil from onshore production	• Eucalyptus plantations in Brazil and South Africa
Water footprint accounting processes included in study	• Oil exploration • Refinery processing • Petrochemical processing • Polyester fibres production	• Eucalyptus plantations • **Integrated production** (1) of Dissolving wood pulp & viscose fibres
Geographic sustainability assessment locations included in study	• Oil exploration: **no hotspot identification**(2) • Refinery • Petrochemicals • Polyester fibres production	• Eucalyptus plantations • Dissolving wood pulp production • Viscose fibres production

Notes:

(1) For the water footprint accounting of viscose production processes, it was not possible to access data for dissolving wood pulp and fibres production separately. Therefore, water footprint accounting for viscose was calculated using data from integrated production (pulp and fibres).

(2) Hotspots are locations where environmental flow requirements and/or water quality standards are being violated – checking is part of the Water Footprint Assessment methodology. Due to the numerous possible origins of oil, and considering that only a small share of crude oil ends up in polyester production, no hotspot checking for oil exploration was undertaken.

2.2.2 Water footprint accounting

The water footprint of a product is defined as the total volume of fresh water that is used directly or indirectly to produce the product. It is determined by quantifying water consumption and pollution in all steps of the production chain.

The water footprint includes three components:

- Green water footprint is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural and forestry products;
- Blue water footprint is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time; and
- Grey water footprint is the amount of fresh water required to assimilate pollutants to meet specific water quality standards.

To calculate the water footprint of a product, it is necessary to understand the way the product is produced, i.e. identify the "production system"[5]. The water footprint is then quantified for each of the sequential process steps of the production system.

From data provided by C&A Europe, the company buys garments containing polyester and/or viscose from several companies in Europe, Asia, Middle East and North Africa. However, no further information on the supply chains of these products was provided. Therefore, the origin, production processes and geographic locations specific to C&A Europe's raw material supply could not be identified and thus the current study focuses on major global producers.

2.2.3 Water footprint sustainability assessment and response strategies

The sustainability assessment covers the following aspects:

- Geographic assessment: Mapping of main producers and assessment of local water scarcity and water pollution conditions to identify hotspots. i.e., locations where environmental flow requirements and/or water quality standards are being violated, by looking at blue water scarcity (BWS) and Water Pollution Levels (WPL) for the major global production locations.
- Water footprint efficiency assessment: The production water footprint of polyester and viscose calculated in this study are based on available global data and not on specific producers or production sites. Therefore, it is not possible to compare in full the production water footprints calculated in this study against other water footprints or benchmarks. The study addresses water footprint efficiency by undertaking comparisons between the production water footprints calculated and identifying amongst these, the processes and technologies that can contribute most to polyester's and viscose's water footprint efficiency.

The results of this study, in particular, the relevance of each water footprint component and related process, and the water footprint hotspot identification with regard to blue water scarcity and Water Pollution Levels, are used to develop recommendations for the textile industry (brands, retailers and producers). The recommendations aim at sustainable sourcing of these fibres' raw materials and processing supply chains.

[5] sequential process steps of production

3 Global context of polyester, viscose and cotton fibres

Polyester and viscose are manmade fibres, whereas cotton is a natural fibre. Manmade fibres are classified into three classes, those made from natural polymers, those made from synthetic polymers and those made from inorganic materials (see Figure 1).

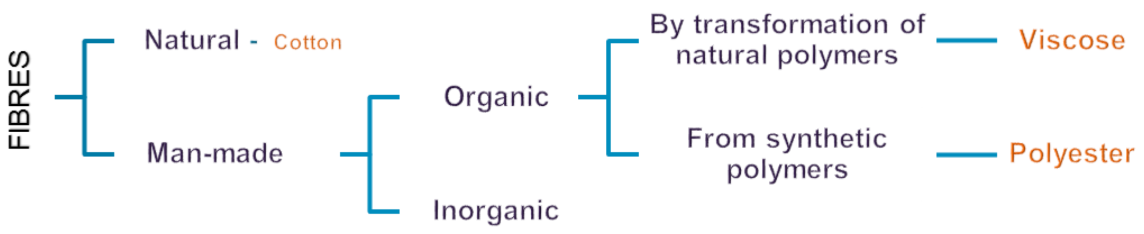


Figure 1 – Fibres classification

The most common natural polymer fibre is viscose, which is made from cellulose[6].

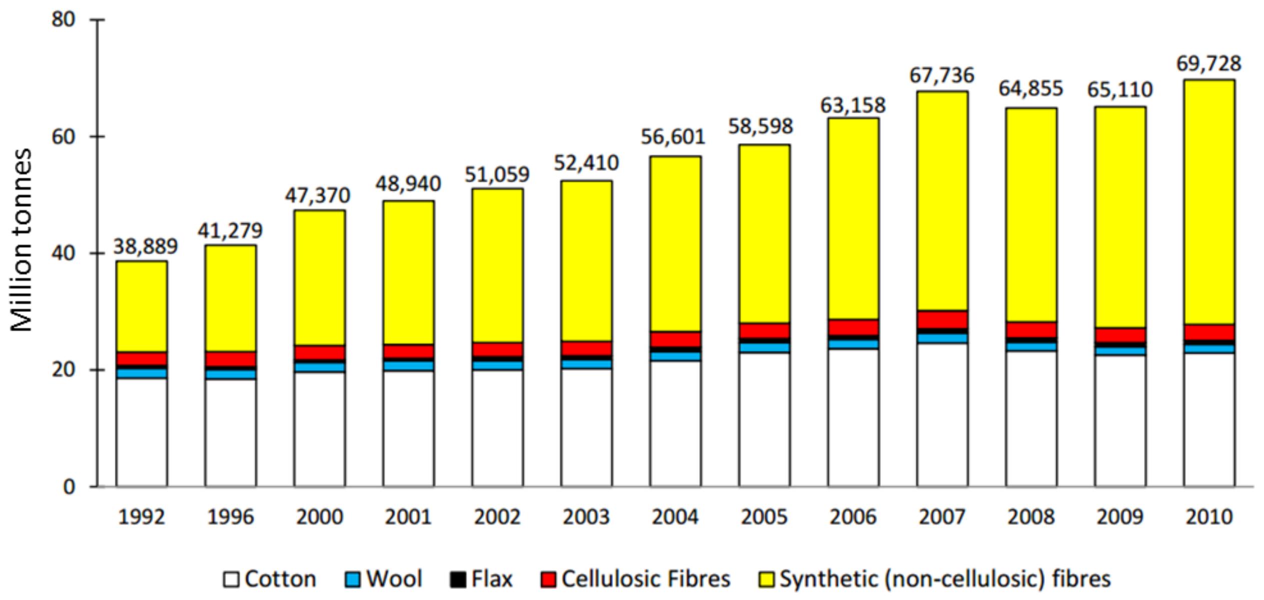
There are many fibres made from synthetic polymers. The most common are polyester, polyamide (i.e. nylon), acrylic and modacrylic, polypropylene, segmented polyurethanes (elastic fibres known as elastanes or spandex), and specialty high-tenacity fibres.

Cotton still accounts for a large share of the global fibres market, but the market share for manmade fibres is increasing.

Currently manmade fibres account for almost 76% of all fibres produced worldwide, and in 2015 world production was 68.9 million tonnes[7].

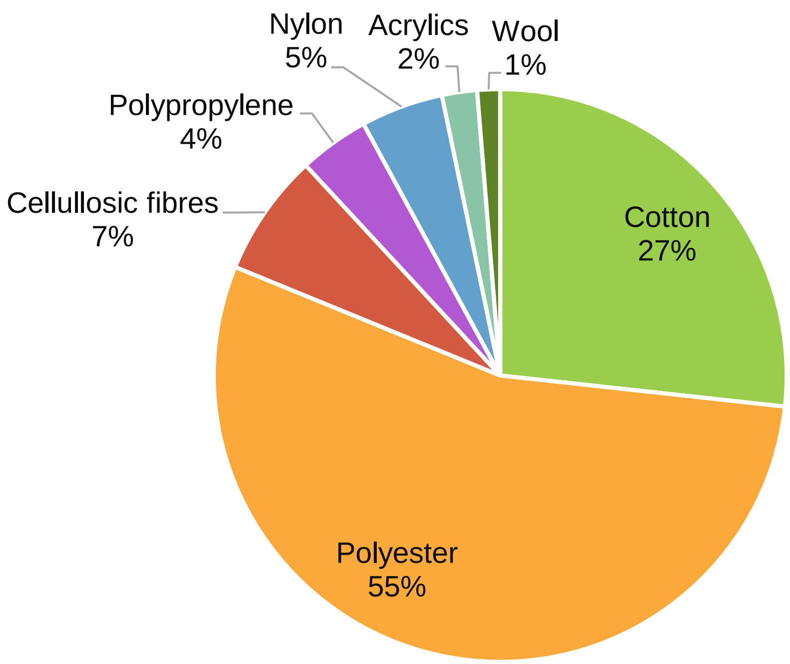
Trends in the global textile industry's use (referred to as 'consumption') of synthetic non-cellulosic fibres, cellulosic fibres (including viscose) and natural fibres are shown in Figure 2. Figure 3 shows global mill consumption of fibres in 2015.

[6] European Man-made Fibres Association: http://www.cirfs.org/
[7] CIRFS European Man-made Fibres Association: http://www.cirfs.org/KeyStatistics.aspx



Source: FAO/ICAC World Apparel Fibre Consumption Survey 2013

Figure 2 – Trends in global apparel fibre consumption



Source: Textile Exchange Preferred Fiber and Materials Market Report 2016

Figure 3 – Global spinning mills' consumption of fibres in 2015

Polyester: Polyester filament production has been increasingly dominated by China, which currently holds more than 55% of the global production capacity with the expansion of polyester production in recent years focused mainly in China.

Viscose: Asia also dominates viscose production. China has become the world's largest viscose fibre producer, with its output accounting for approximately 62% of the global total in 2012. By 2013, China had more than doubled its viscose fibre production in comparison to 2007.

Cotton: Cotton production takes place in over 100 countries but has traditionally been concentrated in only a few. Over the last three decades, the four leading producing countries have accounted for an increasing share of world production. China, India, the United States and Pakistan accounted for 48% of world production in 1970/71 and 75% in 2009/10. China is the world's largest cotton producer and the world's largest consumer of cotton fibre, with a share of around 25% of global cotton production in 2013/14[8].

[8] Cotton Australia 2016. http://cottonaustralia.com.au

4 Water Footprint Assessment of polyester

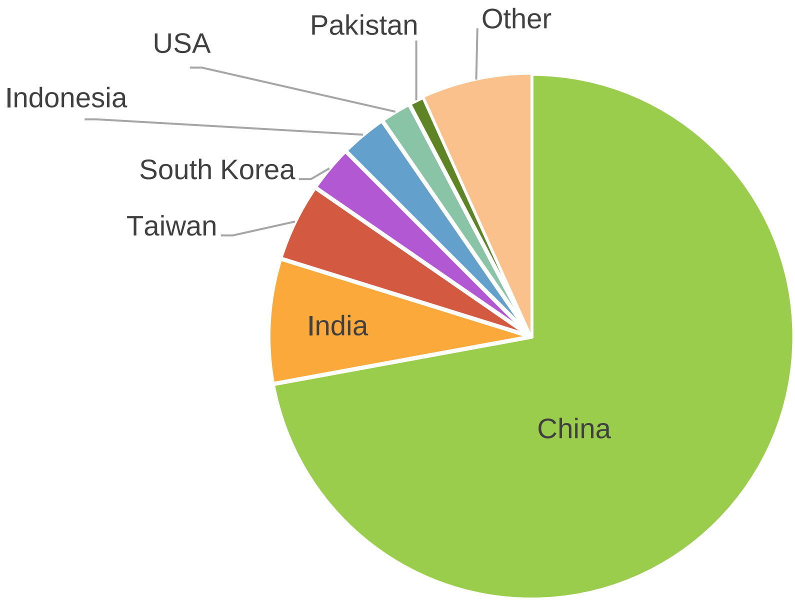
Polyester fibre is the most-used synthetic fibre worldwide, with the lowest production cost among all competing fibres. The major application for polyester fibres is the production of fabrics, which are used in apparel or other finished textile goods. In 2016, apparel represented approximately half of the polyester fibre end uses[9].

In 2015, the global production of polyester reached 52.8 million tonnes for the textile industry[10]. Since 1990, overall demand for polyester fibres has grown at a sustained rate of nearly 7% per year globally [11].

Polyester fibres were developed and patented during the 1940s and were marketed from the 1950s onwards. By 2000, they accounted for the largest share of manmade fibres with a global quantity in excess of 16 million tonnes per year. The global development in the production of polyester fibres during the last 25 years is characterised by a shift of production from developed countries (Europe, US, Japan) towards emerging economies (Asia and South America) and a continued growth scenario in these new economies with a focus on large scale production[12].

Asia as a region accounts for approximately 92% of global polyester fibre production and 86% of global consumption. A major contributor is China, which has the largest demand for polyester in the world[13], and accounts for 65% of global polyester fibre consumption. China consumes polyester fibres in the textile weaving, dyeing, and apparel-making industries, and exports large amounts of finished goods, including apparel, curtains, and bedding, around the world. Western Europe's and North America's share of polyester fibre consumption has declined and remains low, accounting for only 8% of global demand in 2016. Other countries such as South Korea and Taiwan have also seen their apparel and textile exports decrease over the past few years, leading to lower polyester fibre demand in these countries[14].

[9] IHS Chemical Economics Handbook (November 2016): https://www.ihs.com/products/polyester-fibers-chemical-economics-handbook.html
[10] Textile Exchange Preferred Fiber Market Report 2016; https://www.cooperhewitt.org/2016/10/11/global-apparel-industry-insights/
[11] IHS Chemical Economics Handbook (November 2016): https://www.ihs.com/products/polyester-fibers-chemical-economics-handbook.html
[12] Reference Document on Best Available Techniques in the Production of Polymers, European Commission, 2007
[13] http://bjxgen.highchem-tech.com/business/jishujianjie.htm
[14] IHS Chemical Economics Handbook (November 2016): https://www.ihs.com/products/polyester-fibers-chemical-economics-handbook.html



Source: World Polyester Fibre – Trend in Demand and Supply 2015 (YarnsandFibres.com)

Figure 4 – World's largest polyester fibre producers in 2015

Polyester has an oil feed-stock. The raw material can either be crude oil or gas, and both can be produced either onshore or offshore. Water consumption and wastewater from these operations vary substantially, depending on the location and processes used.

Crude oil or gas is processed at refineries into naphtha which is subsequently used for petrochemical production to obtain mono-ethylene glycol (MEG) and terephtalic acid (TPA) or dimetyl terephthalate (DMT)[15]. These raw materials then go through a polymerisation process, which results in the production of polyester (PET – Polyethylene terephthalate) chips, filament yarn or staple fibres.

Polyester's production is not linear. The petrochemical industry is quite complex as it is responsible for the production and processing of several raw materials, which are used to produce a variety of products. Oil processing stages up to polymerisation can take place in either a single facility or at several independent facilities, some of which are very specialised in one product (e.g., ethylene, the main precursor of MEG).

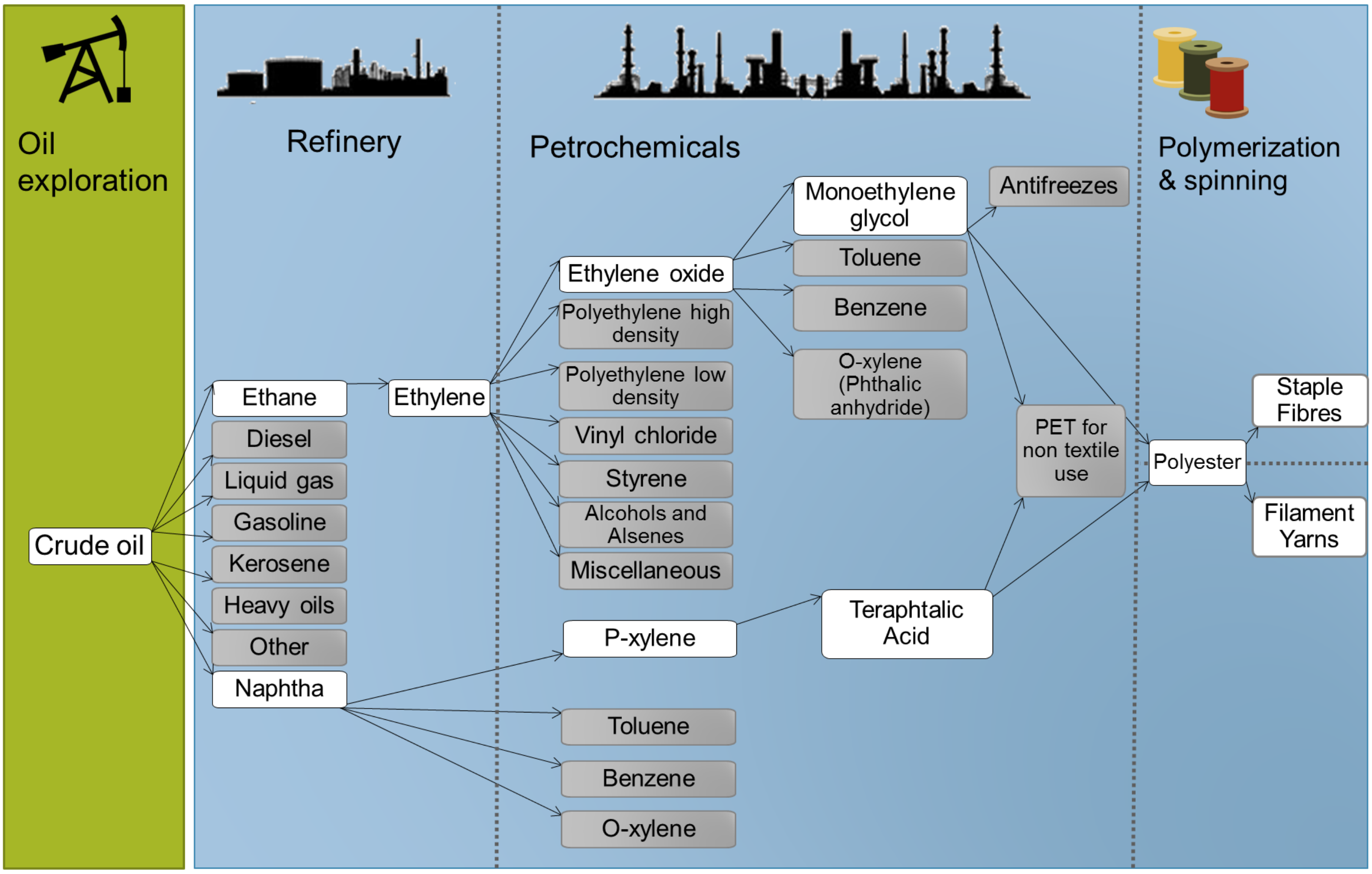
Some plants, such as Reliance's in India (one of the largest polyester fibre producers in the world) include all the processes from crude oil recovery to fibres, filament and chips production, along with the production of many other oil-based products.

[15] TPA is more commonly used than DMT due to several advantages of TPA over DMT (https://www.ihs.com/products/world-petro-chemical-analysis-pta-dmt.html), such as: about 15% percent less TPA is required per unit of polyester produced than DMT; bulk density of TPA is two times higher than DMT's and thus transportation costs and storage requirements for TPA are significantly lower. The largest polyester producers considered in this study and described below in this section, use TPA for PET production. Therefore, the current study focuses on polyester polymers production from TPA + MEG.

All of these aspects contribute to a very high level of complexity in the petrochemical industry, which makes mapping polyester's (and other chemicals) production system both at global or local levels a considerable challenge.

Assumptions

The polyester production system used in this study to calculate the water footprint of polyester is a sub-set of potential production scenarios for polyester fibres production, in which the raw material is onshore crude oil followed by three processing stages taking place at three different facilities: refinery, petrochemical and polymerization and spinning of polyester fibres and filaments. A simplified version of this production system is shown in Figure 5. This simplified production system does not reflect the reality of a given existing production chain, but rather a potential production scenario (see Annex 2 for specific on data assumptions).



Note: Each column represents a different step in the production system. Columns separated by dotted lines represent processes that were considered independent in the current assessment, but which can take place in shared facilities. White boxes highlight intermediate and final products used in the water footprint calculations, whereas grey boxes show products for other uses (details presented in Annex 2).

Figure 5 – Polyester production system

4.1 Polyester producers

The largest global polyester producers are listed in Table 2. Their operations include upstream petrochemical (polyester's raw materials, such as TPA), midstream polyester (PET) and downstream textiles (fibres/fabrics).

The combined polyester production capacity of Indorama, Reliance, Far Eastern New Century and Hengli Group totals almost 12 million tonnes/year and is equivalent to more than 20% of 2015's global polyester production for textile.

These four producers of polyester will be the geographic focus of this Water Footprint Assessment.

Table 2 – Largest polyester producers globally

Company	Annual production capacity	Countries of production
Indorama (includes Trevira)	4.3 million tonnes of polyester polymers: - 65,000 tonnes of polyester staple fibres - 100,000 tonnes of polyester filament yarns - 115,000 tones of polyester chips The company also produces spun yarns of different fibres including polyester and blends with polyester (capacity unknown) and grey fabrics (42 million metres per year).	Indonesia, Malaysia, India, Turkey, Sri Lanka, Senegal, Nigeria and Uzbekistan
Reliance (includes Recron Malaysia)	2.5 million tonnes of polyester staple fibre and filament yarn. The company also produces polyester polymers raw materials, namely Purified Terephthalic Acid (5,000,000 million tonnes), Ethylene Glycols (1.5 million tonnes of MEG) and Ethylene Oxide.	India and Malaysia
Far Eastern New Century (Far Eastern Group)	2 million tonnes of polyester chip, polyester staple fibres and filament yarns, PET bottles and PET films.	Taiwan, Southeast Asia and China
Hengli Group	2.6 million tonnes of Purified Terephthalic Acid and Purified Terephthalic Acid products (data uncertain with regards to specific polyester production capacity).	China

Sources: Companies' websites and http://www.tradekey.com/company/hengli-group-9415126.html

4.2 Polyester fibre manufacturing

Polyester fibres are manufactured by one of several methods. The method used depends on the form the finished polyester will take. The most common forms for the textile industry are filament and staple:

- In the filament form, each individual strand of polyester fibre is continuous in length, producing smooth-surfaced fabrics.

- In staple form, filaments are cut to short, predetermined lengths. In this form polyester is easier to blend with other fibres[16].

Both filament and staple fibre processing involves polymerisation (condensation polymerization of teraphtalic acid and monoethylene glycol) and melt spinning (fibres are spun and dried), which are similar processes for both fibres. In medium and smaller production facilities, there is usually an intermediate step of pelletizing (turning output products from polymerization into chips before melt spinning). However, large producers may integrate processes in order to produce the polyester melt with higher efficiency and higher output. This means the polymer melt is directly converted into the textile fibres or filaments without the intermediary step of pelletizing[17].

For filaments, chips are melted at 260-270°C to form a syrup-like solution. The solution is put in a metal container called a spinneret and forced through its tiny holes. The number of holes in the spinneret determines the size of the yarn, as the emerging fibres are brought together to form a single strand. At the spinning stage, other chemicals may be added to the solution to make the resulting material flame retardant, antistatic, or easier to dye. When polyester emerges from the spinneret, it is soft and easily elongated up to five times its original length. When the filaments dry, the fibres become solid and strong instead of brittle. Drawn fibres may vary greatly in diameter and length, depending on the characteristics desired for the finished material. Also, as the fibres are drawn, they may be textured or twisted to create softer or duller fabrics.

For staple fibres, in the melt spinning process, the spinneret has many more holes and the rope-like bundles of polyester that emerge are called tow. Newly-formed tow is quickly cooled in cans that gather the thick fibres. Several lengths of tow are gathered and then drawn on heated rollers to three or four times their original length. Drawn tow is then fed into compression boxes, which force the fibres to fold like an accordion. After the tow is crimped, it is heated to completely dry the fibres and set the crimp. Following heat setting, tow is cut into shorter lengths[18].

4.3 Water footprint accounting results

The water footprint of polyester was calculated considering the four steps of polyester's production system presented in Figure 5, and covering different production scenarios namely:

1. Oil exploration: onshore exploration[19]
2. Refinery processing: naphtha and ethylene production
3. Petrochemicals: MEG and TPA production
4. Fibres manufacturing, including two types of fibres:
    a. staple fibre

[16] http://www.madehow.com/Volume-2/Polyester.html#ixzz3vnSenDy3
[17] http://www.madehow.com/knowledge/Polyester.html#ixzz4glDEyQV1
[18] Length is defined by the fibres with which the polyester will be blended with. For instance, for blends with cotton it is cut in 3,2-3,8 cm pieces whereas for blends with viscose 5 cm lengths are cut. (http://www.madehow.com/Volume-2/Polyester.html#ixzz3vnfQ06qz)
[19] Oil exploration includes activities from exploratory drilling to oil production from wells.

b. filament yarn

Polyester does not have a green water footprint, since no plants are required for its production. The blue, grey and total water footprint range values[20] are presented in Table 3 and detailed information on data and water footprint of different processes are presented in Annex 2.

Table 3 – Water footprint of polyester fibres

		Water footprint (m^3/tonne)	
		Minimum	Maximum
Polyester Filament Yarns	**Blue**	**50**	**52**
	Grey	**50,640**	**70,981**
	Total	**50,690**	**71,033**
Polyester Staple Fibres	**Blue**	**30**	**32**
	Grey	**51,036**	**71,377**
	Total	**51,066**	**71,409**

The proportions between the blue and grey water footprint are shown in (Figure 6).

[20] Ranges derive from data for water footprint of onshore crude oil exploration which vary significantly with location, although differences between minimum and maximum polyester's water footprints end up not being as significant as in the raw materials processing.

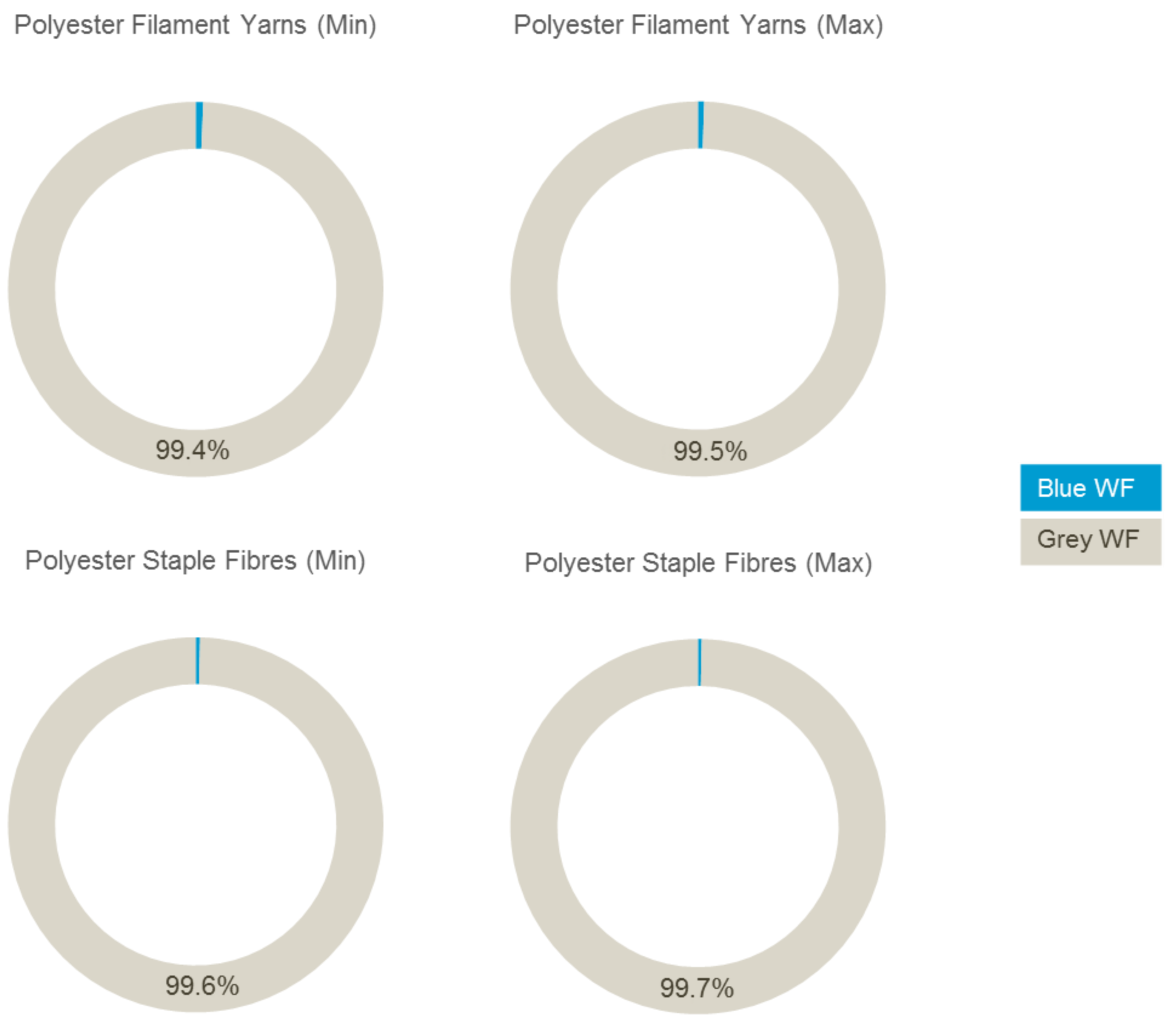


Figure 6 – Water footprint components for polyester fibres

4.3.1 Blue water footprint

The blue water footprint for polyester fibres primarily occurs during the fibre manufacturing stages. The total water footprint of polyester filament yarns is lower than that of polyester staple fibres, although not very significantly (around 1%). The blue water footprint however, is around 40% higher for polyester filament yarn than for staple fibres. This is due to the need for high temperatures and steam for melting the fibres during the spinning stage.

4.3.2 Grey water footprint

The grey water footprint for polyester comes from all production phases of the oil exploration and refinery phases.

The largest share of the water footprint of polyester is grey water footprint, representing over 99% of the total water footprint of polyester.

The grey water footprint was calculated based on the water quality parameters for which data was available at each production phase. Except for oil exploration, the grey water footprint of polyester process steps was determined using indicators for organic loads, chemical or biological (COD or BOD[21]). However, international best practice and environmental management guidelines – such as the World Bank Pollution Abatement Book and European Commission Reference Documents on Best Available Techniques[22] – refer to additional water quality indicators that need to be monitored and "controlled", in the respective industries. The water quality parameters used for grey water footprint calculations are presented in Table 4, as well as those that were excluded in this study due to lack of data.

[21] Indirect measure of the amount of organic compounds in water: BOD = Biochemical Oxygen Demand; COD = Chemical Oxygen Demand
[22] BREFs - Reference documents under the Integrated Pollution Prevention and Control Directive (IPCC, 2008/1/EC) and the Industrial Emissions Directive (IED, 2010/75/EU).

Table 4 – Water quality parameters associated with polyester production

Process steps	**Water quality parameters** used for grey WF calculations	**Other relevant water parameters** no data found
 Onshore crude oil exploration	**Benzene** Cadmium Benzo(a)pyrene Phenol Toluene Anthracene Naphthalene Copper Nickel Total xylenes Lead Arsenic	Oil and grease Dissolved and suspended solids BOD and COD Cadmium Chromium Lead Mercury
 Refinery	COD **BOD** Phenol Benzene Lead	Oil and grease Dissolved and suspended solids Chromium Benzo(a)pyrene Sulphide Nitrogen Thermal alteration
 Petrochemical	COD **BOD** Phenol Benzene	Oil and grease Dissolved and suspended solids Cadmium Chromium Copper Vinyl chloride Sulphide Nitrogen Thermal alteration
 Polymerization and spinning	**COD**	BOD

Note: The critical water quality indicator determining the grey water footprint results are in bold.

Sources: World Bank Pollution Abatement Book; European Commission BREFs.

For the oil exploration phase, the quality and handling of ‘produced water’ is the primary concern related to the grey water footprint. Produced water is water found in the same underground formations as oil and gas and is brought to the surface along with oil or gas. Produced water is the largest volume by-product or waste stream associated with oil and gas exploration and production. In the USA, produced water from oil and gas onshore activities was estimated at more than 3.3 billion cubic metres[23] in 2007 and on average, about 1 to 1.5 cubic metres of water are produced for every barrel of crude oil (~0.12 m^3), in onshore and offshore activities.

Produced water contains some of the chemical characteristics of the formation from which it was produced and associated hydrocarbons. Produced water properties (both physical and chemical) and volume vary considerably depending on the geographic location of the field, the geologic formation, the type of hydrocarbon product being produced, and the lifetime of a reservoir. For example, early in the life of an oil well, oil production is high and water production is low. As the production age of the well increases, the oil production decreases and the water production increases. When the cost of managing produced water exceeds the profit from selling oil, production is terminated and the well is closed.

Produced water contains varying quantities of heavy metals, volatile aromatic hydrocarbons (such as benzene, toluene and xylene) and a vast array of other potentially toxic compounds. In the current study, benzene in produced water from oil exploration is the highest contributor to polyester’s total water footprint (see Annex 2 for the grey water footprint results for oil exploration). Another important constituent of concern in onshore operations is the salt content of produced water. Some studies indicate that produced water is more saline than seawater[24] and therefore requires large quantities of water to dilute the salt concentration.

For oil exploration, additional water is often needed to maintain sufficient pressure in a reservoir, for which produced water may be used, but the water may also be supplied from other sources including groundwater and seawater. In such cases, chemicals are added to the water, such as corrosion and scale inhibitors, emulsion breakers, coagulants, and solvents. These additives can become part of the produced water and can affect its overall toxicity[25].

Strategies for managing produced water are driven by the value of the hydrocarbon resource. As produced water is viewed as a waste by-product to the oil and gas industry, historically, the most commonly practiced management strategies are aimed at disposal rather than beneficial use. The most common practices for produced water disposal include land application, or discharge to surface water, subsurface injection, and offsite trucking[26].

Produced water can be treated using a range of mitigation techniques including filtration, biological processes, and reverse osmosis before being reintroduced into the environment. All these methods entail financial investments and occur where environmental standards require these activities[27].

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[23] 21 billion bbl in original source; 1 bbl (US barrels) is equivalent to approximately 159 litres
[24] Produced water volumes and Management Practices in the United States. Agronne National Laboratory, 2009
[25] Produced Water Volumes and Management Practices in the United States. Agronne National Laboratory, 2009
[26] Oil and Gas Produced Water Management and Beneficial Use in the Western United States, USA Department of the Interior Bureau of Reclamation 2011
[27] Epstein, Paul R. and Selber, Jesse (Editors), 2002. OIL: A Life Cycle Analysis of its Health and Environmental Impacts. The Center for Health and the Global Environment, Harvard Medical School

4.4 Sustainability assessment

4.4.1 Geographic assessment

To assess the sustainability of polyester's water footprint, known production locations were mapped. This mapping was based on facility locations for the major polyester producers, namely Indorama, Reliance, Far Eastern New Century and Hengli groups. Due to the large amount of oil exploration sites in the world and the uncertainty of oil location sources for these groups, oil exploration is assessed to provide a broader perspective, however it is not included in the hotspot analysis.

The sustainability assessment was undertaken for the facilities listed in Table 5, and their locations are mapped in Figure 7.

Table 5 – Locations included in sustainability assessment of polyester production

Indorama Group	Facilities location	Type of production
Indorama petrochemicals	Port Harcourt City, Nigeria	Petrochemicals
Trevira	Two sites: Bobingen and Guben in Germany	Fibres production
Indorama Synthetics	Jatiluhur, Purwakarta, Indonesia	Fibres production
Filament yarns plant	Baddi, Himachal Pradesh, India	Filament yarns production
PET producing plant	Panipat, Haryana, India[28]	PET production
Reliance Group	**Facilities location**	**Type of production**
Jamnagar SEZ	Jamnagar, Gujarat, India	Refinery and petrochemicals
Recron Malaysia	Two production sites in Malaysia	Polyester production
Polyester filament yarn mill	India	Filament yarns production
Far Eastern New Century	**Facilities location**	**Type of production**
Oriental Petrochemical Corporation	Shanghai, China	Petrochemicals
FENC Fabrics plant	Pudong Zone, Shanghai, China[29]	Fibres production
Everest textile fabrics plant	Taiwan[30]	Fibres production
Chemical Fibre Plant	Taipei, Taiwan	PET and fibres production[31]
Hengli Group	**Facilities location**	**Type of production**
Fibres production mill	Shanghai, China	Fibres production

[28] Plant to be acquired by the group: http://www.borderless.net/indorama-to-acquire-pet-producer-in-india/
[29] Approximate location
[30] There are two other plants in Shanghai and Thailand, but exact location was not possible to determine
[31] Production type uncertain

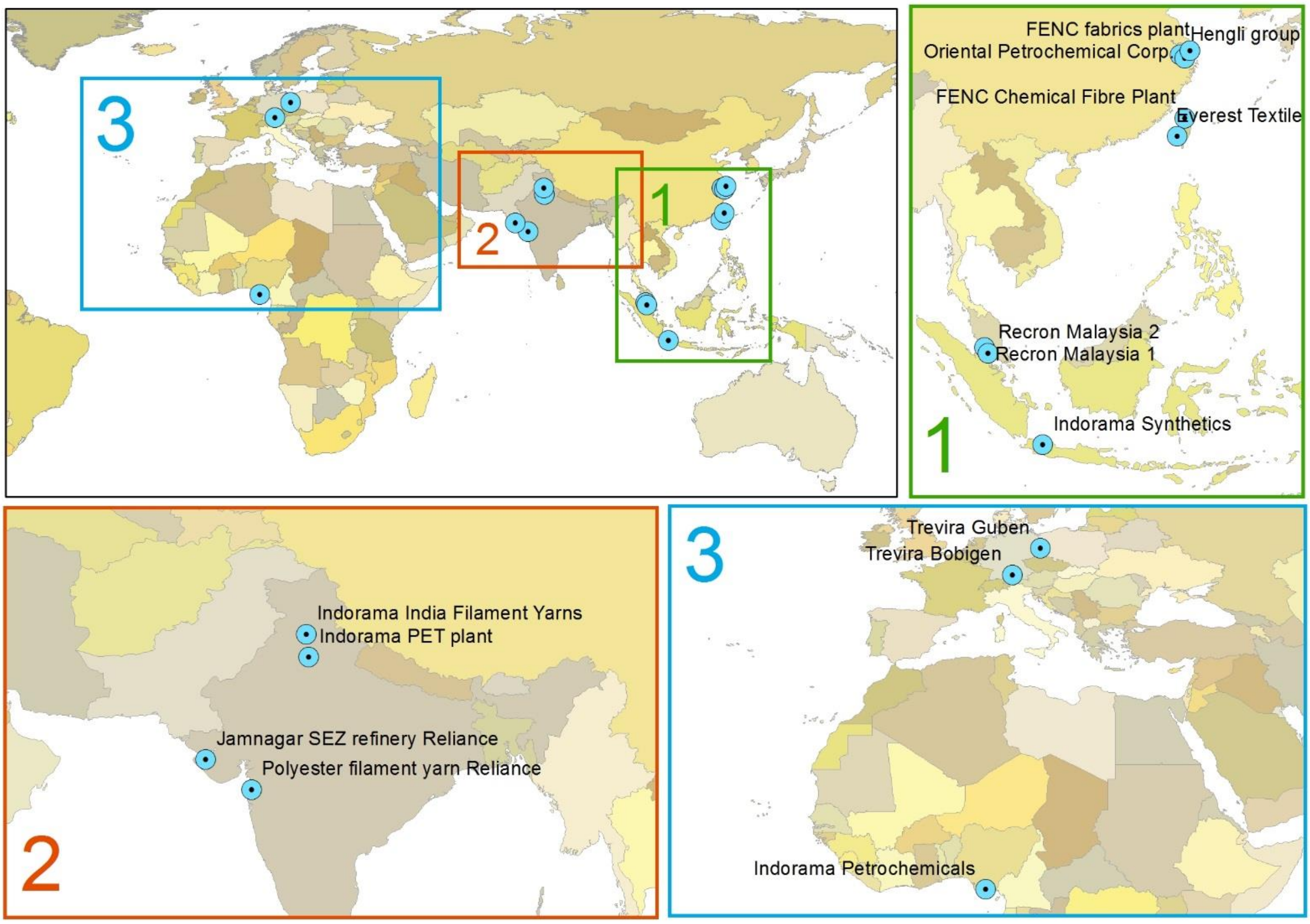


Figure 7 – Locations for sustainability assessment of polyester production

The level of blue water scarcity (BWS) and Water Pollution Levels (WPL)[32] for nitrogen and phosphorus were assessed for each location resulting in the identification of sustainability hotspots. Hotspots are locations where blue water scarcity and/or Water Pollution Levels (for nitrogen or phosphorus) exceed sustainable limits[33].

Further local water quality aspects relevant to polyester production stages were used in this analysis[34] to provide additional information on the severity of existing water quality issues at production facilities' locations. These indicators were not used as hotspot indicators, since they refer to comparative loads of each pollutant and are not based on freshwater ecosystem thresholds/ assimilation capacity[35].

The water quality indicators selected for the polyester sustainability assessment relate to polyester production emissions, namely:

[32] According to Mekonnen & Hoekstra, 2016
[33] Additional information available in Annex 1
[34] Based on Vörösmarty et al, 2010
[35] Additional information available in Annex 1

- Organic load (Labile carbon expressed as BOD): applicable to all stages of polyester production.
- Thermal alteration (increase in water temperature): applicable to all stages of polyester production except oil production.
- Potential acidification (Surface water acidification caused by deposition of nitrogen oxides [NO_X] and sulphur oxides [SO_X]): applicable to air emissions at refinery and petrochemical stages.

Results of the sustainability assessment and complementary analysis on water pollution are presented in Table 6.

Table 6 – Sustainability assessment for polyester related producers

Process step/Facility	BWS	WPL Nitrogen	WPL Phosphorus	Scarcity Hotspot	Pollution Hotspot	Organic load	Thermal alteration	Potential acidification*
Refinery & Petrochemicals								
Indorama Petrochemicals	Low	Low	Low	**N**	**N**	**High**	Low	Low
Reliance Jamnagar SEZ refinery	**Severe**	**Severe**	**Severe**	**Y**	**Y**	**High**	Low	**High**
Oriental Petrochemical Corporation	Moderate	**Severe**	Significant	**Y**	**Y**	**High**	Low	Low
PET processing & Fibres production								
Indorama Synthetics	Low	Low	Low	**N**	**N**	**High**	Low	**High**
Trevira Bobingen	Low	Low	Significant	**Y**	**Y**	Moderate	Low	Low
Trevira Guben	Low	**Severe**	**Severe**	**Y**	**Y**	Moderate	**High**	**High**
Reliance Polyester filament yarn mill India	**Severe**	Low	Significant	**Y**	**Y**	**High**	**High**	Low
FENC Chemical Fibre Plant	Low	Low	No data	**N**	**N**	**High**	Low	Low
FENC fabrics plant	Significant	**Severe**	Significant	**Y**	**Y**	**High**	Low	Moderate
Everest Textile	**Severe**	Low	No data	**Y**	**N**	**High**	Low	Low
Indorama Filament yarns plant, India	**Severe**	**Severe**	**Severe**	**Y**	**Y**	**High**	Low	**High**
Indorama PET producing plant, India	**Severe**	Significant	**Severe**	**Y**	**Y**	**High**	**High**	Low
Recron Malaysia 1	Low	Low	Low	**N**	**N**	**High**	Moderate	Moderate
Recron Malaysia 2	Low	Low	Low	**N**	**N**	**High**	Low	Moderate
Hengli Group fibres production mill	Moderate	**Severe**	Significant	**Y**	**Y**	**High**	Low	**High**

***Note**: Although it is likely that some of the production sites do not include petrochemical production activities, potential acidification was analysed for all locations, since it is not possible at this stage to identify which sites include PET production processing.

Ten out of 15 polyester production locations have one or more triggers for being a sustainability hotspot. Six out of 15 locations are in areas with severe or significant blue water scarcity. For nine out of 13 locations Water Pollution Levels are either significant or severe.

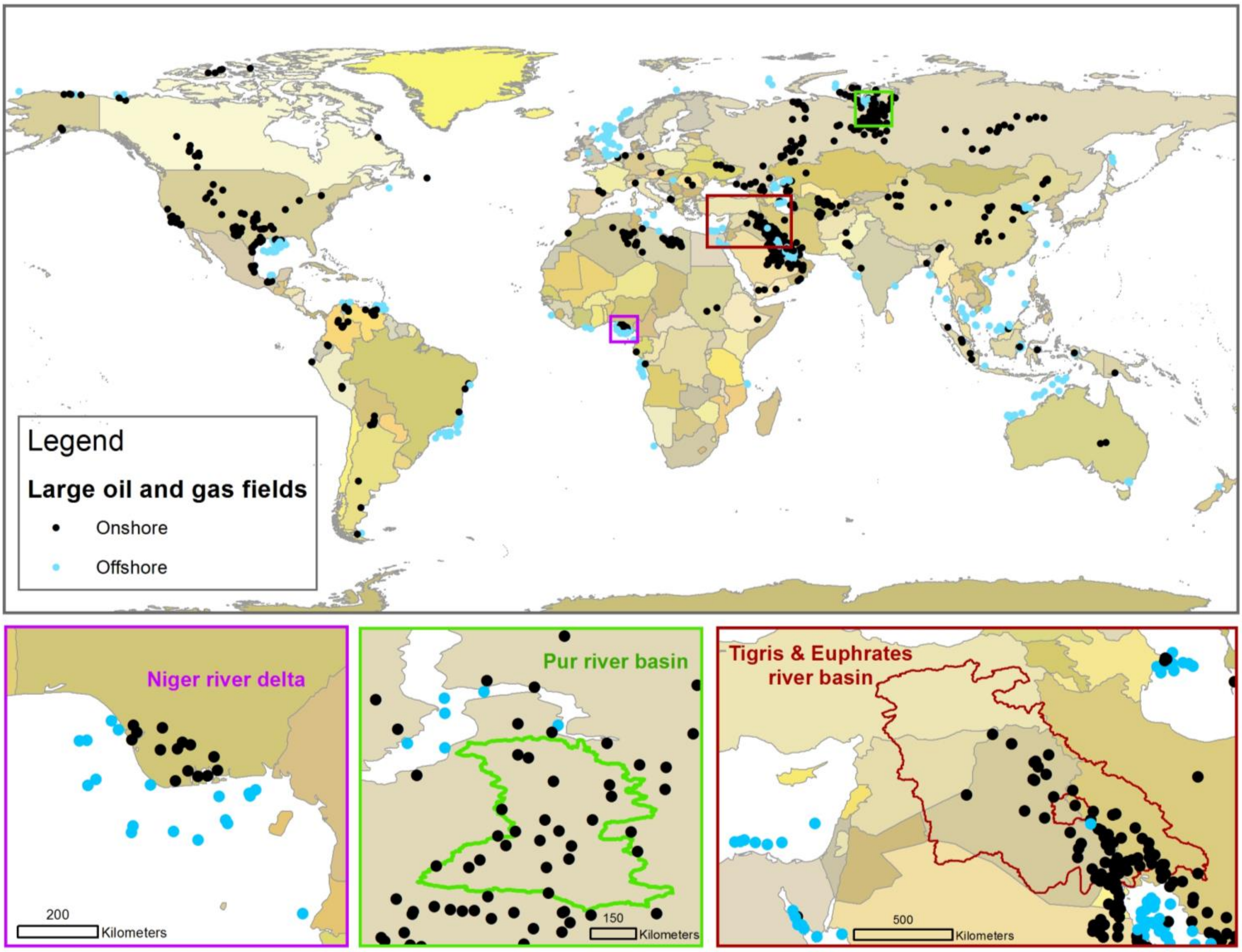
Except for Trevira mills in Germany where organic loads are moderate, organic loads in all locations are high, including the three sites not identified as hotspots based on blue water scarcity and Water Pollution Levels (Recron Malaysia and Indorama Synthetics fibres mills). Five locations have high potential acidification, whilst three are moderate. Most of the locations register a low thermal alteration (11 out of 15).

Indorama's filament yarn and PET plants in India, Reliance's refinery and filament yarn plant in India and FENC petrochemicals and fibre plants in China have all been identified as hotspots, and have potential additional water pollution problems due to organic loads and potential acidification.

The results of this analysis are of particular relevance considering that grey water footprint is by far the largest water footprint component of the total water footprint of polyester at all production stages. These results suggest that, even if only partially, the polyester production industry is contributing to the high levels of pollution in these areas. These companies should therefore work within their own operations to reduce their water footprint; and collectively with industry peers, other water users and local authorities to promote sustainable water use within the river basins they are operating.

Oil exploration

Due to the numerous possible origins of oil (see Figure 8 for the largest oil and gas fields in the world), and considering that only a small share of crude oil ends up in polyester production (around 1%), no hotspot checking for oil exploration was undertaken. It is likely that, even for Indorama and Reliance who conduct oil exploration and own refineries, oil for their polyester production is sourced from many different locations. In Reliance's corporate reports, for instance, there is a reference to crude oil purchased from Iran and South America.



Source: WorldMap, Center for Geographic Analysis, Harvard University

Figure 8 – Major oil and gas fields in the world

According to the International Energy Agency[36], the top oil producers in 2012 were: Russia and Saudi Arabia each with around 13% of the world's oil production, followed by the USA with 9% of the world's production. The Pur River basin in Russia and the Tigris & Euphrates River basin in Saudi Arabia, both containing a large concentration of oil fields, face severe blue water scarcity.

Indorama Petrochemicals in Nigeria likely sources their oil locally. Although the quantity of oil drilling in Nigeria is small compared to that done in many other nations, lack of regulatory bodies and dependence on oil for income have led to sub-standard production operations. Oil pollution from normal operations – including spills, accidents, leaks and waste discharges – has caused

[36] http://www.iea.org/publications/freepublications/

significant ecological damage to the Niger River delta. According to a 1995 report[37], at least 2,300 cubic metres of oil - from at least 300 spills - contaminates the Niger Delta region annually. Authors argue that this is the "official" number reported, but that the actual amount of oil spilled annually "may be 10 times higher".

4.4.2 Efficiency assessment

When the water footprint is measured in volumes of water consumed or polluted per unit of production, it is possible to understand how efficiently water is being used, i.e., are the production quantities as large as possible for the amount of water being used? The production water footprint, i.e., cubic metres of water per tonne of production, can be used to identify which practices and technologies result in the largest production quantities per unit of water.

Limitations

The production water footprint of polyester calculated in this study is based on available global data and not on specific producers or production sites. Therefore, it is not possible to compare this water footprint from this study against other production water footprints or benchmarks.

It is however possible to identify some of the processes and technologies that may contribute the most to polyester's water footprint efficiency. These are:

- Oil exploration phase: Produced water resulting from oil exploration is the greatest contributor to polyester's water footprint. Although the characteristics of produced water vary considerably with geology and local conditions, adequate water treatment of produced water before disposal will significantly reduce the grey water footprint.
- Refinery and petrochemical phases, including fibres production: Enhancement of wastewater treatment in the refinery and petrochemical industry will contribute to the reduction of the grey water footprint. Wastewater treatment in these industries varies substantially between facilities because of differences in local regulations and enforcement and local technological and financial capacity. Water recycling and the types of cooling water systems used also influence blue water footprint efficiency.

4.5 Conclusions

The blue water footprint for polyester primarily occurs during the fibre manufacturing stages, whilst the grey water footprint comes from all production phases with the oil exploration and refinery phases contributing the largest share.

While polyester can be manufactured from several raw materials, this study is focused only on onshore crude oil. Crude oil is currently the most common input raw material for polyester fibres,

[37] Moffat/Linden report (1995) in Epstein, Paul R. and Selber, Jesse (Editors), 2002. OIL: *A Life Cycle Analysis of its Health and Environmental Impacts*. The Center for Health and the Global Environment, Harvard Medical School

but it may also include other oil and gas sources. The study is also limited in assessing data from industrial processing phases, since many different processes occur at refineries and petrochemicals and not all of them are directly related to polyester's intermediate raw materials, but which were not possible to assess separately. Future studies should consider water footprints of various raw materials, including "produced water" management practices, polyester's specific raw and intermediate materials processing with different technologies and processes, and the use of recycled materials for polyester production.

Despite the limitations, the results from this assessment clearly indicate that grey water footprint is the largest component of polyester's water footprint, especially at the oil exploration phase due to "produced water", which is the largest by-product of these activities and often contains toxic pollutants that are not always properly treated before disposal.

Most refineries are already applying best available technology for blue water savings, especially in water scarce regions. However, in many sites, cooling water is not being recycled and not being accounted for as part of water consumption or wastewater. This cooling water may contribute to both the grey water footprint (temperature increase) and the blue water footprint (due to evaporation, or if it is returned in a different time and/or at a different place)[38].

Ensuring the application of best practices in the industry to reduce water consumption, but more importantly, in handling produced water and industrial effluents treatment and disposal, is crucial in reducing polyester's water footprint.

Despite the small role of polyester in the oil industry, the impacts of polyester's grey water footprint need to be acknowledged and addressed, especially when polyester already accounts for 55% of the total textile fibres production globally and is expected to keep growing.

The largest polyester fibre producers already own oil exploration and industrial processing operations for the entire fibre production process. For these corporate groups, the textile industry represents one of their main sources of income. There is therefore an opportunity for brands and retailers to start working collectively with these large producers to address their water impacts and risks in polyester production.

The sustainability of polyester's water footprint depends on where the processing stages take place and the specific processes and respective management practices used. If the water footprint is situated in a sustainability hotspot, it is not sustainable.

[38] Refineries and petrochemicals effluent temperatures can be up to 17º C higher than intake water (EC BREF, World Bank Pollution Abatement Handbook)

Two thirds of the locations in the polyester supply chain included in this study were in sustainability hotspots for either water scarcity, water pollution or both. Addressing unsustainable water use and management in sustainability hotspots is crucial in securing a sustainable supply chain.

Mapping polyester's full supply chain can be difficult, due to the complexity of its production system. Likewise, influencing and engaging directly with the first stages of polyester's supply chain (oil production and refinery/petrochemicals) may be limited due to the comparatively small role of polyester in the overall oil and petrochemical industries. However, considering that many garment producers source polyester fibres from the major producing groups, mapping the supply chain can be achieved if brands' and retailers' suppliers are sourcing materials from large integrated producers.

As many locations of the major polyester producers included in this study are in sustainability hotspots, it is important for C&A to map their polyester supply chain to more accurately assess the sustainability of their polyester sourcing and start working with their suppliers towards sustainable water use.

As previously stated, the results presented in this current study are based on onshore oil production for polyester's raw materials water footprint calculations. However, polyester may also be produced from other raw materials such as gas and, more importantly, unconventional resources. Shale gas is a rapidly growing sector, particularly in the USA and China, and this is likely to dominate the market in the future, becoming a major source for all petroleum-based products, including polyester.

Air pollution and hazardous waste are critical aspects of refineries, petrochemical and chemical fibres industry. These pollution and waste products are a source of acid precipitation and other toxins that enter the freshwater through rainfall, thereby increasing the grey water footprint. Hazardous waste is also a potential source of contamination for soil and water. The water footprint associated with these pollutants is not included in the current assessment, however may be an important component to consider in future assessments.

Polyester fibres may also be produced through either chemical or mechanical recycling of PET from bottles or garments. Regardless of the differences between the two types of processing used in producing recycled polyester fibres, these fibres may have a lower water footprint than virgin polyester. The production of recycled polyester fibres was not included in this study and could be an important area of further study.

5 Water Footprint Assessment of viscose

Viscose is derived from cellulose. The raw materials used for viscose production are diverse and include wood, cotton and bamboo. Currently, hardwood and softwood forests and plantations are the main source of cellulose used in viscose production. Wood cellulose is transformed into dissolving wood pulp and sold to fibre producers for either filament or staple fibres production[39].

Viscose production is growing globally with the largest share of dissolving wood pulp now being produced to make viscose for the apparel industry. Chinese government policies favour viscose, which has contributed to the boost in the market share of viscose fibres[40].

Although the current market share of viscose fibres is still relatively small when compared to cotton or polyester, increased production of viscose for the textile industry is expected in the coming years.

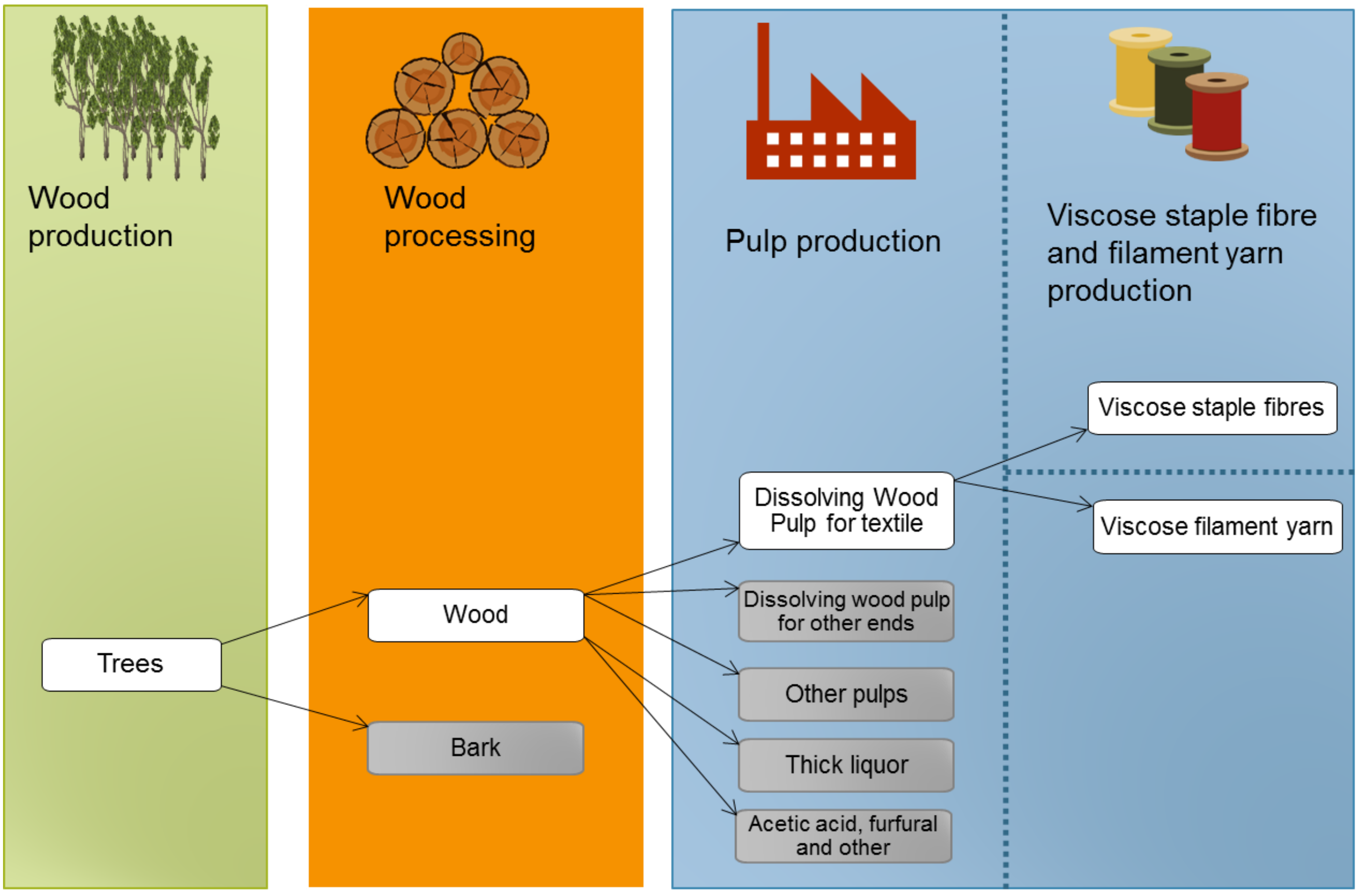
Other major end uses for dissolving wood pulp are also increasing, however not as quickly as viscose fibres. These alternative end uses include: acetate (for cigarette filters or plastics), ethers (wide range of uses like pharmaceuticals, food, oil drilling, etc.) and nitrocellulose (inks, explosives)[41].

Responding to this growing demand, several producers of cellulose for the paper industry are acquiring plantations and/or adapting their production facilities to produce dissolving wood pulp. Examples of these producers include Sodra, Rayonier, Sappi in South Africa and Grupo Jari in Brazil[42].

Assumptions

The viscose production system used in this study to calculate the water footprint of viscose is a subset of potential production scenarios for viscose fibres production, in which cellulose is sourced from eucalyptus plantations and pulp and fibres produced at the same facility; a simplified version of this production system is shown in Figure 12. This simplified production system does not reflect the reality of a given existing production chain, but rather a potential production scenario (see Annex 2 for specific on data assumptions).

[39] European Man-made Fibres Association: http://www.cirfs.org/
[40] http://www.tappi.org/content/events/11diss/fortin.pdf
[41] PCI Fibres Research Report 2009
[42] http://www.sodra.com/Documents/PDF/Finansiellt/eng/Sodra_Annual_Report_2013.pdf
https://doc.research-and-analytics.csfb.com/docView?language=ENG&source=ulg&format=PDF&document_id=868415111&serialid=RlW61pjP9ociuBYHuruLbq1cyvloQeGJbyddNySNO4U%3D



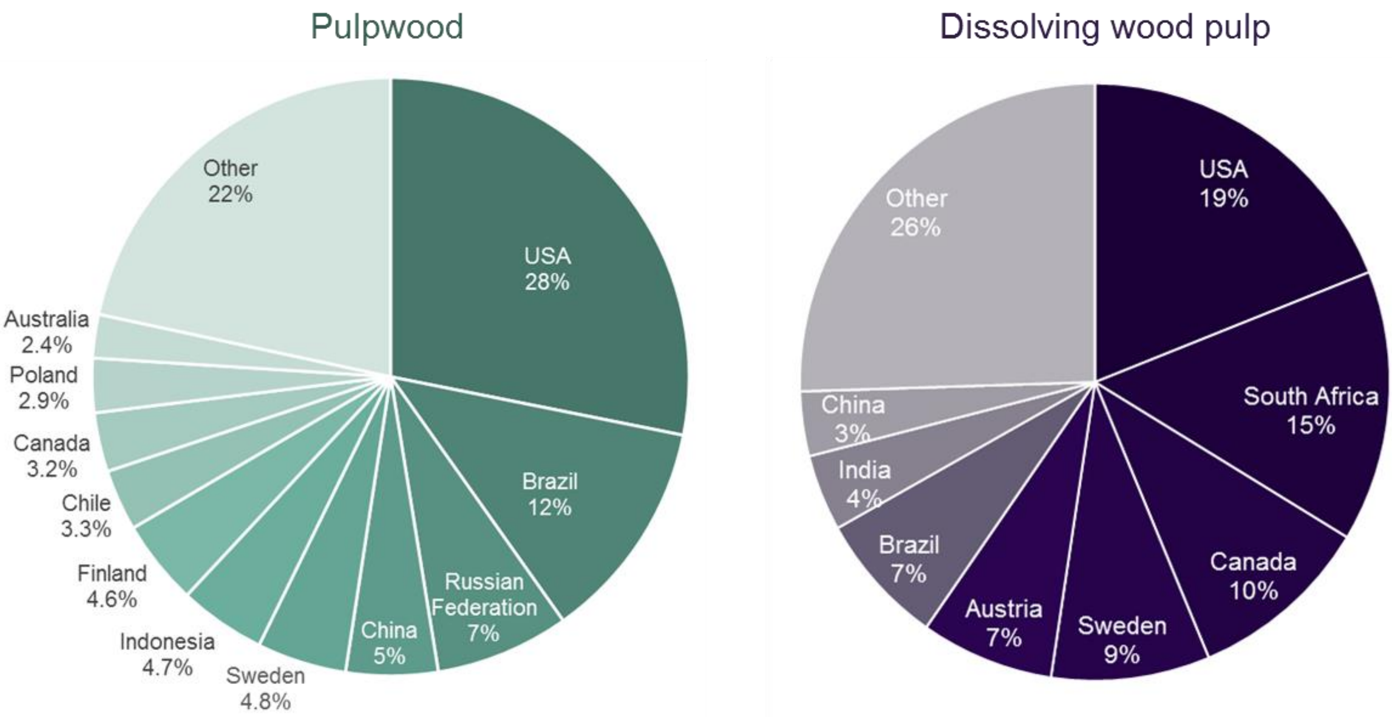
Note: Each column represents a different step in the production system. Columns separated by dotted lines represent processes that often take place at different facilities, but which were assessed in this study as integrated. White boxes highlight intermediate and final products used in the water footprint calculations, whereas grey boxes show products for other uses (details presented in Annex 2).

Figure 9 – Viscose production system

5.1 Viscose producers

Figure 10 presents the world's largest producers of pulpwood[43] (wood for pulp production) and the world's largest dissolving wood pulp producing countries in 2015, according to FAO statistics. More than half of global pulpwood production – which include not only dissolving wood used in viscose production, but also other types of pulp, for example, for paper production – takes place in the USA, Brazil, Russian Federation and China. Dissolving wood production is led by the USA, South Africa, Canada, Sweden and Austria.

[43] Under FAO category of "Pulp wood, round and split" which includes "Roundwood that will be used for the production of pulp, particleboard or fibreboard. It includes: roundwood (with or without bark) that will be used for these purposes in its round form or as splitwood or wood chips made directly (i.e. in the forest) from roundwood, coniferous and non-coniferous", according to FAO Forest Products Definitions http://www.fao.org/forestry/34572-02d9152c9571f5e09b9b54a76d37d47f3.pdf

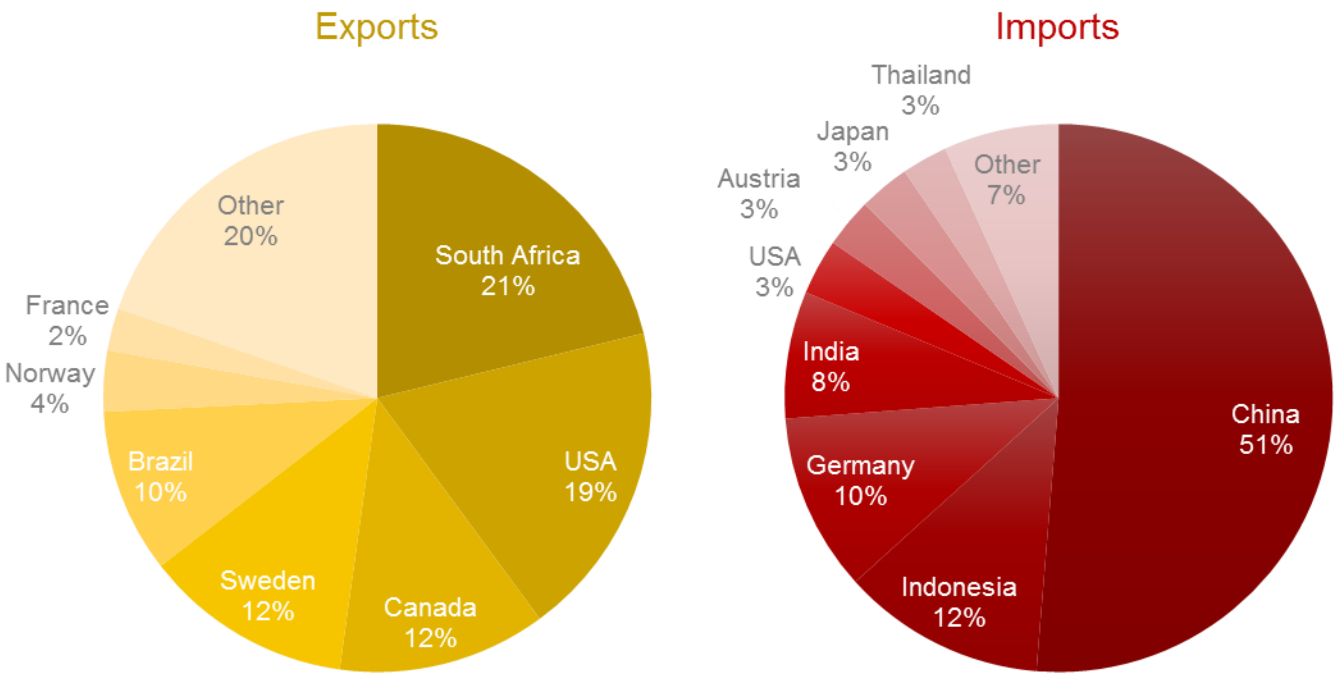


Source: FAO statistics: http://www.fao.org/faostat/en/#data/FO

Figure 10 – Major pulpwood and major dissolving wood pulp producers in 2015

Figure 11 presents the major dissolving wood pulp exporters and importers in 2015. This figure shows that 69% of the dissolving wood pulp produced globally is for export. South Africa and the USA are the biggest exporters and in 2015 accounted for 40% of the global export market followed by Canada, Sweden and Brazil with 34% of the global export market. The main importing region is Asia with China importing 51% of the global dissolving wood pulp production - China accounts for only 3.5% of global dissolving wood pulp production but for 51% of global imports due to its large viscose staple fibres production. In Indonesia, there is an ongoing investment in production of dissolving wood pulp[44].

[44] http://www.thejakartapost.com/news/2016/03/02/sinar-mas-prepares-launch-pulp-mill-year.html; https://www.wetlands.org/publications/joint-statement-on-asia-pulp-and-papers-oki-mill-in-south-sumatra-indonesia/



Source: FAO statistics: http://faostat3.fao.org/download/F/FO/E

Figure 11 – Major dissolving wood pulp exporters and importers in 2015

No data are available for pulpwood imports and exports, instead available trade data refer to roundwood trade, which may be used for other end products other than pulp production. It is therefore not a simple task to identify the origin of wood used for some of the largest dissolving wood pulp producers. Despite this, based on the data presented above and considering roundwood trade data[45] it is possible to understand the following:

- United States of America: the USA is the world's largest producer of wood for pulp production, the world's largest dissolving wood pulp producer and the world's second largest dissolving wood pulp exporter. It is therefore expected that most of the wood used for dissolving wood pulp production is produced in the USA and that both wood and pulp are exported from the USA for viscose fibres production elsewhere in the world. The main dissolving wood pulp producers and/or exporters importing wood from USA are China, Canada and India.
- South Africa and Brazil: Both countries are large dissolving wood pulp exporters, with South Africa being the top exporter and the second largest producer. Although South Africa is not amongst the largest wood producers, trade data indicate that both South Africa and Brazil are more likely to use national wood resources for dissolving wood production than for other uses.
- Canada and Sweden: Both countries are amongst the largest dissolving wood pulp producers and exporters in the world. They are both amongst the largest roundwood producers, however they also import significant volumes of wood (although the end use of the imported roundwood is not possible to identify). Canada mainly imports

[45] Industrial Roundwood trade data for 2012 and 2013 in FAO 2013, Yearbook of Forest Products

roundwood from the USA, and Sweden mainly from Norway, Latvia and the Russian Federation.

- Austria and India: These countries are amongst the largest dissolving wood pulp producers in the world with the data indicating that most of the wood is produced elsewhere. Austria mainly imports roundwood from Czech Republic, Germany and Slovakia. India mainly imports coniferous roundwood from New Zealand and the USA, and tropical roundwood from Malaysia, Myanmar, Papua New Guinea and Ghana.
- China: China is amongst the world's largest producers of wood for pulp production, accounting for 3.5% of global dissolving wood pulp production and is also the largest dissolving wood pulp importer in the world. The main countries exporting non-tropical wood to China are the Russian Federation, New Zealand, the USA and Canada; tropical roundwood is sourced from several countries, with the largest exporters found to be Papua New Guinea, Solomon Islands and Malaysia.
- Indonesia: The country is not amongst the largest roundwood exporters or importers in the available statistics. However, the country is amongst one of the largest wood for pulp producers with ongoing investments to expand pulp production and has the second highest rate of deforestation globally. Indonesia forests have been under the spotlight from many international organisations and numerous campaigns because of the destruction of Sumatra's natural forested area into land-use such as eucalyptus (for pulp production, including dissolving wood pulp for viscose fibres) and palm oil plantations[46].

The global dissolving wood pulp industry is highly concentrated and the key industrial players are Sappi, Aditya Birla, Lenzing, Bracell and Rayonier. In 2014, the total dissolving wood pulp capacity of these five producers accounted for about 53% of global production, with Sappi alone holding approximately 19% of global production capacity. A few years ago, Sappi shifted their full production to hardwood, moving from the paper industry to the textile industry, sourcing from eucalyptus plantations in South Africa and mills located in Mpumalanga and Kwazulu Natal provinces. Their customers are the largest viscose fibres producers in the world, including Lenzing, Aditya Birla Group and major producers in China. In 2009, Sateri Cellulose (currently Bracell[47]) supplied 40% of the dissolving wood pulp imports into China.

The largest global production companies for dissolving wood pulp (DWP) and viscose fibres are presented in Table 7.

[46] The Hot Button Issue - The CanopyStyle Report 2016: http://canopyplanet.org/wp-content/uploads/2016/10/The-Hot-Button-Issue-The-CanopyStyle-Report-2016.pdf

[47] Currently part of the Royal Golden Eagle Group, which also owns Sateri.

Table 7 – Dissolving wood pulp and viscose fibre producers

DWP producer	Annual production capacity (tonnes)	Country of pulp production	Wood	Main known pulp buyers	Annual viscose production capacity (tonnes)
Sappi	1,340,000	South Africa USA	90% Eucalyptus 10% Wattle	Lenzing, Austria Aditya Birla, India	See below
Aditya Birla Group	800,000	Canada Sweden Laos (still under expansion)	Canada: Birch, Maple and Aspen Laos: Eucalyptus Europe: softwood, primarily from Sweden and Latvia	Aditya Birla Group, India	620,000
				Shandong Yamei, China	260,000
Lenzing	567,000	Austria Czech Republic	Beech trees	Lenzing	753,000 (excluding Lyocell)
Rayonier	485,000	USA	Predominantly Loblolly Pine	Uncertain	
Bracell (previously Sateri Cellulose)	443,000	Brazil	Eucalyptus	Sateri, China	> 550,000 (1.6 million planned for 2020)
Unknown	Unknown	Unknown	Unknown	SanYou Chemical Industries, China	480,000

Sources: Sappi, AV Group, Rayonier, Bracell, Neucel, Lenzing, and SanYou Group websites and annual reports; "The hot button issue: The Canopystyle report 2016" in http://canopyplanet.org/resources/the-hot-button-issue-canopys-viscose-report/www.canopyplanet.org; FAO statistics (http://faostat.fao.org/); News and analysis websites assessed in 2014, 2015 and 2016[48]

Considering the tree types used in dissolving wood pulp production and the world's largest producers of dissolving wood pulp for the textile industry, and the necessity of limiting the focus of this study to a single raw material, this assessment focuses on eucalyptus plantations in Brazil (Bracell/Sateri) and South Africa (Sappi) as the source of raw material for viscose production.

[48] http://tembec.com/en/products/high-yield-hardwood-pulp
http://www.sodra.com/Documents/PDF/Finansiellt/eng/Sodra_Annual_Report_2013.pdf
https://doc.research-and-analytics.csfb.com/docView?language=ENG&source=ulg&format=PDF&document_id=868415111&serialid=RlW61pjP9ociuBYHuruLbq1cyvloQeGJbyddNySNO4U%3D
http://ppimagazine.com/mills/north-america/no-signs-market-dissolving
http://www.referenceforbusiness.com/history2/58/Buckeye-Technologies-Inc.html
http://www.researchinchina.com/Htmls/Report/2012/6337.html
http://www.helon.cn/html/20120621/n330218.html
http://ymkj.gmc.globalmarket.com/company.html
http://www.prnewswire.com/news-releases/global-and-china-dissolving-pulp-industry-report-2016-2020-300317383.html
"Roadmap to sustainable textiles and clothing: Eco-friendly Raw Materials, Technologies, and Processing Methods Series: Textile Science and Clothing Technology Muthu, Subramanian Senthilkannan (Ed.). 2014"

5.2 Viscose fibre manufacturing

Dissolving wood pulp production follows the following process steps:

1. Trees are harvested, peeled and cut into logs, usually where they are grown. The logs are then transported to the mill where they are chopped into small pieces (chips).
2. Chips then undergo a process of purification and separation of the wood fibres.
3. The resulting brown pulp is washed and cleaned through the process of cold caustic extraction, which increases the purity of the pulp.
4. The by-product of the washing process is a black liquor[49], which is evaporated and then burned in the recovery boiler. This burning generates steam used in turbines to produce electricity.
5. After cleaning and washing, the pulp is bleached with chemicals, upon which it is pressed and dried with hot air.

Fibre production uses the so-called ‘viscose process’ where the alkaline pulp is treated with carbon disulphide and dissolved by adding sodium hydroxide solution. A viscous orange-brown solution called ‘*viscose*’[50] where cellulose precipitates with carbon disulphide and the by-product hydrogen sulphide is released.

The viscose solution is next turned into fibre strings. This is done by forcing the liquid through a spinneret, which works like a shower-head, into an acid bath. In the acid bath, the acid coagulates and solidifies the filaments, now known as regenerated cellulose filaments. After being bathed in acid, the filaments are ready to be spun into yarn.

Similar to polyester, in the spinning process viscose can be turned into staple fibres or into filament yarns. In the filament form, each individual strand of viscose fibre is continuous in length, whereas in staple form, filaments are cut to short, predetermined lengths, making viscose easier to blend with other fibres. In the spinning process, if staple fibre is to be produced, a large spinneret with large holes is used. If filament fibre is being produced, then a spinneret with smaller holes is used. Staple fibres are cut into short pieces after the spinning bath. These short fibres, which are each approximately 4 cm long, are spun into textile yarns or processed into ‘non-woven’ products. In contrast, filament yarns are spun into long fibres which can be used immediately.

Staple fibres make up approximately 85% of total viscose fibre production, with filaments composing the remaining 15%[51]. The viscose staple fibres market is segmented into regular viscose fibres, used mainly in textile and non-woven applications, and specialty viscose fibres,

[49] “Black liquor” is the waste product from the process of digesting pulpwood into pulp removing lignin, hemicelluloses and other extractives from the wood to free the cellulose fibres. It can also be designated as "brown liquor” or “thick liquor” depending on the specific process. Approximately 7 tonnes of black liquor are produced in the manufacture of 1 tonne of pulp (Biermann, 1993). Early kraft pulp mills discharged black liquor to watercourses but nowadays its recovery for energy production. Pulp mills do not only have the capacity of generating part of their own energy needs, from black liquor and forest waste biomass, as they often sell energy to the local grid, when momentary energy production exceeds the mills’ needs.
[50] Or sodium cellulose xanthate
[51] EC BREF Polymers

which include flame retardant viscose fibre for bedding linings and high absorbency fibres for hygiene products, etc.

The viscose fibres considered for water footprint calculations are what is often referred as “regular rayon” or “conventional viscose”, produced by the ‘viscose process[52]’, and therefore do not include viscose fibres produced through other processes, such as cuprammonium or Lyocell[53], or with specific characteristics such as “High Wet Modulus” (modal) or “high tenacity rayon”.

The production system considered assumes that dissolving wood pulp and fibres are produced at the same facility[54]. Integrated production of pulp and fibres does not reflect the largest share of global production. However integrated production of pulp and fibres is becoming a trend amongst the largest viscose staple fibres producers, due to its benefits[55], such as the energy recovery[56].

5.3 Water footprint accounting results

The water footprint of viscose was calculated based on the three steps of viscose’s production system presented in Figure 9, and covering different production scenarios, namely:

1. Wood production, which include two scenarios:
    a. eucalyptus plantations in Brazil (Bracell/Sateri plantations)
    b. eucalyptus plantations in South Africa (Sappi plantations)
2. Wood processing, which includes the same scenarios as step 1; and
3. Dissolving wood pulp and viscose fibre production, which include the following scenarios:
    a. dissolving wood pulp production + viscose staple fibre production
    b. dissolving wood pulp production + viscose filament yarn produced with continuous washing
    c. dissolving wood pulp production + viscose filament yarn produced with batch washing[57]

The results are presented in Table 8 and detailed information on data and water footprint of different processes are presented in Annex 2.

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52 Process built on the reaction of cellulose with a strong base (sodium hydroxide), followed by treatment of that solution with carbon disulfide to give a xanthate derivative.
53 Lyocell production uses an organic solvent in the pulp solution, (instead of carbon disulphide and sodium hydroxide used in the ‘viscose process’) and a closed-loop system process, which recovers or decomposes most of the solvents and emissions.
54 The reason for adopting integrated production relates to the unavailability of independent production data, as presented in section 2.2. See Annex 2 for more information on data used, their assumptions and limitations
55 1)Grasim industries (part of Aditya Birla Group: Harihar unit houses a facility for the manufacture of both viscose staple fires and dissolving wood pulp. “The company’s rayon grade pulp plant was the first pulp manufacturer in India to use totally indigenous wood resources”. http://www.adityabirla.com/about/grasim-industries-viscose-staple-fibre-sector; 2)“Birla Lao Pulp & Plantations Company Limited (part of the Aditya Birla Group) “was established in 2006 as part of the Group's initiative to achieve complete backward integration for the viscose staple fibre business” http://www.adityabirla.com/businesses/Profile/Birla-Lao-Pulp-and-Plantations-Company-Limited; 3) Sateri Viscose International is building the first integrated viscose fibre factory in Indonesia, which is expected to be completed in 2018 http://www.thejakartapost.com/news/2016/11/21/rge-group-operate-integrated-viscose-fiber-factory-2018.html
56 Excess of energy produced in pulp production can be used in fibres production.
57 Filament yarns can be produced with different washing methods: continuous or in batches. Continuous washing requires larger amounts of zinc input.

Table 8 – Water footprint of viscose

		Water footprint (m^3/ton)	
		Wood from plantations in Brazil	Wood from plantations in South Africa
Viscose staple fibres	**Green**	**33**	**55**
	Blue	**156**	**156**
	Grey	**489**	**786**
	Total	**678**	**996**
Viscose filament yarn from continuous washing	**Green**	**33**	**55**
	Blue	**370**	**370**
	Grey	**30,192**	**30,489**
	Total	**30,596**	**30,914**
Viscose filament yarn from batch washing	**Green**	**33**	**55**
	Blue	**80**	**80**
	Grey	**3,192**	**3,489**
	Total	**3,305**	**3,624**

Based on the data available for this study, the process step that contributes the most to the total water footprint of viscose is dissolving wood pulp and fibre production, which has the highest blue and grey water footprint components. Viscose staple fibres have the lowest water footprint, whereas the highest water footprint occurs in the production of filament yarns produced with continuous washing (see Annex 2 for details).

The relative contribution of the different water footprint components to viscose's total water footprint is presented in Figure 12.

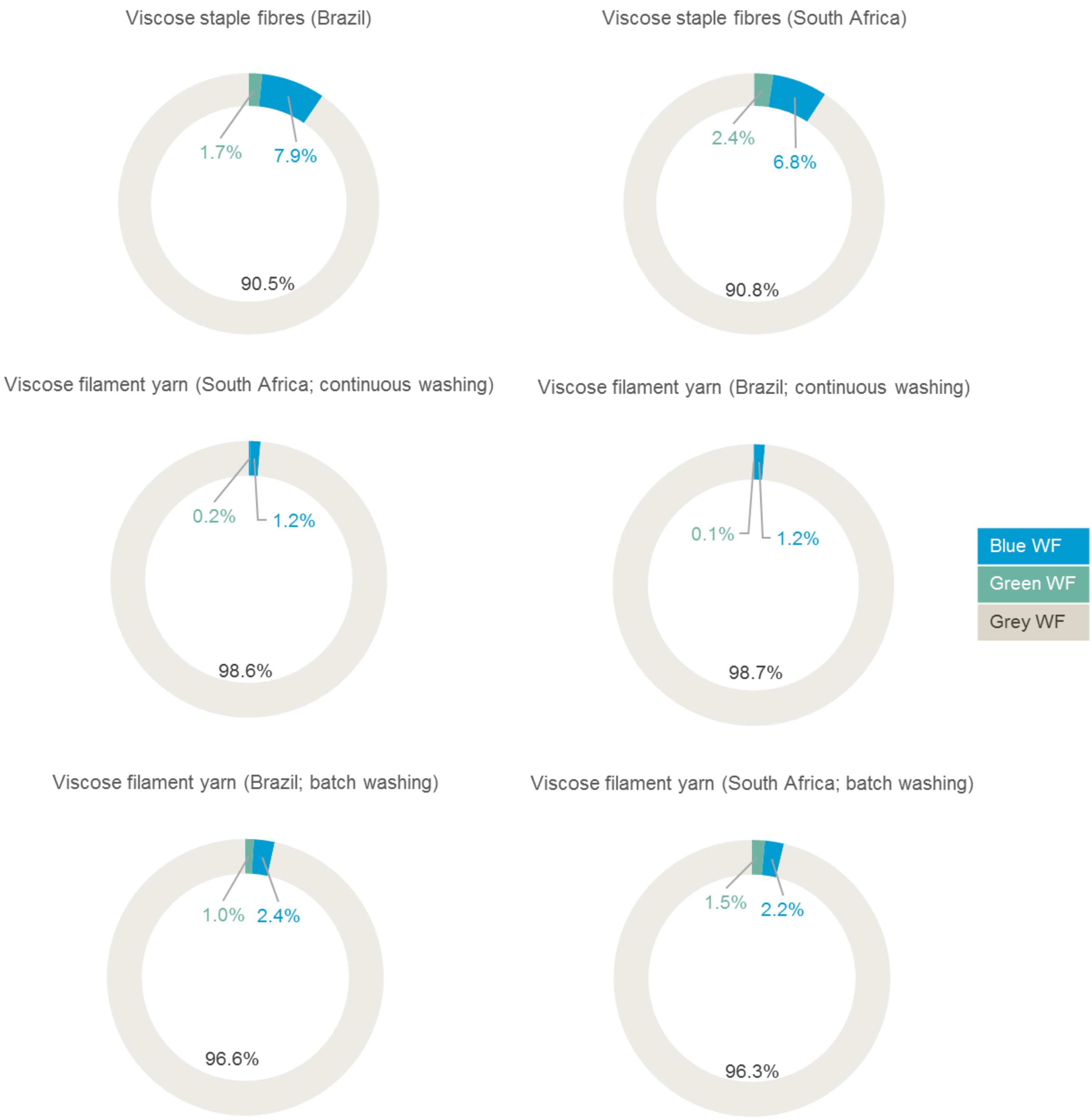


Figure 12 – Water footprint components of viscose

5.3.1 Green water footprint

The green water footprint of viscose is associated with the wood production phase. From all water footprint components of viscose, the green water footprint has the lowest contribution to the overall total water footprint. Nonetheless, it is important to note that the green water footprint is associated to the land on which wood is grown and therefore maximising its efficiency promotes sustainable land use development.

The water footprint of the wood production stage includes a consumption water footprint (evapotranspiration), which in this study only includes a green water footprint as there was no evidence of irrigation (blue water footprint) being used[58].

The green water footprint of eucalyptus plantations in South Africa is larger than in Brazil, which is very likely to be related to the local natural conditions, such as climate and soil, but also to the species used and the total growth period, which is shorter in Brazil.

5.3.2 Blue water footprint

The blue water footprint of viscose is the largest for filament yarn production with continuous washing, being around two times larger than the blue water footprint of staple fibres and almost five times larger than filament yarn production with batch washing, because of higher zinc inputs in the process, consequently generating higher loads of zinc in effluents.

For wood processing, there is a blue water footprint associated with wood washing before entering the mills' facilities. However, no data were available for the amounts of water required for wood processing, and therefore it was assumed to be zero. Wood processing was nonetheless included in the water footprint calculations, due to the significance of product fractions involved, since only part of the wood is used for pulp production.

Dissolving wood pulp is generally produced close to wood sources. However, fibre producers often purchase dried dissolving wood pulp produced elsewhere, and rehydrate it at the fibre production destination. As it was only possible to obtain data for mills where pulp and fibres are produced in the same mill, these calculations underestimate the water footprint of fibres produced in a location different to that of the pulp production. When pulp is produced at a different location than the fibre mills, it must be dried for transport and rehydrated again with water for fibre production, which adds to the consumption water footprint.

5.3.3 Grey water footprint parameters

Similar to polyester, the grey water footprint contributes the largest share of the total water footprint of viscose for all stages of production, including the wood production stage.

[58] In Bracell/Sateri plantations irrigation is applied in the first development stages of eucalyptus, but there is a reference to "gel irrigation" and it was not possible to obtain data that allowed accounting for the associated blue water footprint.

Filament yarns produced with continuous washing have a significantly higher water footprint; it is 10 times higher than filament yarns produced with batch washing and more than 15 times higher than the water footprint of staple fibres.

This is due to the grey water footprint of the continuous washing process, which is responsible for a high level of zinc emissions in effluents. Differentiated data on pulp production and fibre production would allow a more detailed analysis of the individual processes contributing to the water footprint.

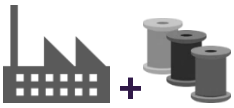
Relevant water quality indicators for viscose's different production system steps and those used in calculating the grey water footprint are presented in Table 9. Data were only available for calculating the grey water footprint based on nitrogen at the wood production stage and COD and zinc for the dissolving wood pulp and fibres production stage.

For plantations, the grey water footprint is associated with the application of nutrients such as nitrogen and phosphorus. While pesticides may be used, and would therefore contribute to the grey water footprint, no data was available to include them in these calculations. Likewise, due to lack of data, no grey water footprint was calculated for the wood harvesting and processing stage or for other relevant water quality parameters.

AOX compounds[59] which are particularly relevant to viscose production as they result from pulp bleaching and can have toxic effects for humans and the aquatic environment, were not included in the grey water footprint calculation. Data was only available for total AOX emissions in effluents, which could not be used in the calculation since water quality standards differentiate contributors to AOX and the maximum allowable concentrations vary substantially.

[59] AOX = Adsorbable organic halogens = organic sum parameter comprising such organics that contain chlorine, bromine or iodine atoms and are adsorbable to activated carbon

Table 9 – Water quality parameters used for grey water footprint calculations

Process steps	**Water quality parameters** (used for grey WF calculations)	**Other relevant water parameters** (data unavailable)
 Wood production (Eucalyptus plantations)	**Nitrogen**	Phosphorus Pesticides
 Wood processing	N/A	Organic matter (BOD and/or COD) Suspended solids
 DWP + staple fibres/filament yarns	COD **Zinc**	AOX compounds BOD Hydrogen sulphide Metals (Fe, Mn, Mg, Al) Total Ammonia Thermal alteration

Note: Critical water quality indicator for grey water footprint results are in **bold**.

Sources: World Bank Pollution Abatement Book; European Commission BREFs.

The critical water quality indicator for the grey water footprint of dissolving wood pulp + viscose staple fibres and filament yarns production is zinc[60]. Zinc load is much higher in filament yarn production, especially with continuous washing. COD is also present in effluents for all processes and is also much higher in filament yarn production with continuous washing followed by staple fibres production and filament yarn production with batch washing.

5.4 Sustainability assessment

5.4.1 Geographic assessment

To assess the sustainability of viscose's water footprint, known production locations for Sateri and Sappi groups were used. These locations are presented in Table 10 and in Figure 13. For this study, it was assumed that dissolving wood pulp produced by Sappi was used at Lenzing and Aditya Birla viscose fibres mills.

The locations of eucalyptus plantations were mapped according to information found on companies' websites and using maps of each country's vegetation patterns. The actual

[60] Zinc sulphate is used in the production of both viscose staple fibres and viscose filament yarns. During spinning, viscose is pressed through the spinnerets into the spinning bath that contains sulphuric acid which decomposes the xanthate and zinc sulphate.

locations may vary slightly from those used in this study. Mill locations were determined from information available at companies' websites and confirmed with aerial imagery.

Table 10 – Locations for sustainability assessment of viscose production

Sateri Group	**Facilities location**	**Type of production**
Bracell Eucalyptus plantations	Brazil	Wood
Bracell Mill	Brazil	Dissolving wood pulp
Sateri Fujian	China	Fibres production
Sateri Jiangxi	China	Fibres production
Sappi Group	**Facilities location**	**Type of production**
Eucalyptus plantations	South Africa	Wood
Ngodwanna mill	South Africa	Dissolving wood pulp
Saiccor mill	South Africa	Dissolving wood pulp
Lenzing mill (Lenzing)*	Austria	Fibres production
Purwakarta mill (Lenzing)	Indonesia	Fibres production
Nanajing mill (Lenzing)	China	Fibres production
Birla Jingwei fibres (Aditya Birla)	China	Fibres production
Indian Rayon Compound (Aditya Birla)	India	Fibres production
Thai Rayon (Aditya Birla)	Thailand	Fibres production
PT Indo Bharat Rayon (Aditya Birla)	Indonesia	Fibres production

*__Note__: Lenzing mill also includes dissolving wood pulp production. However cellulose raw materials are different and therefore, under the scope of this analysis it included in the locations of viscose fibres' production

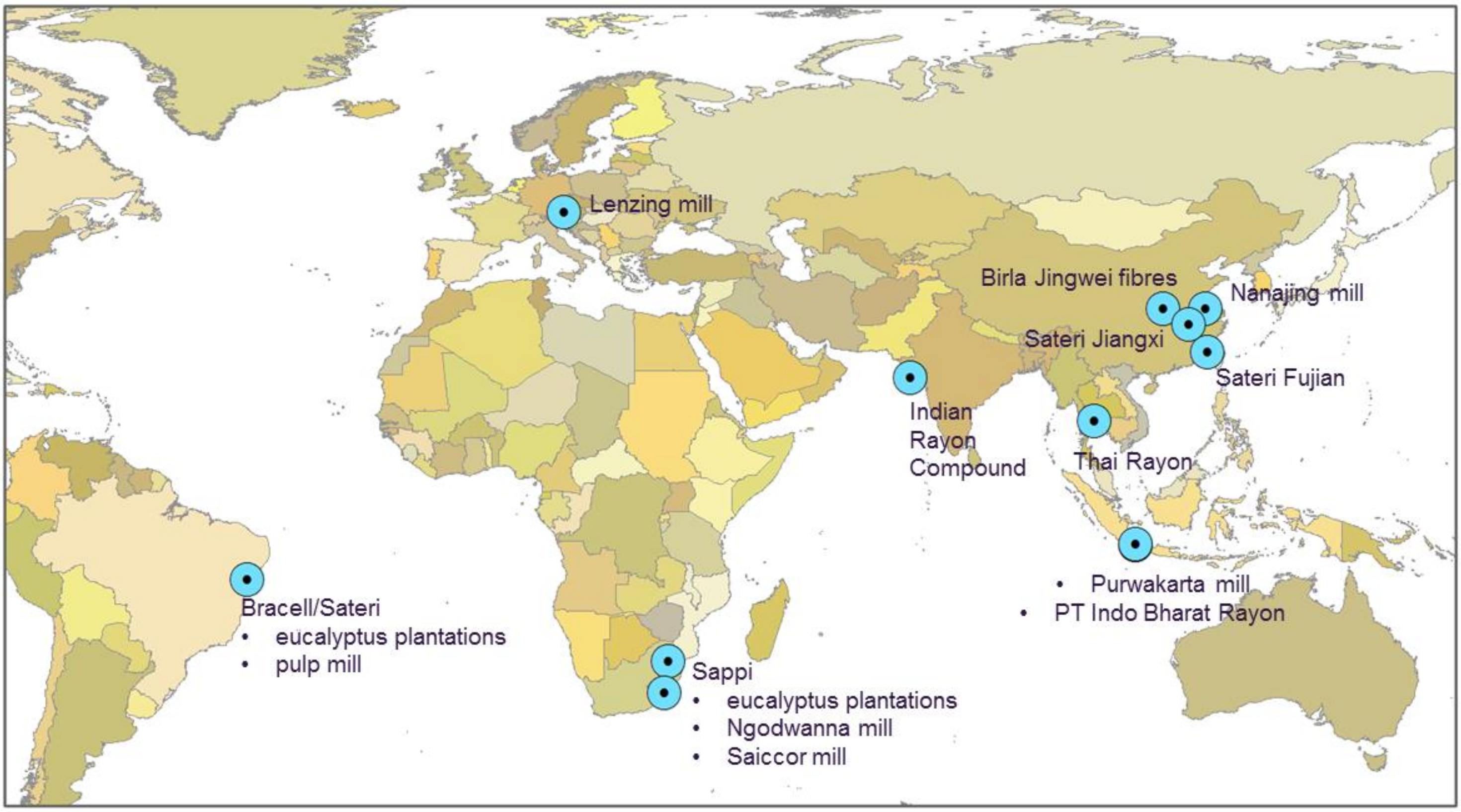


Figure 13 – Sites used for the sustainability assessment of viscose production

Blue water scarcity (BWS) and Water Pollution Levels (WPL)[61] for nitrogen and phosphorus were assessed for each location resulting in the identification of sustainability hotspots. Hotspots are locations where blue water scarcity and/or Water Pollution Levels exceed sustainable limits, meaning that either environmental flow requirements and/or water quality standards are not being met[62].

As with polyester, additional local water quality aspects relevant to viscose production stages were used in this analysis[63] to provide additional information on the severity of existing water quality issues at production facilities' locations[64].

The selected water quality indicators are:

- Organic load (Labile carbon expressed as BOD): applicable to all stages of viscose production;
- Pesticide loading (based on country-level data on pesticide application to croplands): applicable to wood production stage;
- Sediment loading (total suspended solids based on predicted annual water erosion rates): applicable to wood production and processing stages; and

[61] According to Mekonnen & Hoekstra, 2016
[62] Additional information available in Annex 1
[63] Based on Vörösmarty et al, 2010
[64] Additional information available in Annex 1

- Thermal alteration (increase in water temperature): applicable to wood pulp and fibre production.

Results of the sustainability assessment and complementary analysis on water pollution are presented in Table 11. Since tree plantations cover more than one unit of analysis for blue water scarcity and Water Pollution Levels, both the highest value and the most commonly occurring value are presented.

Table 11 – Sustainability assessment for viscose producers

Site		BWS	WPL Nitrogen	WPL Phosphorus	Scarcity Hotspot)	Pollution Hotspot	Sediment loading	Pesticides	Thermal alteration	Organic load
Eucalyptus plantations										
Brazil Sateri/Bracell	Highest	Significant	Significant	Significant	Y	Y	**High**	**High**	N/A	**High**
	Predo-minant	Significant	Significant	Significant			**High**	**High**	N/A	**High**
South Africa Sappi	Highest	**Severe**	**Severe**	**Severe**	Y	Y	**High**	**High**	N/A	**High**
	Predo-minant	Low	Significant	Significant			**High**	**High**	N/A	**High**
Dissolving wood pulp										
Sateri DWP mill (Bracell)		Significant	Low	Significant	**Y**	**N**	N/A	N/A	Low	**High**
Sappi DWP mill – Ngodwanna		Low	Low	Significant	**N**	**Y**	N/A	N/A	Low	Moderate
Sappi DWP mill 2 – Saicor		Low	Low	Significant	**N**	**Y**	N/A	N/A	Low	**High**
Fibres production										
Sateri Jiangxi fibre production		Low	**Severe**	Low	**N**	**Y**	N/A	N/A	Moderate	**High**
Sateri Fujian fibres		Significant	Low	Significant	**Y**	**Y**	N/A	N/A	Low	**High**
Lenzing mill (Lenzing)		Low	Low	**Severe**	**N**	**Y**	N/A	N/A	Low	Low
Purwakarta mill (Lenzing)		Low	Low	**Severe**	**N**	**Y**	N/A	N/A	**High**	**High**
Nanajing mill (Lenzing)		Low	**Severe**	**Severe**	**N**	**Y**	N/A	N/A	**High**	**High**
Birla Jingwei fibres (Adytia Birla)		Low	Significant	**Severe**	**N**	**Y**	N/A	N/A	Low	**High**
Indian Rayon Compound (Adytia Birla)		Low	**Severe**	**Severe**	**N**	**Y**	N/A	N/A	Low	**High**
Thai Rayon (Adytia Birla)		**Severe**	Low	**Severe**	**Y**	**Y**	N/A	N/A	**High**	**High**
PT Indo Bharat Rayon (Adytia Birla)		Low	Low	**Severe**	**N**	**Y**	N/A	N/A	**High**	**High**

All locations across all stages of viscose production assessed in this study are in a sustainability hotspot, indicating that either environmental flow requirements and/or water quality standards are being violated.

Eucalyptus plantations in both South Africa and Brazil are in hotspots. Plantations in South Africa are in areas that have severe levels for both blue water scarcity and Water Pollution Levels, whereas in Brazil, eucalyptus plantations are in areas with significant blue water scarcity and Water Pollution Levels. In addition to being located in hotspots for water scarcity and pollution levels, high levels of sediment, organic loads and pesticides are also found in these locations.

With regard to pulp mills and fibre production sites, blue water scarcity is severe in Thai Rayon and significant in Sateri's pulp mill in Brazil and Sateri Fujian fibre mill in China. Water Pollution Levels, either for phosphorus and/or nitrogen, are severe or significant in all pulp and fibre mills locations, and organic loading is high in all mill locations except for Sappi's Ngodwanna mill where it is moderate.

5.4.1 Efficiency assessment

As previously stated for polyester, the production water footprint can be used to identify which practices and technologies result in the greatest amount of product per unit of water.

Limitations

The water footprints of viscose's production calculated in this study are based on available global data and not on specific producers or production sites, except for the wood production stage, which has some data limitations. Therefore, it is not possible to compare the production water footprints in this study against other water footprints or benchmarks.

It is however possible to make some comparisons between the production water footprints that were calculated and identify some of the processes and technologies that can contribute to improving viscose's water footprint efficiency. These are:

- Wood production stage:
    - Grey water footprint efficiency: The grey water footprint of the wood production stage relates to chemicals used as fertilisers in plantations. The water footprint calculations for eucalyptus plantations in South Africa and Brazil were based on average application loads of nitrogen in the two regions. Managing the application of nitrogen to limit the amount that is leached or runs off from the soil may reduce the grey water footprint. It is important to note that pesticides are likely to increase the grey water footprint; care must be taken in selecting and applying pesticides as part of grey water footprint management. Forestry management practices and wood processing practices such as soil erosion prevention and adequate management of organic waste may play an important

    - role in grey water footprint efficiency in the wood production stage (note: it was not possible to determine this within this study).
    - Green and blue water footprint efficiency: Eucalyptus plantations in Brazil have a more efficient green water footprint than plantations in South Africa, which is likely related to local conditions, such as climate and/or soil. However, plantations in Brazil are irrigated (blue water) in the earlier stages of the plants' development, which could mean that green+blue water footprint efficiency may not be higher than South African plantations. Natural forests and other platantions, depending on management practices, are likely to have different water footprint efficiency (both green+blue and grey) than intensive plantations of non-indigenous species. This analysis was not covered in the present study.
- Dissolved wood pulp production:
    - Grey water footprint efficiency: Dissolved pulp production generates "waste" which is often used as by-products (for energy production in the facility and/or sold for other uses). Pulp production technologies that allow recovery of such products have greater water footprint efficiency (e.g. reduction/elimination of sulphate loads in effluents or reduction of toxic air emissions responsible for water acidification). Pulp bleaching may generate AOX compounds in effluents, depending on the pulp bleaching technology applied. Reducing or eliminating these may lead to greater grey water footprint efficiency. Pulp production generates significant loads of organic matter in effluents (COD, BOD). These can be reduced by applying improved wastewater treatment technologies.
- Viscose fibres production:
    - Grey water footprint efficiency: The results of this study show that the water footprint of staple fibres is more efficient than filament yarn's water footprint. However, additional data and analysis is needed to confirm these results, due to data limitations in this study. Grey water footprint efficiency is related to processes applied and wastewater management and these do not necessarily always relate to final product. Zinc loads in wastewater depend on the spin bath recovery technology applied, sulphate loads depend on the use or disposal of by-products, and organic matter loads and other emissions to water depend on the type of wastewater treatment.

Viscose's water footprint varies significantly according to the industrial processes applied to pulp and fibre production. It is important to note that a certain process may be applied due to the specific output products (e.g. staple or filament yarn; fibre specific properties) or because of other trade-offs, like energy consumption or air emissions[65]. Hence, it may not always be possible to replace one production technique with another to achieve a smaller water footprint.

[65] Pulp and viscose fibres production are energy consumptive processes, with a significant carbon footprint and also hazardous air emissions.

5.5 Conclusions

The size and sustainability of viscose's water footprint will depend on what processes are applied, the respective management practices and where the processing stages take place.

This study is limited in scope to considering only eucalyptus plantations as the raw material input for viscose, which is a common raw material, but it is often mixed with other wood sources. The study is also limited in assessing data from integrated production of pulp and fibres, which is common within some facilities of the largest producers, but does not reflect the majority of current viscose production. Future studies should consider water footprints of various raw materials (including forest/cultivation management practices and raw materials processing; and the use of recycled materials), non-integrated production of dissolved wood pulp and fibres, and different industrial processes and technologies for pulp and fibres production.

Despite data limitations, the results clearly show that the grey water footprint is the largest contributor of viscose's total water footprint. Currently, most of the largest producers are already applying best available technologies for blue water savings in processing, especially in developed countries where steam recovery and water recycling systems are often adopted. Likewise, in developed countries pulp production by-products, such as thick liquor and furfural are recovered and turned into commercially valuable products or used for the mill's energy generation. In pulp and fibres integrated production, there is also a series of environmental benefits, such as the use of energy generated for pulp production being used in the production of fibres or the fact that pulp does not have to be dried and transported to a different location for fibre production.

However, the growing viscose market is currently located in countries with limited regulations or enforcement such as China, India and Indonesia. For these countries, there is almost no information available about practices and techniques adopted in dissolving wood pulp or viscose fibres mills and it is not possible to know which management practices are being applied.

Regarding green water footprint in wood production, the water footprint accounting results show a lower green water footprint in Brazil[66]. This may in part be due to lower rates of evapotranspiration, rotation periods, soils, etc. Moreover, South African plantations are distributed in areas with severe blue water scarcity. Although no blue water is used for irrigation of eucalyptus in South Africa, the plantations may contribute to the water scarcity problems of the region. Therefore, it is worthwhile investigating ways of promoting green water footprint management and efficiency improvements, particularly if plantations or forests are located in water scarce areas.

The sustainability assessment shows all analysed sites falling in areas with water scarcity and/or water pollution problems. It is important to note that viscose's supply chain is easier to trace back and map when compared to polyester, due to the lower complexity of its production system. As the viscose market is highly concentrated, being dominated by only a few corporate groups, this creates a good opportunity for engagement and collaborative work, as has already been demonstrated through the work of CanopyStyle. It is therefore important to map the supply

[66] Although Brazil's forest WF is likely to be underestimated, since irrigation is applied in the earlier stages of plants' growth (see Annex 2 for data limitations on Brazil's plantations blue WF).

chain to understand where there are water sustainability issues associated with viscose production and start working with key suppliers in hotspot regions.

It is also important to add a final note on different types of viscose raw materials, processing and final products, which will also have a different water footprint, and these were not assessed as part of this study.

6 Cotton, polyester and viscose comparative assessment

6.1 The water footprint of cotton, polyester and viscose

To provide a comparison of the water footprint of the three fibre types – cotton, polyester and viscose – the results from this study were compared to the results from two studies on the water footprint of cotton.

However, data and scope limitations in this study as well as those on cotton restrict the accuracy of the comparisons. This comparison is presented to provide an initial understanding of the water footprint of different fibre types and to identify key focus areas for additional research.

An initial study[67] based on global data for agriculture production of cotton[68] provided a first indication of the water footprint of cotton. The global data on cotton's grey water footprint only addresses nitrogen loads, and does not include pesticide use. Later, a detailed study of cotton cultivation in India using farm level data showed significant variation in the water footprint depending on the agricultural practices used and the state within which it was produced[69], demonstrating the importance of having specific data and assessing different practices to have a better understanding about cotton's water footprint ranges.

Hence, significant differences in the water footprint of polyester and viscose to what is reported in this study may arise if specific, detailed studies are undertaken for these two fibres, as was undertaken for cotton. Therefore, to fully understand the water footprint of these three fibre types and compare them, further analysis of the specific processes used is needed.

Despite the limitations of comparing the water footprint results of this study for viscose and polyester with the water footprint of cotton from previous studies, and the necessary caution in the interpretation and use of these results, some important aspects can be highlighted:

- Data indicate that on average polyester has the highest water footprint, only surpassed by some conventional cotton farms in India, in which highly toxic pesticides are used.
- On average, viscose has the lowest water footprint, except for filament yarns produced with continuous washing that surpasses the water footprint of cotton from farms using REEL or organic farming practices as well as cotton's global average water footprint.
- The grey water footprint contributes a higher proportion of the total water footprint of viscose and polyester, than it does for cotton, except for farms that use highly toxic pesticides.

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[67] Franke, N. and Mathews, R. (2013). *C&A's Water Footprint Strategy: Cotton Clothing Supply Chain*.
[68] Mekonnen, M. M. and A. Y. Hoekstra (2010)
[69] *Toward sustainable water use in C&A's cotton supply chain*, Safaya et al 2016. The study covers three types of cotton farming: conventional, organic and REEL Cotton Programme (Responsible Livelihood Enhanced Environment) The main difference between these farming practices relates to chemical inputs. REEL farms are stricter in the use of synthetic chemical pesticides and fertilisers than conventional farms, and organic farms are the strictest on chemical inputs and use more compost, urea, neem and organic seeds.

The key outcome of this comparison is that actual practices and technologies used in fibre production have a clear effect on the fibres' total water footprint and its components.

6.2 Sustainability of cotton, polyester and viscose's water footprint

From a **geographic perspective**, the sustainability assessment revealed that 10 out of the total 15 sites assessed for polyester and all 14 sites assessed for viscose are water sustainability hotspots. Like most cotton cultivation, production of these raw materials is taking place in river basins with unsustainable levels of water scarcity and/or water pollution. If polyester and viscose are sourced from the producers analysed in this study then their production is not sustainable.

From an **efficiency perspective**, the most recent study on cotton revealed that if all farmers performed to the level of the farms with the lowest water footprints (2013 growing season organic farms located in Gujarat, India), there would be a savings of 88% of the annual grey water footprint of these farms. Therefore, a substantial reduction of pressure on water resources could result from a change in practice[70].

The same is valid for polyester and viscose:

- For polyester, results show that adequate management practices – handling, treatment and disposal – of produced water during oil exploration, could significantly reduce polyester's total water footprint. Likewise, enhancement of wastewater treatment at the industrial level (refineries, petrochemicals and polyester fibres production) which contributes more than 98% of polyester's total water footprint would contribute to the reduction of organic matter loads (COD and BOD) in effluents and therefore decrease polyester's grey water footprint.
- In viscose fibres production, zinc loads in wastewater depend on the spin bath recovery technology applied, while sulphate loads depend on the use or disposal of by-products, and organic matter loads and other emissions to water depend on the type of wastewater treatment. In pulp production, AOX loads can be largely reduced or even eliminated depending on the pulp bleaching technology applied.

It is therefore important to understand what processes and technologies are being used by suppliers in all stages of fibre production and to improve those processes that are not meeting international standards for the water consumed or the pollutant loads released to water bodies.

[70] Safaya et al 2016.

7 Response formulation

The objectives of this study are to have a first level water footprint accounting of polyester and viscose and to begin to develop an understanding of the sustainability of polyester and viscose fibre production related to water. With polyester and viscose being amongst the most important fibres used in textile production, companies should address the ways in which these fibres are produced and how they impact water and land resources.

There are two main outcomes of this study.

1. The water footprint accounting undertaken in this study reveals that significant volumes of water are required to produce both polyester and viscose, and that the largest share of these fibres' water footprint is related to pollution.
2. Many of the locations where polyester and viscose are produced face water scarcity or high levels of water pollution, or both.

Therefore, implementing practices and investing in technologies for transforming industrial production towards lower water pollution loads is a critical step toward sustainable production of these materials. Simultaneously, brands and retailers need to work with their supply chain to improve the sustainability, i.e., reduce water scarcity and water pollution, in the locations where their suppliers operate.

These results can be used as a starting point for brands and retailers to develop a water stewardship strategy related to these fibres. Water stewardship is a journey (Figure 14) that may involve investing in water stewardship actions in a company's direct operations and supply chain, as well as engaging with others to improve local water conditions through collective action, engagement with local communities and with government. Disclosing the water footprint, in direct operations or supply chain, its sustainability and the actions taken provides the opportunity to engage stakeholders throughout the company's value chain in water stewardship.

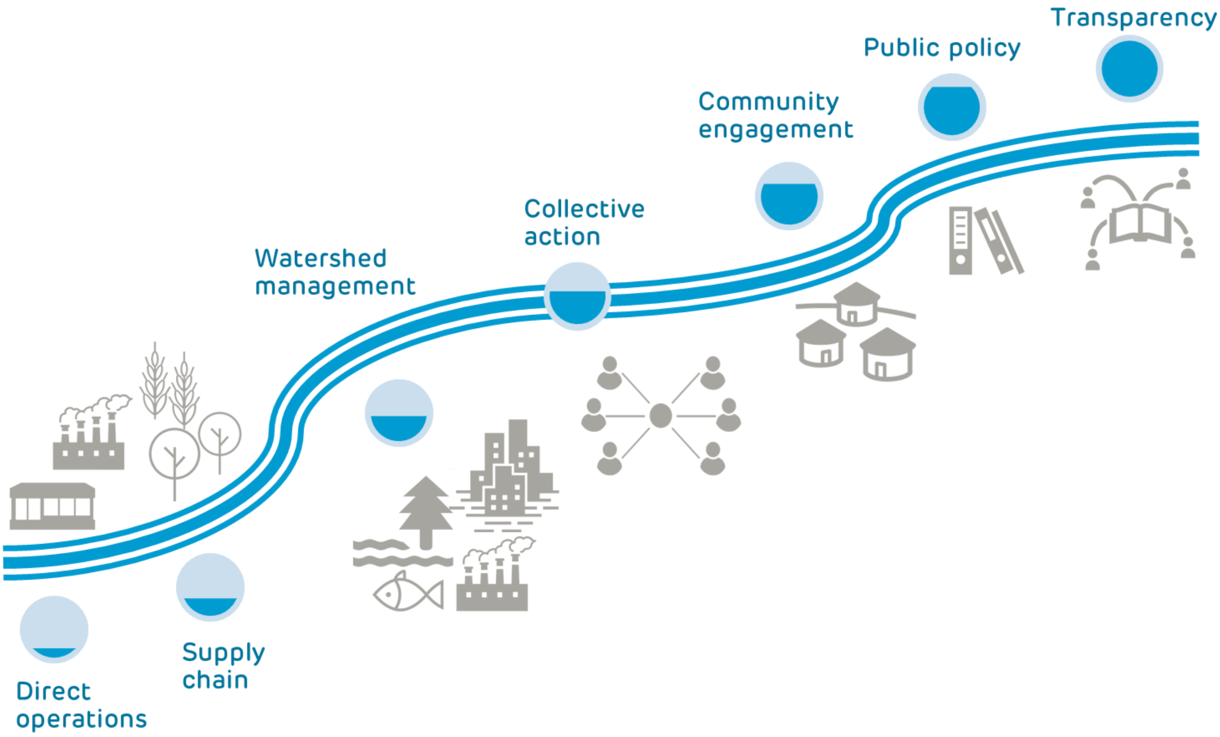


Figure 14 – Corporate water stewardship journey

There are five goals for water stewardship actions that can guide brands and retailers as they design their water stewardship strategy:

1. Measuring and monitoring the water footprint and its sustainability;
2. Improving water performance;
3. Improving local water conditions;
4. Educating the value chain about water stewardship; and
5. Engaging with external stakeholders and disclosing results.

To address the two key outcomes of this study, – the magnitude of the water footprint and the sustainability issues in the locations in which it occurs – brands and retailers will need a two-pronged approach to water stewardship: working individually within their own company's value chain and working collectively with other brands, retailers and stakeholders to transform the sector.

7.1 Working with suppliers

As brands and retailers begin their water stewardship journey, their initial focus will be on their supply chain as the water footprint in their direct operations (retails stores and offices) is negligible in comparison to the supply chain water footprint. Mapping the full clothing supply chain is challenging due to its complexity, however, for polyester and particularly viscose fibres, their production is relatively concentrated in a few large producers. Therefore, identifying suppliers for at least a proportion of the sourced fibres should be possible.

Engagement with suppliers should aim at supporting improvements in suppliers' water footprint performance, i.e., implementing best practices and investing in innovation and technology that reduce the water footprint, and improving local water conditions. Supplier engagement can include:

1. Defining targets and performance indicators for water footprints and their sustainability and monitoring progress toward these targets;
2. Developing procedures to allow supply chain traceability and transparency; and
3. Developing and implementing internal procurement policies and procedures that require suppliers to use best available technology and best practices, engage in collective action to achieve sustainable water use and management and report on water footprint performance and its sustainability.

Ultimately, all suppliers at every stage of the supply chain should achieve the same level of water performance and operate in sustainably managed catchments or aquifers. However, as a starting point, the decision tree presented in Figure 15 can help in identifying which suppliers to engage with first and the priority actions for those suppliers. As shown in the figure, brands and retailers should engage with suppliers located in hotspots first. These are locations experiencing water scarcity and/or high water pollution levels. Depending on whether the supplier is already using best available technologies and best practices or not and the role of the supplier and/or sector in the local catchment (or aquifer), the engagement with the supplier may range from adopting best available technologies and best practices to engaging with other water users and local institutions to work collectively on overall catchment (or aquifer) sustainability.

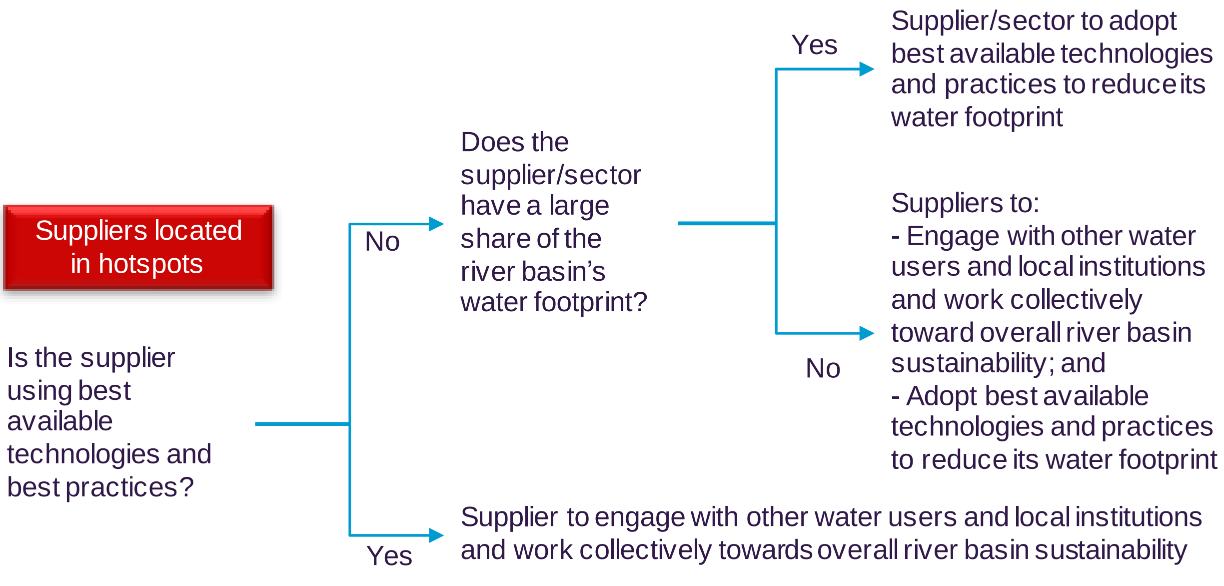


Figure 15 – Path for identifying key strategic actions with suppliers located in hotspots from raw materials to final products

Bringing awareness to and building capacity in the supply chain for water stewardship will open the way to improving the sustainability of fibres production.

7.2 Working with others

Individual actions by brands and retailers in engaging their suppliers in implementing water stewardship actions and proceeding along the water stewardship journey will make an important contribution to increasing the sustainability of polyester and viscose fibre production. However, to truly transform the sector, joining forces together and with other stakeholders, is needed to achieve the step-change required within the industry to make it sustainable. Complementing direct engagement with suppliers with sector-wide actions and initiatives will strengthen the signal sent to suppliers from brands and retailers that a sustainably supply of these fibres is desired. It can also expand the reach beyond what is possible for a single company. There are several multi-stakeholder initiatives such as Textile Exchange and the Sustainable Apparel Coalition that are supporting efforts to improve the sustainability of textile production.

Unsustainable water use and management is, in most cases, a result of a multitude of actions, poor or inadequate information, policies with divergent aims and weak governance. Addressing these underlying factors can rarely be done by one party, but instead must be done collectively. One approach to addressing this complex of conditions that result in unsustainable production is for brands and retailers to buy from producers who have been certified as a proxy for providing their own oversight of all aspects of production. With the dual aims of achieving the most efficient production possible and for polyester and viscose to be produced in sustainably managed basins, many companies rely on multi-stakeholder initiatives to develop the criteria for a sustainably produced commodity, provide the training for auditors, and manage the certification system.

This study highlights the significant contribution that the industrial phase of viscose production makes to the water footprint of viscose fibres and this is not yet being fully addressed in a coherent, sector-wide, way. CanopyStyle is working to reduce the impacts of the wood production stage of viscose on ancient and endangered forests, ensuring wood is sourced from acceptable sources. CanopyStyle brand policies also preferentially request Lyocell processing and promote the use of closed-loop alternatives. However, it is recommended, that brands and retailers support further collective engagement in the industrial phase of viscose fibre production both in terms of reducing the water footprint, with a particular focus on the grey water footprint (pollution loads), and to improve the sustainability of the locations where this production is occurring.

As polyester fibre grows in its market share as well in the total amounts being produced, it becomes increasingly important to develop multi-stakeholder initiatives that address the production chain of polyester fibres. Recognising that there are difficulties in identifying the locations of oil production for all polyester fibre manufacturing, engaging with suppliers with integrated business models, i.e., from refinery (and eventually oil production) to fibres, is a good starting point.

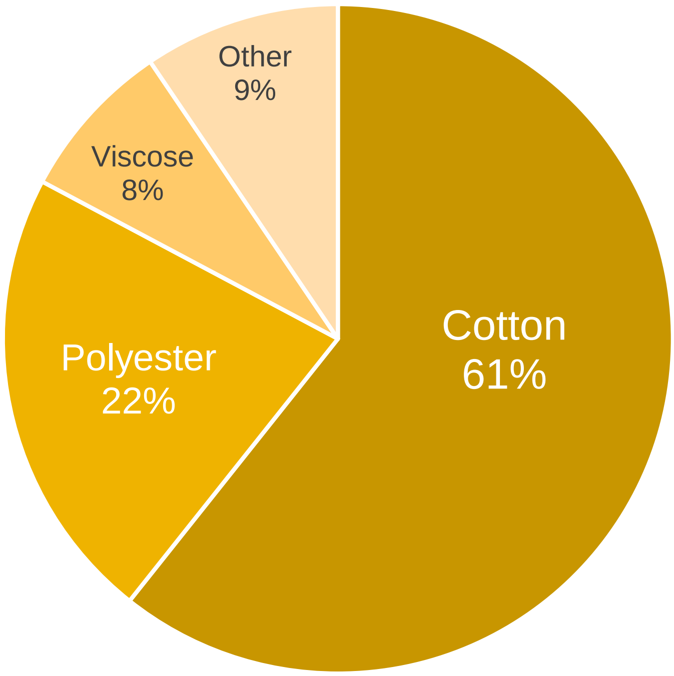
Achieving sources of sustainably produced polyester and viscose is not a solo journey and must be done in combination with a wide range of other organisations. There are a growing number of positive examples of the public and private sectors collaborating, in some cases also with non-governmental organisations, to achieve shared goals of greater social, economic and environmental sustainability in development. These public-private partnerships (PPP) benefit from the interests of the private sector in economic development and the interests of the public sector and civil society in social and environmental values and may focus on a specific project or outcome.

The journey of water stewardship requires a long-term commitment and must be responsive to the changing landscape within which brands and retailers, and their suppliers, operate. Technologies and practices evolve as innovation drives improvements. Local water conditions, regulations and water stewardship opportunities change over time. Customers' expectations, and those of local communities, investors, government and other stakeholders, change as the understanding of water risk and the impacts of the sector on water scarcity and water quality grows and the global drive toward sustainable development strengthens.

Openly sharing data, results, lessons learned and priority actions with others on this journey will help speed the process. Although it is not an end in itself, transparency about a company's water footprint and other water issues helps build an informed community, one that can drive the agenda of sustainable, efficient and equitable water use forward and support leaders on this journey. Disclosing a brand's or retailer's water stewardship strategy, reporting on targets and the results from the implementation of water stewardship actions is an important engagement tool that opens a dialogue throughout the value chain and with stakeholders and garners their support in the transformation to a sustainable supply of polyester and viscose fibres.

8 Polyester and viscose at C&A Europe

Cotton fibres make up the largest share in C&A's apparel, followed by polyester and viscose as the second and third main fibres, respectively. In fiscal year 2015, C&A Europe's proportional purchase (in weight) of fibres was 61% cotton, 22% polyester and 8% viscose (Figure 16**Error! Reference source not found.**).



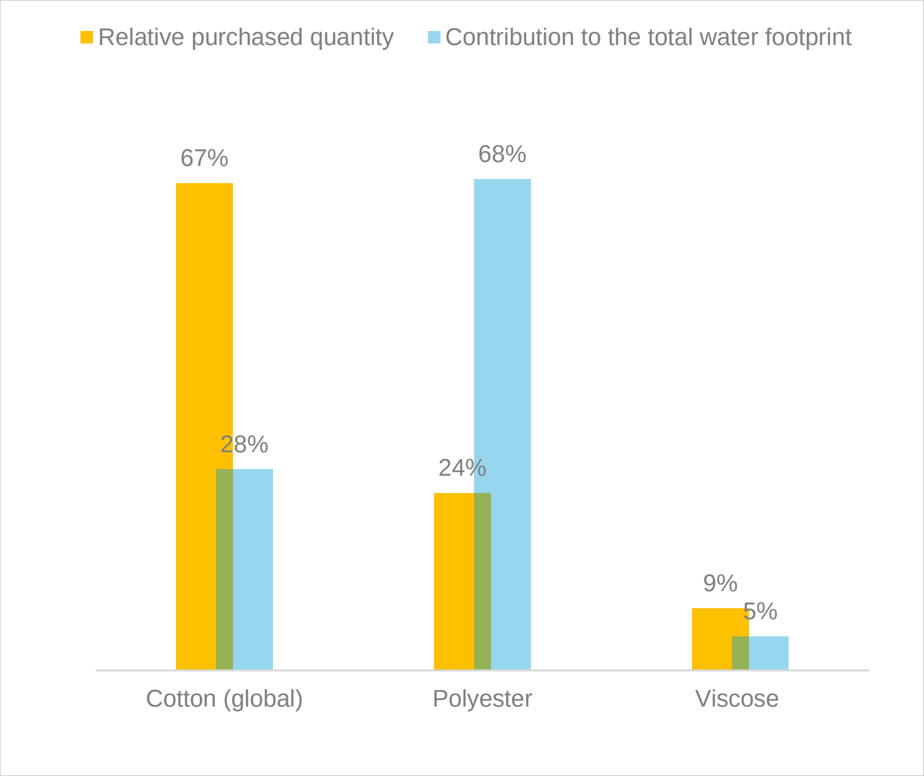
Source: Data from C&A Europe

Figure 16 – C&A Europe's fibres purchases (relative weight amounts) in 2015

Reflecting the variations in the water footprint for each fibre type, the contribution of the three raw materials (in weight) to C&A Europe's water footprint is proportionally different to the proportion of quantities purchased, as presented in Figure 20[71].

However, data and scope limitations in this study as well as those on cotton restrict the accuracy of the comparisons. This comparison is presented to provide an initial understanding of the water footprint of C&A's main fibres.

[71] Relative purchased quantities in Figure 16 differ from the ones in Figure 17 since the latest only includes cotton, polyester and viscose relative purchases and does not include other fibres, as in Figure 16.



Notes: Cotton global = based on global average for cotton lint (WaterStat[72]); Relative contributions to C&A Europe's water footprint based on totals only for these three raw materials.

Figure 17 – Polyester, viscose and cotton's relative contribution to C&A Europe water footprint in relation to purchased amounts (weight)

While cotton represents 67% of the fibres purchased by C&A Europe, it only represents 28% of the combined water footprint for these three fibres. Polyester shows the opposite effect whereby the quantities of fibres purchased is 24% while these fibres represent 68% of the combined water footprint. Viscose represents a slightly smaller proportion of the water footprint than the purchased quantities.

This comparison uses the global average water footprint for cotton to follow in line with the use of globally available data for calculating the water footprints of polyester and viscose. However, as has been shown earlier, the water footprint of cotton based on farm level data differs from the global average water footprint. It should be expected that calculations of the water footprint for polyester and viscose would change when data is collected directly from the production locations reflecting the actual processes used. Therefore, this comparison can be useful to C&A Europe in understanding that the proportion of the water footprint for all fibres purchased may not be the same proportion as that of the quantities purchased of those fibres. It also highlights the necessity of understanding the relationship between specific practices and technologies and their water footprint. This is important to address when developing C&A's water stewardship

[72] Mekonnen, M.M. and Hoekstra, A.Y. (2011) The green, blue and grey water footprint of crops and derived crop products, Hydrology and Earth System Sciences, 15(5): 1577-1600.

strategy as priorities for taking action to address water in the supply chain need to reflect the water footprint, and its sustainability, of these fibres.

Assuming an average water footprint for polyester and viscose based on the results of this study and comparing them with cotton's global average water footprint, polyester will contribute to 68% of C&A Europe's total water footprint from these three materials and viscose only 5%.

These results clearly indicate that as C&A moves toward its goal of sourcing more sustainable raw materials for its products, it will be important to identify who the major producers of polyester and viscose fibres used by C&A's direct suppliers are, and to make plans for engaging either directly or indirectly with these producers to improve water performance, i.e., reduce the water footprint, of the fibres production through implementing best practices and investing in best available technology. Additionally, it will be important to identify the production locations to guide C&A's engagement with suppliers to those that are operating in water scarcity and/or water pollution level hotspots. In these locations, it will be insufficient to work with suppliers only on their direct operations; it will also be necessary for suppliers to engage with others in achieving the overall sustainable use and management of water resources in these hotspot locations.

C&A can use the results of this study as a basis for developing a targeted strategy for reducing C&A's polyester and viscose water footprint and to influence others to work collectively toward the sustainable production of polyester and viscose fibres.

Without specific production locations for polyester and viscose fibres purchased by C&A Europe, it is not possible to assess their sustainability from the environmental perspective, i.e., whether the production is located in hotspots or not. To accurately compare the sustainability of the three raw materials (cotton, viscose and polyester) in C&A's supply chain, further data collection and analysis will need to be undertaken. To meet C&A's target of sourcing more sustainable raw materials, it will be necessary to delve more deeply into their production chain and its locations. This knowledge will help with prioritising which suppliers to engage with and guiding that engagement to the most important actions that will lead to a sustainable supply of these raw materials.

These actions should be designed to meet the five goals of water stewardship actions:

1) measuring and monitoring the water footprint and its sustainability;

2) improving water performance;

3) improving local water conditions;

4) educating the value chain about water stewardship; and

5) engaging with external stakeholders and disclosing results.

These goals can be met by defining targets and performance indicators for water footprints and their sustainability and monitoring progress toward these targets; developing procedures to allow supply chain traceability and transparency; and developing and implementing internal procurement policies and procedures that require suppliers to use best available technology and best practices, engage in collective action to achieve sustainable water use and management and report on water footprint performance and its sustainability.

C&A is already communicating targets for sourcing sustainable materials and has engaged in meaningful initiatives focused on achieving more sustainable production of raw materials for cotton and viscose, such as the Better Cotton Initiative (focused on cotton farming) and CanopyStyle. However, these initiatives fall short of the full spectrum to activities required to ensure that cotton, polyester and viscose are being produced sustainably.

C&A can use the results of this study to advocate for the need for standards that address all water sustainability issues in the production systems of polyester and viscose, with a particular emphasis on the grey water footprint of the industrial phases and the unsustainable water pollution levels in surface and groundwater where the suppliers have operations.

To date, there are gaps in sustainability standards; they are not addressing all stages of the production process of viscose and there is insufficient attention to the sustainability of polyester fibre production. This might require a working together with other brands, retailers and stakeholders, especially where C&A's power to influence on its own may be limited. Furthermore C&A can bring its experience with Water Footprint Assessment to brands, retailers and stakeholders, helping to develop a common language across the parties and the issues – from raw materials up to the river basin.

C&A already has a history of sharing its information, e.g., previous reports conducted with Water Footprint Network have been made publicly available. This report represents the first study to analyse in depth the water footprint of polyester and viscose including all phases of these raw materials' production system and to conduct a geographic sustainability assessment for the main producers included in the study[73]. As customers and other stakeholders understand the positive social, economic and environmental benefits of C&A's commitment to sustainable materials, there will be more pressure on other brands to follow suit bringing a transformational, and pre-competitive, energy to the transition to a more sustainable textile industry. C&A can be a leader in this transformation by making a long-term commitment to water stewardship.

[73] A study about the water footprint of textile sector in the United Kingdom, which included polyester and viscose, was published in 2012. However, in this study, there was no sustainability assessment and for polyester "*data were not available for the water footprint of polymerisation and resin conversion for the oil-derived synthetic fibres, and therefore the results are likely to be under-estimates for these types of fibre*" ("Review of Data on Embodied Water in Clothing". Summary Report. July 2012. URS prepared for WRAP).

9 References

Biermann, Christopher J. (1993). Essentials of Pulping and Papermaking. San Diego: Academic Press, Inc. ISBN 0-12-097360-X.

Brazilian Forestry Science and Research Institute (2005). Recommendations for Eucalyptus fertilization.

Dye, P. 2013. A review of changing perspectives on Eucalyptus water-use in South Africa, Forest Ecology and Management.

Epstein, Paul R. and Selber, Jesse (Editors), 2002. *OIL: A Life Cycle Analysis of its Health and Environmental Impacts*. The Center for Health and the Global Environment, Harvard Medical School.

European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers.

European Man-made Fibres Association, http://www.cirfs.org/

Fakhru'l-Razi A, Pendashteh A, Abdullah LC, Biak DR, Madaeni SS, Abidin ZZ (2009). Review of technologies for oil and gas produced water treatment. Journal of Hazardous Materials.

FAO Forest Products Definitions, Food and Agriculture Organization. http://www.fao.org/forestry/34572-02d9152c9571f5e09b9b54a76d37d47f3.pdf

FAO. 2006. Global Forest Resources Assessment: progress towards sustainable forest management 2005, Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO. 2013. Yearbook of Forest Products. Food and Agriculture Organization of the United Nations. http://www.fao.org/forestry/statistics/80570/en/

FAO/ICAC. 2013. World Apparel Fibre Consumption Survey. Food and Agriculture Organization of the United Nations and International Cotton Advisory Committee. https://www.icac.org/cotton_info/publications/statistics/world-apparel-survey/FAO-ICAC-Survey-2013-Update-and-2011-Text.pdf

Franke, N. and Mathews, R. (2013). C&A's Water Footprint Strategy: Cotton Clothing Supply Chain. http://waterfootprint.org/media/downloads/CA_Strategy_Final_Report_Formatted_06.08.2013.pdf

Franke, N.A., Boyacioglu, H. and Hoekstra, A.Y. (2013) Grey water footprint accounting: Tier 1 supporting guidelines, Value of Water Research Report Series No. 65, UNESCO-IHE, Delft, the Netherlands. http://waterfootprint.org/media/downloads/Report65-GreyWaterFootprint-Guidelines_1.pdf

Gonçalves, J.L.M. (2005) Recomendações de adubação para Eucalyptus, Pinus e Espécies Nativas. Documentos Florestais. Piracicaba – IPEF (Brazilian Forestry Science and Research Institute) http://www.ipef.br/silvicultura/adubacao.asp

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M., 2011. The Water Footprint Assessment Manual: Setting the global standard. Earthscan, London, UK, ISBN: 978-1-84971-279-8.

Mekonnen, M. M. and A. Y. Hoekstra (2010). The green, blue and grey water footprint of crops and derived crop products. Value of Water Research Report Series No. 47. Delft, The Netherlands, UNESCO-IHE.

Mekonnen, M. M. and A. Y. Hoekstra (2011). "The green, blue and grey water footprint of crops and derived crop products." Hydrology and Earth System Sciences (5): 1577-1600.

Mekonnen, M. M., Gerbens-Leenes, P. W. and Hoekstra, A. Y. (2015). The consumptive water footprint of electricity and heat: a global assessment. Environmental Science Water Research & Technology, March 2015.

Mekonnen, M.M. and Hoekstra, A.Y. (2015) Global gray water footprint and water pollution levels related to anthropogenic nitrogen loads to fresh water, Environmental Science and Technology, 49(21): 12860−12868.

Mekonnen, M.M. and Hoekstra, A.Y. (2016) Four billion people facing severe water scarcity, Science Advances, 2(2): e1500323.

Preferred Fiber and Materials Market Report. Textile Exchange. 2016. http://textileexchange.org/2016-preferred-fiber-and-materials-market-report-overview/

Safaya et al 2016. Improving the Sustainability of Cotton Production: An Assessment of the Water Footprint of Agricultural Practices in C&A’s Supply Chain. Water Footprint Network. C&A and C&A foundation.

Smith CW and du Toit B (2005). The effect of harvesting operations, slash management and fertilisation on the growth of a Eucalyptus clonal hybrid on a sandy soil in Zululand, South Africa. Southern African Forestry Journal – No. 203, March 2005.

UECE 2014. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water, Available at: http://www.who.int/water_sanitation_health/glaas/2014/en/

United States Department of Energy (2004) A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane.

United States Department of Energy (2009) Produced water volumes and management practices in the United States, Argonne National Laboratory.

United States Department of the Interior Bureau of Reclamation (2011) Oil and Gas Produced Water Management and Beneficial Use in the Western United States.

Van Oel, P.R. and Hoekstra, A.Y. (2012). Towards quantification of the water footprint of paper: A first estimate of its consumptive component, Water Resources Management, 26(3): 733-749.

Vörösmarty, C. J., P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. Reidy Liermann & P. M. Davies (2010). Global threats to human water security and river biodiversity. Nature 467, 555–561.

World Bank (1999). Pollution Prevention and Abatement Handbook.

Wu, M. Mintz, M. Wang and S. Arora (2009). Water Consumption in the Production of Ethanol and Petroleum Gasoline. Environmental Management, 44, 981-997.

Annex 1

WATER FOOTPRINT ASSESSMENT METHODOLOGY: DETAILS ON WATER FOOTPRINT CALCULATIONS AND SUSTAINABILITY ASSESSMENT INDICATORS AND CRITERIA

The methodology described in this annex and it follows the Water Footprint Assessment Standard[74].

Water footprint accounting

The water footprint of a product is defined as the total volume of fresh water that is used directly or indirectly to produce the product. It is estimated by considering water consumption and pollution in all steps of the production chain.

The water footprint of a product can be calculated through the stepwise accumulative approach and will account for the water footprint of the several processes involved and the products' "product fractions" and "value fractions" within the production system.

Hence, in order to estimate the water footprint of a product, it is necessary to first understand the production system, i.e. the sequential process steps of production. The production system of a product consists of all the sequential process steps applied to produce it. A production system can be a linear chain of processes; it can take the shape of a product tree (many inputs ultimately resulting in one output product) or it may rather look like a complex network of interlinked processes that eventually lead one or more products

The production systems of polyester and viscose are presented in the main report Figure 5 and Figure 9, respectively.

The water footprint of each process step in the production of polyester and viscose was estimated based on available data (see Annex 2). Likewise, data on product and value fractions for all process steps and resulting products was also gathered and the water footprint of polyester and viscose was then calculated.

[74] Hoekstra et al. 2011

The water footprint of a product is calculated by applying the expression:

WATER FOOTPRINT OF A PRODUCT

$$WF_{product}[p] = \left[WF_{process}[p] + \sum_{i=1}^{n} \frac{WF_{product}[i]}{f_{product}[p,i]} \right] x\ f_{value}[p]$$

In which:

- $WF_{product}[p]$ = water footprint (volume/mass) of output product p,
- $WF_{product}[i]$ = water footprint of input product i
- $WF_{proc}[p]$ = process water footprint of the processing step that transforms the N input products into the output products, expressed in water use per unit of processed product p (volume/mass).
- $f_{product}[p,i]$ = product fraction
- $f_{value}[p]$ = value fraction

The expression is applied to all three water footprint components: green, blue and grey water footprint. In the current assessment, green water footprint only applies to the wood production stage of viscose (for polyester, green water footprint does not apply).

The product fraction of an output product p that is processed from an input product i (fp[p,i]) is defined as the quantity of the output product (w[p]) obtained per quantity of input product (w[i]):

$$\mathrm{fp}[\mathrm{p},\mathrm{i}] = \frac{\mathrm{w}[\mathrm{p}]}{\mathrm{w}[\mathrm{i}]}$$

The value fraction of an output product p (fv[p], monetary unit/monetary unit) is defined as the ratio of the market value of this product to the aggregated market value of all the outputs products (p=1 to z) obtained from the input products:

$$\mathrm{fv}[\mathrm{p}] = \frac{\mathrm{price}[p] \times \mathrm{w}[p]}{\sum_{p=1}^{z}(\mathrm{price}[p] \times \mathrm{w}[p])}$$

The water footprint of polyester equals the sum of polyester’s blue and grey water footprints. For viscose the water footprint is the sum of green, grey and grey water footprints.

The blue WF of a process, WF_{proc_blue} (volume/time), is an indicator of consumptive use of blue water, namely, the fresh surface water or groundwater. The blue WF of a process step is calculated as:

$$WF_{proc\_blue} = BlueWaterEvaporation + BlueWaterIncorporation + LostReturnflow$$

where *BlueWaterEvaporation* is (blue) surface water evaporation; *BlueWaterIncorporation* is (blue) water incorporated into the product; *LostReturnflow* is the amount of water after use which does not return to the same catchment in the same period of the water abstraction.

The green WF of a process, *Wfpro_green* (volume/time), refers to the total evapotranspiration (*GreenWaterEvaporation*) of rainwater stored in soil plus the water incorporated into the harvested crop or wood (*GreenWaterIncorporation*). The green WF of a process step is calculated by:

$$Wfproc\_green = GreenWaterEvaporation + GreenWaterIncorporation$$

The grey WF of a process, *Wfproc_grey* (volume/time), is calculated by:

$$WF_{proc\_grey} = \frac{L}{c_{max} - c_{nat}}$$

where *L* (mass/time) is the load of the pollutant under study; c_{max} (mass/volume) is the maximum acceptable concentration specified by the ambient water quality standard in consideration, and c_{nat} (mass/volume) is the natural background concentration of that pollutant in the receiving water body.

In the case of point sources of water pollution, i.e., when pollutants are directly released into a surface water body in the form of a treated or non-treated wastewater disposal, the grey WF can be estimated by:

$$WF_{proc\_grey\_point} = \frac{Effl \cdot c_{effl} - Abstr \cdot c_{act}}{c_{max} - c_{nat}}$$

where *Effl* (volume/time) is the discharge rate of effluent while *Abstr* (volume/time) is the abstraction rate. C_{effl} and c_{act} are the concentrations of the pollutant under study in the effluent and in the source water of abstraction, respectively.

In the case of diffuse source pollution (in the current study only applicable to the wood production stage of viscose), the grey water footprint is estimated using:

$$WF_{proc\_grey\_diffuse} = \frac{\alpha \cdot Appl}{c_{max} - c_{nat}}$$

where α is the leaching-run-off fraction. It represents the fraction of applied chemicals (e.g. fertiliser) on land eventually reaching freshwater bodies after land-soil-water interactions. *Appl* (mass/time/area) is the application of the chemicals on land or into the soil.

The following processes were considered for polyester water footprint calculation:

- WF of onshore crude oil exploration
- WF of Ethylene
- WF of Naphtha
- WF of Monoethylene Glycol (MEG)
- WF of Terephtalic acid (TPA)
- WF of TPA process (TPA + MEG)
- WF of polyester Filament Yarns
- WF of polyester Staple Fibres

The following processes were considered for viscose water footprint calculation:

- WF of Eucalyptus growth in Brazil and in South Africa
- WF of Wood processing
- WF of Dissolving Wood Pulp plus viscose staple fibre
- WF of Dissolving Wood Pulp plus viscose filament yarn production with continuous washing
- WF of Dissolving Wood Pulp plus viscose yarn production with batch washing

Water footprint sustainability assessment

Sustainability of a WF can be assessed from an environmental, social and economic perspective. In this particular study, the assessment aims not only the WF of polyester and viscose, but also comparing the sustainability of these two textile raw materials with cotton, in C&A's supply-chain.

When assessing the WF sustainability, sustainability indicators and the criteria for the assessment need to be established. Blue water scarcity (BWS)[75] and water pollution level (WPL)[76], which are related to blue WF and grey WF, respectively, are the environmental sustainability indicators commonly applied in WFA.

Blue water scarcity

BWS in a catchment is defined as the ratio of the total of blue WF in the catchment to the blue water availability of the catchment. It is expressed by:

$$WS_{blue}[x,t] = \frac{\sum WF_{blue}[x,t]}{WA_{blue}[x,t]}$$

where WS_{blue} is the BWS in a catchment x in a certain period t, ΣWF_{blue} is the total blue water footprint in the catchment in that period, and WA_{blue} is the blue water availability.

The blue water availability (WA_{blue}) in a catchment x in a certain period t is quantified by the difference between the natural run-off in the catchment and the environmental flow requirement (EFR), which can be expressed by:

$$WA_{blue} = R_{nat} - EFR \quad [\text{volume/time}]$$

where Rnat is the natural run-off of the catchment in the period under study.

The classification of overall BWS is:

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[75] According to Mekonnen & Hoekstra, 2016
[76] According to Mekonnen & Hoekstra, 2015

- **low** blue water scarcity (BWS<1.0): the total blue WF is lower than 15% of the natural runoff and does not exceed the blue water availability; presumed environmental flow requirements are not violated.
- **moderate** blue water scarcity (BWS=1.0 – 1.5): the blue water footprint is between 15% and 22.5% of the natural runoff; environmental flow requirements are not met.
- **significant** blue water scarcity (BWS=1.5 – 2.0): the blue water footprint is between 22.5% and 30% of the natural runoff; environmental flow requirements are not met.
- **severe** water scarcity (BWS>2.0). The blue water footprint exceeds 30% of natural runoff; environmental flow requirements are not met.

Water pollution levels

Water pollution level (WPL) is defined as the fraction of the waste assimilation capacity consumed. WPL [x,t], it is calculated by taking the ratio of the total grey water footprints (WF_{grey}) in a catchment to the actual runoff (R_{act}) of that catchment.

$$WPL[x,t] = \frac{\sum WF_{grey}[x,t]}{R_{act}[x,t]}$$

Water pollution level was classified as follows:

- **low** water pollution level (surface WPL <1.0): the total grey WF on surface water is less than 100% of the actual runoff; the pollution load is smaller than the critical load and the assimilation capacity of the receiving water body is not fully consumed.
- **significant** water pollution level (surface WPL =1.0 – 2.0): the total grey WF on surface water is between 100% and 200% of the actual runoff; the pollution load is 1 to 2 times larger than the critical load and the assimilation capacity of the receiving water body has been exceeded.
- **severe** surface water pollution level (surface WPL >2.0): the total grey WF on surface water is larger than 200% of the actual runoff; the pollution load is larger than 2 times larger than the critical load and the assimilation capacity of the receiving water body has been exceeded.

In the study, WF sustainability assessment was carried out using BWS and WPL and WF hotspots for polyester and viscose production systems were identified. Hotspots are the areas where the blue WF of the area is larger than the blue water availability of the area and/or the grey WF of the area exceeds the assimilation capacity for water pollution of the area, therefore indicating that the blue WF and/or the grey WF are unsustainable, respectively.

Nitrogen is a relevant water quality indicator in polyester production at the refinery and petrochemicals stages of the production system (see Table 4 in section 4.3). Although nitrogen is not a relevant water quality indicator in other steps of polyester production and phosphorus is not a relevant water quality indicator in any of polyester's production system step, Water Pollution Levels for these two parameters are still considered important as they indicate whether freshwater bodies have degraded water quality.

For viscose, both dissolving wood pulp production and viscose fibre production are processes that generate a large amount of organic waste in effluent. Therefore, nitrogen and phosphorus are relevant water quality indicators.

Producing locations, for polyester and viscose, were also assessed for other water quality indicators relevant to the different stages of production of these two materials. The water quality indicators derived from a study which covers an analysis of a wide range of pollutants loads into fresh water bodies globally: *Global threats to human water security and river biodiversity* (Vörösmarty et al, 2010). Levels are considered high when they are larger than 75% of all load levels, moderate between 25 and 50% and low when below 25%.

This analysis brings additional information on the severity of existing water quality issues at the production locations. However, the severity does not necessarily reflect sustainability issues, as the study from which data is extracted classifies pollutants' loads from a comparative analysis of loads globally and not based on freshwater ecosystem thresholds or assimilation capacity. Hence, these indicators were not used for identifying sustainability hotspots.

Annex 2

Results of Water Footprint Calculations, Data Sources, Assumptions and Limitations

POLYESTER

Polyester	Values	Data sources	Assumptions and limitations
Process 1: crude oil exploration			
Blue WF (m^3/ton) of crude oil production	**min 2.38 max 6.13**	Wu, M. Mintz, M. Wang and S. Arora (2009). Water Consumption in the Production of Ethanol and Petroleum Gasoline. Environmental Management, 44, 981-997	Based on data for 90% of total US onshore oil production
Grey WF (m^3/ton) of crude oil production		• A White Paper Describing Produced Water from Production of Crude Oil, Natural Gas, and Coal Bed Methane, U.S. Department of Energy 2004 • Produced water volumes and management practices in the United States, Argonne National Laboratory, USA Department of Energy 2009 • Oil and Gas Produced Water Management and Beneficial Use in the Western United States, USA Department of the Interior Bureau of Reclamation 2011 • Review of technologies for oil and gas produced water treatment, Fakhru'l-Razi et al Journal of Hazardous Materials 2009 • Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014 • Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)	Data from onshore oil exploration in the US. Wastewater volume = 8% of produced water volume. 71% of all produced water is being injected for enhanced recovery while 21% is being injected for disposal. These 21% were not included in the grey water footprint calculations.
Anthracene	min 66.60 max 94.15		
Benzene	**min 110.27 max 157.52**		
Benzo(a)pyrene	min 88.80 max 126.86		
Naphthalene	min 37.00 max 52.86		
Phenol	min 71.23 max 101.76		
Toluene	min 70.34 max 100.49		
Total xylenes	min 25.90 max 37.00		
Arsenic	min 1.63 max 2.33		
Cadmium	min 106.471 max 152.11		
Copper	min 33.32 max 47.59		

Polyester	Values	Data sources	Assumptions and limitations
Lead	min 9.76 max 13.95		
Nickel	min 31.69 max 45.27		
Process 2: refinery			
Product fraction	Oil to Ethylene: 0.02 Oil to Naphtha: 0.06	• Mass balances and inputs from textile expert • U.S. Environmental Protection Agency (http://www3.epa.gov) • International Energy Agency (www.iea.org) • U.S. Department of Energy (DOE) (www.energy.gov/) • European Petrochemical Association (https://epca.eu/)	• Raw material for MEG is Ethylene • Raw material for TPA is Naphtha • Water footprint of energy no included • Assumed that cooling water is recycled and reused, with a 10% evaporative loss • Different processes in refinery were not separated due to lack of data. Calculations are based in an average unique refinery with all its outputs
Value fraction	Oil to Ethylene: 0.02 Oil to Naphtha: 0.04		
Blue WF (m^3/ton) of Ethylene/Naphtha processing	**min 0.57** **max 2.84**	Wu, M. Mintz, M. Wang and S. Arora (2009). Water Consumption in the Production of Ethanol and Petroleum Gasoline. Environmental Management, 44, 981-997	
Grey WF (m^3/ton) of Ethylene/Naphtha processing		• World Bank (1999). Pollution Prevention and Abatement Handbook. • Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014	Grey water footprint resulting from leakages, storage, storm water and from acidification due to air pollutants is not included
COD	min 47.22 max 94.44		
BOD	**min 3,187.50** **max 4,250.00**		
Phenol	min 10.63 max 106.25		
Benzene	min 0.43 max 42.50		
Lead	min 0.12 max 5.90		

Polyester	Values	Data sources	Assumptions and limitations
Temperature	min 190.00 max 200.00		
Process 3: Petrochemicals			• Water footprint of energy no included • Assumed that cooling water is recycled and reused, with a 10% evaporative loss • Different processes in petrochemicals facility were not separated due to lack of data. Calculations are based in an average unique facility with all its outputs.
Product fraction	Ethylene to MEG: 0.08 Naphtha to TPA: 0.17	• Mass balances and inputs from textile expert • U.S. Environmental Protection Agency (http://www3.epa.gov) • International Energy Agency (www.iea.org) • U.S. Department of Energy (DOE) (www.energy.gov/) • European Petrochemical Association (https://epca.eu/)	
Value fraction	Ethylene to MEG: 0.06 Naphtha to TPA: 0.12		
Blue WF (m^3/ton) of MEG/TPA processing	**10.00**	• World Bank (1999). Pollution Prevention and Abatement Handbook.	
Grey WF (m^3/ton) of MEG/TPA processing		• World Bank (1999). Pollution Prevention and Abatement Handbook. • Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014	Grey water footprint resulting from leakages, storage, storm water and from acidification due to air pollutants is not included
COD	58.4		
BOD	**131.4**		
Phenol	6.57		
Benzene	2.628		
Process 4: Polyester fibres or filament production			
Product fraction	MEG and TPA to Polyester: 1	• Mass balances and inputs from textile expert • Market advisory companies' websites and reports: https://www.ihs.com/index.html; www.platts.com; www.yarnsandfibers.com/	Because at facility 100% of raw materials is for polyester fibres/filaments production, all market values and product fractions of other MEG and TPA products, are not included.
Value fraction	MEG and TPA to Polyester: 1		

Polyester	Values	Data sources	Assumptions and limitations
Blue WF (m^3/ton) of polyester staple fibres processing	**15.00**	European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	
Grey WF (m^3/ton) of polyester staple fibres processing		• European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers • Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014	
COD	**549.67**		
Blue WF (m^3/ton) of polyester filament yarns processing	**35.00**	European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	
Grey WF (m^3/ton) of polyester filament yarns processing		• European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers • Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014	
COD	**153.96**		

VISCOSE

Viscose	Values	Data sources	Assumptions and limitations
Process 1: Wood production		• Yield wood (m3/ha/year): Source FAO 2006 in Van Oel, P.R. and Hoekstra, A.Y. (2012). Towards quantification of the water footprint of paper: A first estimate of its consumptive component, Water Resources Management, 26(3): 733-749. • Reports and information from pulp and viscose producers (available on companies' websites): Sappi, Bracell, Lenzing	Wood sourced from Eucalyptus plantations in South Africa and Brazil
Green WF (m^3/ton) of trees	**South Africa: 36.01** **Brazil: 28.84**	Van Oel, P.R. and Hoekstra, A.Y. (2012). Towards quantification of the water footprint of paper: A first estimate of its consumptive component, Water Resources Management, 26(3): 733-749.	Evapotranspiration (m^3/ha/year) - Data on actual Evapotranspiration (Eta) of sub-tropical eucalyptus forests in South Africa and Brazil
Blue WF (m^3/ton) of trees	**South Africa: 0.00** **Brazil: 0.00**		In Brazilian plantations irrigation is applied in the first development stages of eucalyptus, but there is a reference to "gel irrigation" (Bracell/Sateri) and it was not possible to obtain data that allowed to account for the associated blue WF

Viscose	Values	Data sources	Assumptions and limitations
Grey WF (m^3/ton) of trees		• Water quality standards: Total Nitrogen - Class 3 lower allowed concentration - UNECE Standards for Aquatic life, 2014 • Nitrogen application rates (kg/ha): Smith CW and du Toit B (2005). The effect of harvesting operations, slash management and fertilisation on the growth of a Eucalyptus clonal hybrid on a sandy soil in Zululand, South Africa. Southern African Forestry Journal – No. 203, March 2005; Gonçalves, J.L.M. (2005) Recomendações de adubação para Eucalyptus, Pinus e Espécies Nativas. Documentos Florestais. Piracicaba – IPEF	Eucalyptus plantations both in South Africa and Brazil are subject to diseases. Therefore, pesticides are regularly used. Likewise, other chemicals are applied in fertilisation (e.g. phosphorus). However, no data was available to allow calculating the WF from the use of other chemicals.
Nitrogen	**South Africa: 36.01** **Brazil: 28.84**		
Process 2: Wood processing			For wood processing, there is a blue and a grey water footprint associated with wood washing before entering the mills' facilities. However, no data were available for the amounts of water required for wood processing and pollutants' loads, and therefore it was assumed to be null. Wood processing was nonetheless included in the water footprint calculations, due to the significance of product fractions involved, since only part of the wood is used for pulp production. Value fraction was considered 1, although bark is often used for commercial ends such as energy production. However, the value fraction was not possible to determine.
Product fraction	Eucalyptus to wood: 0.66	• Mass balances and inputs from textile expert • Global Forest Resources Assessment: progress towards sustainable forest management 2005, Food and Agriculture Organization 2005	
Value fraction	Eucalyptus to wood: 1.00		
Green WF (m^3/ton) of processed wood	**N/A**		
Blue WF (m^3/ton) of processed wood	**South Africa: 0.00** **Brazil: 0.00**		
Grey WF (m^3/ton) of processed wood	**South Africa: 0.00** **Brazil: 0.00**		
Process 3: Pulp and fibres production			• Water footprint of energy no included • Assumed that cooling water is recycled and reused
Product fraction	Wood to pulp and fibres: 1.00		Because at facility 100% of raw materials is for fibres production, all market values and product fractions of other wood end, are not included.

Viscose	Values	Data sources	Assumptions and limitations
Value fraction	Wood to pulp and fibres: 1.00		
Green WF (m^3/ton) of integrated dissolving wood pulp + Viscose Staple fibres processing	**N/A**		
Blue WF (m^3/ton) of integrated dissolving wood pulp + Viscose Staple fibres processing	156.00	European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	
Grey WF (m^3/ton) of integrated dissolving wood pulp + Viscose Staple fibres processing		• Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014 • European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	• Data for AOX loads are also available. AOX compounds which are particularly relevant to viscose production as they result from pulp bleaching and can have toxic effects for humans and the aquatic environment, were not included in the grey water footprint calculation. Data was only available for total AOX emissions in effluents, which could not be used in the calculation since water quality standards differentiate contributors to AOX and the maximum allowable concentrations vary substantially, according to compounds relative toxicity to the aquatic environment. • Grey water footprint resulting from leakages, chemical storage, storm water and from acidification due to air pollutants is not included.
Zinc	**1,600.00**		
COD	296.30		
Green WF (m^3/ton) of integrated dissolving wood pulp + Viscose Filament Yarns processing with continuous washing	**N/A**		

Viscose	Values	Data sources	Assumptions and limitations
Blue WF (m^3/ton) of integrated dissolving wood pulp + Viscose Filament Yarns processing with continuous washing	**370.00**	European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	
Grey WF (m^3/ton) of integrated dissolving wood pulp + Viscose Filament Yarns processing with continuous washing		• Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014 • European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	• Data for AOX loads are also available. AOX compounds which are particularly relevant to viscose production as they result from pulp bleaching and can have toxic effects for humans and the aquatic environment, were not included in the grey water footprint calculation. Data was only available for total AOX emissions in effluents, which could not be used in the calculation since water quality standards differentiate contributors to AOX and the maximum allowable concentrations vary substantially, according to compounds relative toxicity to the aquatic environment. • Grey water footprint resulting from leakages, chemical storage, storm water and from acidification due to air pollutants is not included.
Zinc	**30,000.00**		
COD	1,037.04		
Green WF (m^3/ton) of integrated dissolving wood pulp + Viscose Filament Yarns processing with batch washing	**N/A**		
Blue WF (m^3/ton) of integrated dissolving wood pulp + Viscose Filament Yarns processing with batch washing	80.00	European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	

Viscose	Values	Data sources	Assumptions and limitations
Grey WF(m^3/ton) of integrated dissolving wood pulp + Viscose Filament Yarns processing with batch washing		• Natural concentration of pollutants in receiving water bodies based on good quality surface water from UNECE Standards for surface freshwater quality for aquatic life, 2014 and guidance from "Grey water footprint accounting: Tier 1 supporting guidelines (Frank et al., 2013)" • Water quality standards: European Community Environmental Objectives (Surface Waters) Regulations 2009 and Water quality requirements for Aquatic life in UECE 2014 • European Commission, 2007. Reference Document on Best Available Techniques in the Production of Polymers	• Data for AOX loads are also available. AOX compounds which are particularly relevant to viscose production as they result from pulp bleaching and can have toxic effects for humans and the aquatic environment, were not included in the grey water footprint calculation. Data was only available for total AOX emissions in effluents, which could not be used in the calculation since water quality standards differentiate contributors to AOX and the maximum allowable concentrations vary substantially, according to compounds relative toxicity to the aquatic environment. • Grey water footprint resulting from leakages, chemical storage, storm water and from acidification due to air pollutants is not included.
Zinc	**3,000.00**		
COD	222.22		

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info@waterfootprint.org

+31 85 484 9600