The role and business case for existing and emerging fibres in sustainable clothing

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Summary Report

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1 Executive summary

1.1 Rationale and objectives

Textile fibre production has more than doubled over the past 30 years, leading to increased demands for both natural and fossil resources. Consumption of these resources must be controlled in order to reduce our environmental and social impact. However, it is important that novel means of production and consumption are economically viable and do not compromise human health and welfare.

This project aims to evaluate the market potential, environmental and social impacts, of established, niche, and emerging textile fibres to determine the business case for clothing fibres in light of their sustainability impacts. It will also identify key knowledge gaps and opportunities for further research. This information provides one part of the evidence base for the Sustainable Clothing Roadmap coordinated by Defra.

1.2 Approach

The project involved a literature review complemented by the expert advice and technical knowledge of a stakeholder group. It examined both existing fibres with an established market share and emerging fibres that have technical properties suitable for clothing fibre production.

The fibres of interest were divided into three major groups: natural, regenerated (derived from natural polymers but requiring treatment and processing), and synthetic (Table 1). Regenerated and synthetic fibres are commonly grouped as “man-made” fibres.

Table 1. Fibres selected for inclusion in the study.

	Natural		**Man-made**		
			Regenerated		**Synthetic**
	Cellulose	**Protein**	**Cellulose**	**Protein**	
Existing	Cotton Flax (line)	Silk Wool	Viscose		Acrylic Nylon Polyester
Emerging	Flax (short fibre) Hemp Jute Nettle Ramie Spanish broom		Bamboo Lyocell Modal	Soybean	PLA PTT

For the purposes of the assessment of environmental impacts, textile fibre supply chains were divided into four processes: raw material production, fibre preparation, fabric production, and dyeing and finishing. Environmental data were collated for each process. Where data were unavailable, figures from comparable fibres or processes were used. Where relevant, the impacts associated with laundering, during the use phase, and re-use or end of life disposal were considered based on the results of parallel evidence reports conducted as part of the Clothing Roadmap (Reducing the Environmental Impact of Clothes Cleaning (EV0419), Maximising Reuse and Recycling of UK Clothing and Textiles (EV0421).

1.3 Market analysis

Clothing fibre production is dominated by cotton and polyester, which account for 35 and 40% of the global fibre market respectively. These fibres are expected to increase in production and remain dominant for the foreseeable future. Other established fibres, such as wool and acrylic, have seen a decline in market share over the last 30 years and these trends are expected to continue.

At present rates of growth, emerging fibres are unlikely to make significant market gains. Hemp production has declined markedly. Although production of ramie and PLA is expected to increase, their role in the global fibre market is expected to remain small. High production costs and inferior technical qualities present a barrier to growth of natural fibres such as jute, nettle, and Spanish broom.

1.4 Environmental impact

With the exception of cotton, natural fibres are characterised by low energy demands during raw material production, fibre preparation, and fabric production phases. In contrast cotton has a moderate energy demand. Regenerated and synthetic fibres typically have moderate to high energy demands, with acrylic and nylon having very high energy demands. Dyeing and finishing represent the main energy demand for most natural fibres, while polymer production is the main energy demand for synthetic fibres. Water use is low in natural fibre production, with the notable exception of irrigated cotton. Regenerated fibres have high water demands during pulping operations for fibre extraction. Wool and fibres blended with wool have high water requirements during the scouring, dyeing and finishing stages, but overall water demands are similar to natural fibres (with the notable exception of cotton) Regenerated cellulosic fibres exhibit similar energy demands to many synthetic fibres, but with increased water requirements. Cotton production leads to moderate greenhouse gas emissions and waste water production. The energy requirement for polyester results in high greenhouse gas emissions, but polyester production generates little waste water. Chemical use in finishing is higher in cotton than in polyester. Data for other fibres on this aspect is scarce.

Direct land use requirements of natural and regenerated fibres are large, although yields vary widely according to geographical location and cultivation technique. However, the high energy use during production can lead to a much larger “ecological footprint” for synthetic fibres

Organic cultivation and GM technologies may reduce the environmental impact of cotton cultivation through lower energy demands and pesticide use. However, organic farming can reduce yields and so increase demand for land area. Also, herbicide-resistant GM varieties may encourage increased use of broad-spectrum herbicides with potential negative consequences for biodiversity. The key advantage of certified organic production is the additional impact and environmental-compliance requirements that this places on downstream fibre processing operations.

Fibre blending can affect the environmental impact of a textile. In some cases, the different properties of the fibres that make up the blend means textiles must undergo two separate dyeing processes, thus increasing impacts. Blending also makes recycling more difficult. However, this may be offset by improved durability or laundering properties that can significantly reduce energy demands in the use phase.

The key fibre trends and indicative environmental impacts are summarised in Table 2 and Table 3.

1.5 Social impacts

There is a lack of quantifiable information on the social impacts of clothing fibre production and so only a qualitative assessment was possible. Cotton markets are currently distorted by subsidies paid to producers in industrialised nations, leading to lower incomes for farmers in developing countries. Low levels of safety awareness and lack of access to protective equipment also make pesticide use a major health concern in developing nations. Initiatives such as Fairtrade encourage sustainable economic development for farmers in poorer nations, but currently only reach a minority of producers. Organic farming may increase product value and better access to GM varieties could increase yields and profits for developing countries

1.6 Knowledge gaps

Clothing composition data is limited to primary fibre components and so further information is required to determine the market role of fibre blends. Production data for the emerging fibres ramie, Spanish broom, and regenerated bamboo are also limited. Environmental data for niche and emerging fibres and alternative methods of cotton production, particularly to compare conventional, GM and organic production are currently lacking. In addition, more detailed information on the greenhouse gas emissions, waste-water production, and chemical pollution associated with the production of all fibres would allow a more complete environmental assessment to be made. The social implications of all stages of textile fibre production require significant further independent research using standardised methods in order to allow useful, quantifiable sustainability comparisons.

1.7 Conclusions and future prospects

This literature review has revealed significant limitations to our present understanding of textile fibre sustainability. It also highlights major trends and identifies future directions for research work. The market analysis shows the continuing dominance of cotton and polyester fibres in the clothing sector. The environmental assessment shows that these fibres have relatively high environmental impacts when compared to other niche and emerging fibres. However, there are means of reducing such impacts. Recycling polyester, via waste textiles or other polyester waste streams can significantly cut energy use, resource depletion and greenhouse gas emissions. Organic cotton production can reduce the toxicity, energy use and GHG emissions environmental impacts of growing cotton and has the potential to deliver added social benefits, but uptake needs to be encouraged from current low levels. However, this may be at the cost of an increased land requirement where cotton yields are reduced. Development of more heat-resistant forms of PLA look promising as a less energy demanding alternative to cotton and polyester; current limited production hampers assessment of its real potential. Hemp and flax are well-established niche fibres with low environmental impact but are relatively costly to produce, so the market potential is limited. Further work is required to improve the suitability and yield of these, and other fibres with favourable environmental profiles, for wider use in apparel applications. The summaries presented in this report identify the high-level key sustainability impacts of the fibres investigated. Further research is required to fill data gaps and verify these findings to a level that allows direct comparisons between fibres and to examine the wider environmental and social impacts of niche and emerging textile fibres. Consistency in methods, scope, data gathering, and analysis techniques will be key to providing a strong evidence base in accordance with best practice in life cycle assessment (LCA), that can be used by industry and consumer-focussed applications to make informed choices about product sustainability.

Table 2 Fibres ranked by key environmental impacts

	Energy use	**Water use**	**Greenhouse gases**	**Waste water**	**Direct land use**
Decreasing environmental impact ↓	Acrylic Nylon Polyester/PTT *Regen. cellulosic (viscose, Modal)* PLA/Cotton/Lyocel Wool *Natural bast fibres* [1](nettle, hemp,flax)	Cotton Silk Nylon *Regen. cellulosic* Acrylic Hemp Wool *Natural bast fibres* Polyester	Nylon *Synthetic* Polyester Lyocell PLA Viscose Modal Cotton *Natural bast fibres* Wool	Wool *Regen. cellulosic* *Natural bast fibres* Nylon Polyester	Wool Ramie Cotton Flax Hemp Viscose and Modal Jute PLA Lyocell *(Synthetic)*

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[1] Bast fibres are plant fibres collected from the phloem (outer skin) of certain plants, such as ramie hemp or nettle.

Table 3. Summary of market potential and environmental impacts of textile fibre production.

Fibre	**Current Volume (raw fibre)**	**Growth prospects in textiles**	**Fibre Cost $/kg (typical and recent highs in brackets)**	**Relative impacts between fibres (+ = relatively low impacts, ++++ = relatively high impact)**					
				Energy use	Water use	Greenhouse gas emissions	Waste water production	Chemical use in finishing	Land requirement
Acrylic	2.5m t	declining	2.7	+++	++	(+++)	+++	(++ - +++)	N/A
Bamboo	9000t	limited	ID	(++)	(+++)	(+)	(++)	(++ - +++)	(++)
Cotton	27.5m t	increasing	1.2-1.5 (c. 3.3 organic)	++	++++	++	++	+++	+++
Flax	0.45m t	limited	2.0-3.0 (up to 3.5)	+	+	(++)	(++)	(+++)	+++
Hemp	0.08m t	declining	0.5-1.5 (up to 2.0)	+	++	(++)	(++)	(+++)	++ - +++
Jute	3.3m t	limited	<0.5	ID	ID	(++)	(++)	(+++)	++
Lyocell	0.25m t	increasing	ID	++	++	+	(++)	(++ - +++)	+
Modal	Part of viscose share	increasing	ID	++	+++	(+)	(++)	(++ - +++)	++
Nettle	negligible	v.limited	(estimate - high)	(+)	+	(++)	(++)	(+++)	+++
Nylon	4.1m t of which 1.5 m t textiles	increase	2.84	+++	+++	++++	+	(+ - ++)	N/A
PLA	c. 0.01m t	increasing	1.5-2.4	++	(+)	++	ID	(+ - ++)	+
Polyester	30.7m t (17.1m t textile yarn)	increasing	1.1-1.65	++	+	+++	+	+ - ++	N/A
PTT	ID	ID	ID	++	+	+++	(+)	(+ - ++)	(+)
Ramie	0.29m t	limited	3.0-3.5	ID	ID	(++)	(++)	(+++)	++++
Silk	0.1m t	limited	15-26	ID	+++	ID	(++)	ID	ID
Soybean	3000t	limited	ID	ID	ID	ID	(+++)	(++ - +++)	ID
Spanish b.	negligible	v.limited	ID	ID	+	(++)	(++)	(+++)	ID
Viscose	2.92m t	increasing	2.95	++	+++	+	(++)	(++ - +++)	++
Wool	1.2m t	declining	2.8-6.6	+	+	ID	++++	++ - +++	++++

ID = insufficient data, NA = not applicable, Figures in brackets based on use of information from similar fibre types

2 Introduction

2.1 Rationale

Economic development and population growth have increased the demand for both natural and fossil resources. Combustion of fossil fuel leads to greenhouse gas emissions and the use of land for agricultural production reduces the habitat available for other species. Consumption of these resources must be controlled if we are to reduce our environmental impact. However, it is also critical that emerging production methods and consumption of resources are economically viable and uncompromising to human welfare and social development, particularly in countries where employee protection is less well regulated.

The UK strategy for sustainable development incorporates environmental, social, and economic objectives intended to accelerate the shift towards sustainable consumption and production (HM Government 2005). Defra is focusing on high-impact products, one of which is clothing (Defra 2009). Previous studies have assessed energy and raw material use in the production, washing, and disposal phase of textiles. However, these have mainly focused on established fibres rather than emerging fibres. These emerging fibres represent significant knowledge gaps and further research is required to assess the sustainability of the numerous emerging and existing textile fibres available.

2.2 Objectives

This report summarises the key sustainability and market impacts of established and emerging textile fibres. A complete analysis is provided in the accompanying full report. The following key objectives are addressed.

1. Identify and classify existing and emerging textile fibres of market interest.
2. Determine current and near-future scales of production for the fibres identified and evaluate their market potential.
3. Identify the environmental and social impacts of the fibres of interest using existing evidence and expert guidance.
4. Identify knowledge gaps that prevent a thorough analysis of the environmental and social impacts.
5. Present a summary impact table of the sustainability information per fibre in a clear and consistent way.
6. Provide recommendations for policy and industry on the role for existing and emerging fibres in sustainable clothing.

The information and analyses presented in this report contributes to the evidence base for the Sustainable Clothing Roadmap (Defra 2009).

3 Methodology

3.1 Approach

The project mainly involves a literature review, supported by technical discussions and review by members of a stakeholder group. A complete description of the approaches used, limitations and list of stakeholders can be found in the full report.

3.2 Identifying fibres of interest

3.2.1 Selection

This project examines both *existing* fibres with a current and established clothing market share and *emerging* fibres that do not yet have a significant market share but whose fundamental technical properties have been investigated and demonstrated to be appropriate for clothing manufacture.

3.2.2 Classification

A textile fibre is a thread-like material characterised by flexibility, fineness, and a high ratio of length to thickness. Fibres must be capable of being spun into a yarn for use in clothing. Fibres used in clothing manufacture have been divided into three groups, depending on their means of production.

1. Natural fibres develop into a useable fibrous form in the natural environment, although subsequent separation and cleaning is usually required. The three main types of natural fibre, categorised according to their origin are: plant fibres, animal fibres (both hair-like and filamentous), and mineral fibres (such as asbestos).
2. Regenerated fibres are derived from polymers produced in the natural environment, but need further treatment and processing prior to use in textiles.
3. Synthetic fibres are manufactured by converting a synthetic polymeric material, typically derived from fossil resources, to a useable textile fibre via a chemical change.

Regenerated and synthetic fibres are typically grouped as “man-made” fibres.

3.3 Literature review and expert guidance

Market, environmental, and social impact data for each fibre were obtained from a literature review that included life cycle assessment (LCA) studies. Where data were lacking, expert technical knowledge was used to estimate the market opportunities.

Review of outputs by stakeholders was used to refine the environmental impacts and scope of the review. For the purposes of this project, the supply chains for each textile are divided into four distinct processes.

1. Raw material production, including crop production.
2. Fibre preparation.
3. Fabric production and preparation.
4. Dyeing and finishing.

The environmental impacts of laundering and at end of life were also considered as part of this study. The impacts of garment manufacture and transport are dependent on location and garment type and are outside the scope of the environmental impacts and literature reviewed in this study.

Data for each of the four production steps were collated and evaluated. Energy and water use data were most complete and these, along with the more limited sources of published information on other environmental impacts, were used to produce high-level environmental impact summary tables to allow simple, quantitative comparisons of the fibres. Where energy and water use data were not available, data for other comparable fibres, processed in a similar way was used. These tables permit high-level, indicative comparison of key environmental impacts associated with each fibre, but must be treated with caution due to data limitations. Data for other environmental impacts (including greenhouse gas emissions, chemical use, pesticide inputs, and fertiliser applications) were much less readily available, but were included in the analysis. Data on land use impacts were derived using the limited data available on natural fibre yields. As a result of these data limitations, specific referenced sources were used to provide more qualitative judgements were made about the environmental impacts of fibres.

Existing and historic market statistics and production trends were obtained from published sources. However, projections of future market sizes were made using expert guidance and opinion and so should be treated as limited. Information and evidence on social impacts was very limited and so only a small range of subjective literature was used and direct comparisons of different fibre types were not possible. The methods used throughout the study are described in more detail in the full report.

4 Summary of fibres of interest

A complete list of the existing and emerging fibres selected for inclusion in this study is given in Table 4. This section gives a brief description of each fibre and summarises its market potential and environmental impact. Complete market and sustainability data can be found in sections 4 and 5 of the full report.

Table 4. Summary of fibres of interest.

<table>
<tr><th rowspan="3"></th><th colspan="2" rowspan="2">Natural</th><th colspan="3">Man-made</th></tr>
<tr><th colspan="2">Regenerated</th><th rowspan="2">Synthetic</th></tr>
<tr><th>Cellulose</th><th>Protein</th><th>Cellulose</th><th>Protein</th></tr>
<tr><td>Existing</td><td>Cotton
Flax (line)</td><td>Silk
Wool</td><td>Viscose</td><td></td><td>Acrylic
Nylon
Polyester</td></tr>
<tr><td>Emerging</td><td>Flax (short fibre)
Hemp
Jute
Nettle
Ramie
Spanish broom</td><td></td><td>Bamboo
Lyocell
Modal</td><td>Soybean</td><td>PLA
PTT</td></tr>
</table>

4.1 Existing fibres

4.1.1 Natural

4.1.1.1 Cotton

Description	Cellulosic fibres derived from the seed of the cotton plant (*Gossypium* spp.). Dominant natural fibre used in clothing of all types worldwide. Genetically modified pest-resistant and/or herbicide-tolerant cotton is now widely available.
Key producers	China, USA, India, Pakistan, Uzbekistan.
Production	27.5 million tonnes global production in 2007 (FAO 2008). Area cultivated relatively static since 1977, but increased yields due to advances in cotton growing technology.
Market	Accounts for 35% of total fibre market and 78% of natural fibre market. Accounts for 51% of UK clothing by mass (HMRC 2008). Considerable price fluctuation over the last 30 years. Consumption increased 3.5% per annum since 1997 and this trend is expected to continue over the next ten years.

cotton continued

Environment	Very high water demands during growing, with 53% of cotton being irrigated. Overall energy demand is moderate compared to most synthetic fibres, even after accounting for pesticide and fertiliser use. High pesticide and fertiliser use poses risk to water courses.
Social	High pesticide use in conventional cultivation systems poses major health risk in developing nations, although organic, and potentially GM, practices can reduce health problems. Subsidies applied in developed nations reduce world raw cotton prices by up to 14%.

4.1.1.2 Flax (line)

Description	Line flax, or linen, is a cellulosic bast fibre.
Key producers	EU, China.
Production	Approximately 450,000 tonnes per annum.
Market	Accounts for 2.8% of natural fibre market. Fibres relatively coarse without further treatment.
Environment	Low water use at all stages of production. Energy use low. Pesticide applications generally low.

4.1.1.3 Silk

Description	High-value, specialist protein fibre produced by the silkworm.
Key producers	China, India, Japan, Thailand, Brazil,
Production	98,000 tonnes in 2007.
Market	0.28% of natural fibre market. Expected to maintain this share due to specialist use.
Environment	Very high water use in fibre production and spinning. As a protein fibre, assumed to have high energy and water demands at the dyeing and finishing stage.

4.1.1.4 Wool

Description	Proteinaceous fibre. Widely used in suiting due to durability. Can be blended with various man-made fibres.
Key producers	Australia, New Zealand, South Africa.
Production	1.2 million tonnes in 2007, having declined from 2.0 million tonnes in 1990. Production expected to remain stagnant..
Market	Share of fibre market declined from 9% in 1977 to 6.5% in 2007. Global demand expected to drop by 2.1% in 2008/09 as part of an ongoing trend. Value highly dependent on fibre diameter.
Environment	Low energy and water use during production. Water demanding during scouring (cleaning) phase of yarn/textile production. Part of the impacts of fibre production should be offset by allocation of effects to by-product meat production, though this is relative minor as apparel tends to come from sheep specially bred for its fleeces, rather than from those bred for meat.

4.1.2 Regenerated

4.1.2.1 Viscose

Description	Viscose rayon is a regenerated cellulose fibre produced from pulping wood or cotton.
Key producers	China, India, Indonesia, Germany, Austria.
Production	2.92 million tonnes per annum. Production has increased in Asian countries but declined in Western Europe and the USA.
Market	Insufficient data.
Environment	Moderate energy demands, similar to polyester. High water demand, driven by pulping operation. Production leads to release of sulphur dioxide and some carbon disulphide. Low land use demand.

4.1.3 Synthetic

4.1.3.1 Acrylic

Description	Durable synthetic fibre made from polyacrylonitrile. Used in jumpers, hats, scarves, sportswear, and socks.
Key producers	Insufficient data.
Production	2.5 million tonnes per annum. Long-term decline.
Market	Accounts for 6.5% of the synthetic fibre market. Long-term decline.
Environment	High energy demands driven by raw material production and fibre production phases. Moderate water use, but high during fabric production phase (typically due to blending with wool).

4.1.3.2 Nylon

Description	Durable synthetic fibre comprising repeating units bridged by amide linkages. Widely used in swimwear.
Key producers	Asia, North America, Western Europe, Middle East.
Production	4 million tonnes in 2006, of which 1.5 million tonnes used in textiles (Oerlikon 2008).
Market	Accounts for 10% of man-made fibre market.
Environment	High energy demands and high water use (high level of water use in nylon polymer production). High energy use results in high greenhouse gas emissions. However, waste water volumes are relatively low. Recycled nylon has reduced energy requirements for polymer production, but will incur high transportation energy during acquisition than virgin material.

4.1.3.3 Polyester

Description	Strong and durable synthetic fibres produced during reaction of a diol with a carboxylic acid. Most common form is polyethylene terephthalate (PET).
Key producers	China (65% global production)
Production	30.7 million tonnes in 2007.
Market	Accounts for 77% of all man-made fibres and 83% of all synthetic fibres.
Environment	Moderate energy demands overall, except in polymer production phase. But low water use in all phases, and low waste water output. Polyester textiles can be recycled (when at 80%+ purity) delivering significant energy and greenhouse gas savings (up to 80% compared to virgin polyester production). However, at present, facilities and systems for recovery and recycling of polyester clothing are very limited.

4.2 Emerging fibres

4.2.1 Natural

4.2.1.1 Flax (short fibre) and tow

Description	Short-fibre by-product of line flax production that can be processed and blended with cotton, polyester, wool, acrylic, or silk.
Key producers	Europe with export of produce mainly to China for cottonisation (Anon 2008)
Production	Low level - potential for 100,000 tonnes per year within 10 years.
Market	Insufficient data.
Environment	Impact of production same as line flax; impact of dyeing and finishing same as cotton.

4.2.1.2 Hemp

Description	Bast fibre traditionally used in rope and canvas and with new uses in automotive composites and horticultural matting. Potential use as clothing fibre.
Key producers	Small scale production in China and Eastern Europe.
Production	85,000 tonnes in 2007.
Market	Currently accounts for 1% of the natural fibre market. Niche role in the “environmentally aware” clothing market in industrialised countries. Further growth unlikely due to low fibre quality and geographical range although attempts to refine hemp processing methods are underway.
Environment	Low energy use during all stages of fibre and fabric production. Overall low water demand generally, but moderate use of water during retting (fibre separation) phase. Low pesticide and fertiliser use in raw fibre production.

4.2.1.3 Jute

Description	Strong and durable bast fibre produced by *Corchorus* species used to produce low-grade fabrics for carpets, ropes, and sacks. Potential use in clothing when blended with finer fibres.
Key producers	India, Bangladesh.
Production	3.3 million tonnes in 2007 with recent growth.
Market	Natural fibre market share has fallen from 12.5% in 1977 to 9.5% in 2007. No evidence that jute will be cost effective as a clothing fibre.
Environment	Data scarce. Impact likely to be similar to flax or hemp.

4.2.1.4 Nettle

Description	Bast fibre traditionally used in ropes and cloth.
Key producers	EU (negligible current production).
Production	Negligible - less than 150 hectares in the EU 27. Germany, Netherlands and Himalayan Nettle Project.
Market	Potential for some growth but high production costs present a barrier to its use as a textile fibre.
Environment	Low water demand at all stages of production. Energy demand generally low.

4.2.1.5 Ramie

Description	Bast fibre extracted from *Boehmeria nivea* used in knitwear and linen-like textiles. Commonly blended with cotton. Lost cost fibre with well-developed processing technology.
Key producers	China, Brazil, Philippines and South Korea.
Production	Increased from 41,000 tonnes in 1977 to 285,000 tonnes in 2007.
Market	Accounts for 0.8% of the natural fibre market. Further growth unlikely.
Environment	Data scarce. Fabric production and dyeing and finishing stages assumed to be similar to cotton

4.2.1.6 Spanish broom

Description	Natural fibre extracted from Ginestra species traditionally used for cordage and heavy cloth.
Key producers	Experimental projects in Italy and Romania
Production	Negligible
Market	Insufficient data.
Environment	No data available. Fabric production and dyeing and finishing stages assumed to be similar to cotton.

4.2.2 Regenerated

4.2.2.1 Bamboo

Description	Fast-growing, low input crop. Fibres produced using the viscose process.
Key producers	China (Sichuan and Yunnan), Taiwan, Japan and US.
Production	9000 tonnes per year.
Market	Insufficient data.
Environment	High energy use at all stages. Water use generally low, but high during fibre production using the viscose process.

4.2.2.2 Lyocell

Description	Regenerated cellulosic fibre derived from wood pulp, primarily eucalyptus.
Key producers	Lenzing (Austria), Birla (India). Forestry and pulp by Sappi Saiccour (S. Africa)
Production	150,000 tonnes per year.
Market	Insufficient data.
Environment	Chemical and water use lower than viscose and Modal. Moderate energy use and relatively low water use at all stages.

4.2.2.3 Modal

Description	Regenerated cellulosic fibre derived from beech wood. Similar to rayon.
Key producers	Lenzing
Production	80,000 tonnes per year.
Market	Insufficient data.
Environment	Uses viscose process. Moderate energy demands and high water demand, mainly due to pulping operation.

4.2.2.4 Soybean

Description	Regenerated protein fibre derived from residual soybean material after oil extraction.
Key producers	Existing food soybean production in Argentina, Brazil, China, India, and the USA.
Production	3000 tonnes per year.
Market	Negligible current market.
Environment	Low energy demand during raw material production. Later production stages assumed to be similar to wool.

4.2.3 Synthetic

4.2.3.1 Polylactic acid (PLA)

Description	Polyester produced by polymerisation of lactic acid obtained by fermentation of maize starch or sugarcane.
Key producers	Japan, USA, Germany.
Production	80,000 tonnes, expected to increase to 210,000 tonnes by 2012.
Market	Insufficient data.
Environment	Relatively moderate energy demand, highest impact during raw material production. Low water use at all stages of production. Low land requirement compared to many natural fibres. Has the potential to be recycled or re-used under appropriate conditions, which will reduce impacts on energy demand – as shown for polyester.

4.2.3.2 Polytrimethylene terephthalate (PTT)

Description	Synthetic fibre derived from partially renewable feedstock. Plant-derived sugar feedstock fermented to produce (bio-) propanediol, which is then melt spun with terephthalic acid (PET) to form PTT.
Key producers	USA (DuPont, Sorona) China (Jiangsu Zhonglu Technology Co. Ltd)
Production	Insufficient data.
Market	Insufficient data.
Environment	Similar impacts to polyester, on which fibre is predominantly based.

5 Knowledge gaps

5.1 Current and future markets

- Data on the fibre production, and market potential of ramie, Spanish broom, and bamboo were unavailable or very limited.
- Clothing composition data only include the primary fibre component. A more complete and representative picture of UK fibre use in clothing would improve our understanding of how new fibres are being taken up in the market place, given that they are often included in blends to reduce costs during early stages of development.

5.2 Environmental impacts

- There is a lack of LCAs in the textile sector that take account of a wide and contrasting range of fibre types. Few take account of any natural fibre other than cotton.
- There is a specific need for LCAs that account for a wider range of environmental impacts than water and energy use, and in particular that review the impacts of chemical use in fibre production and processing.
- Studies also need to take account of the durability and lifetime of apparel products (including end of life use or re-use) to enable impacts associated with production phases alone to be examined in a wider context.
- LCA studies should take appropriate account to ensure allocation of appropriate environmental burden sharing to any co-products
- There is a general lack of environmental data for emerging fibres, including bamboo, jute, nettle, ramie, and soybean. Environmental data were also lacking for the more established fibres silk and viscose. There is a need for more information on these to be placed in the public domain to enable appropriate comparative analysis.

5.3 Social impacts

- With the exception of cotton, there is a general lack of published data on the social impacts of fibre production. This study has relied on more isolated and subjective reports.

6 Interpretation and implications

The following is a summary of the key findings of the project, including a brief assessment of the market potential and environmental sustainability of the fibres of interest. A complete analysis of the data and more detailed guidance on next steps for policymakers and industry can be found in the full report.

6.1 Major production trends

6.1.1 Current situation

Population growth and increased per capita textile fibre consumption have led to a doubling of global fibre output over the last 30 years (Oerlikon 2008; US Census Bureau 2008). Significant changes have also occurred in the types of fibres produced. The market share of man-made fibres has increased from 40% in 1977 to 56% in 2007 (Oerlikon 2008) and has exceeded that of natural fibres since the mid 1990s (Figure 1). Cotton alone accounts for 78% of the natural fibre market annual production has grown consistently over the last 30 years (Figure 2). However, cotton's share of the total fibre market has declined from 40% to 35% as a consequence of the growth in man-made fibres (Figure 1). Total man-made fibre production has increased from 12.3 million tonnes in 1977 to 44.1 million tonnes in 2007. This is almost entirely due to growth in the polyester market, with production showing an eightfold increase since 1977 (Figure 3).

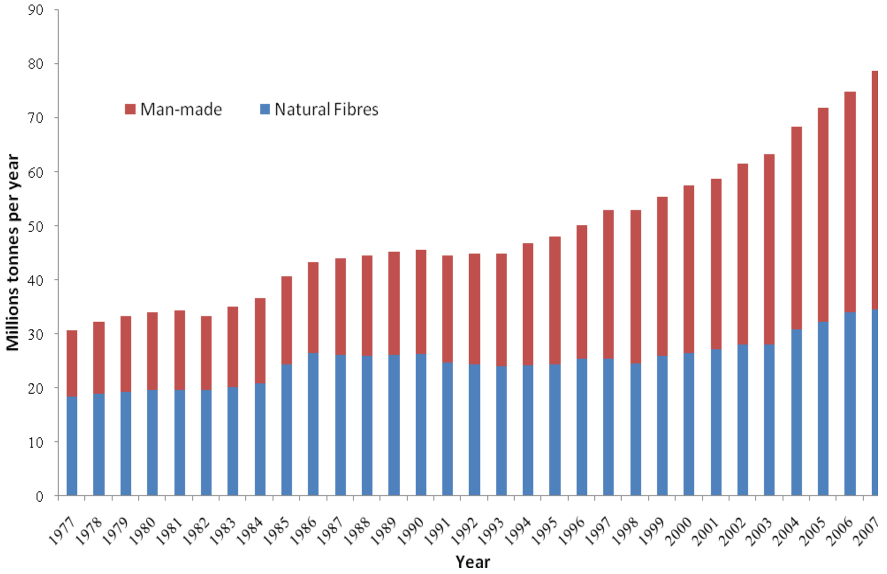


Figure 1. Global fibre production (Oerlikon 2008).

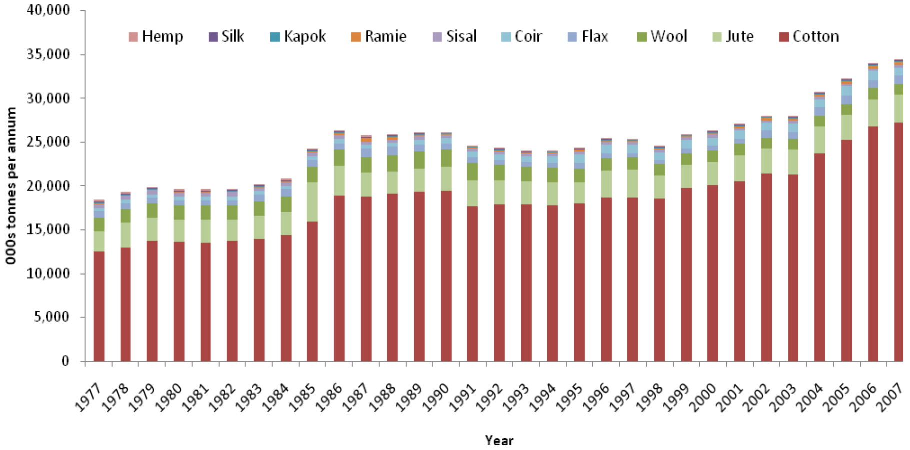


Figure 2. Global production of major natural fibres (FAO 2008).

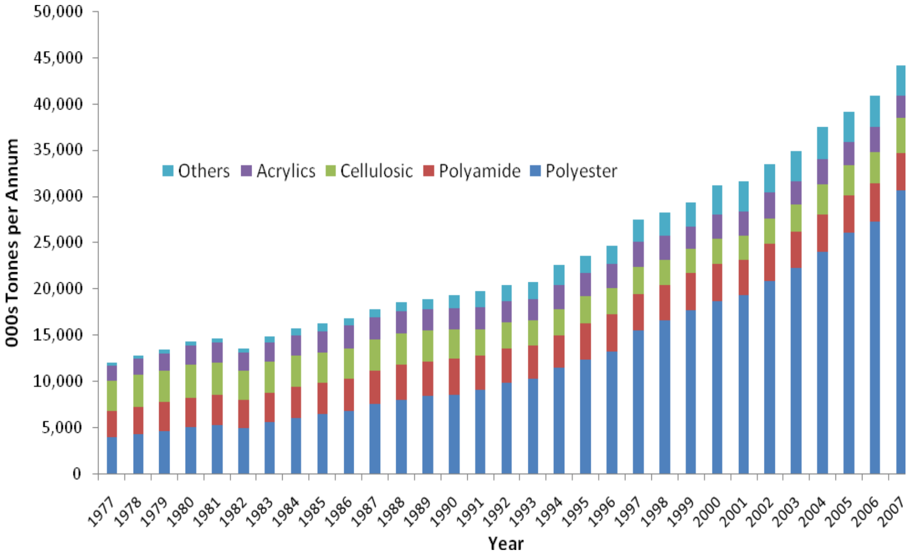


Figure 3. Global production of man-made fibres (Oerlikon 2008).

6.1.2 Potential markets

Increases in cotton and polyester production are expected to continue over the next ten years, with polyester maintaining its dominant market position. Other natural fibres are predicted to retain niche and specialist roles. Flax and silk production is likely to remain relatively constant due to their specialist uses while wool production is expected to continue its long-term decline. Hemp and ramie are predicted to retain small market roles (approximately 1%). Man-made fibre production will continue to be dominated by polyester with China consolidating its position as the world’s primary polyester manufacturer. Acrylic production is expected to continue its long-term decline and nylon production will likely remain constant. Some increase in PLA production is probable as new facilities are constructed in Germany and the USA, but production volumes will remain relatively small for the foreseeable future.

6.2 Sustainability assessment (covering raw materials to finishing stages)

6.2.1 Resource demands and pollution

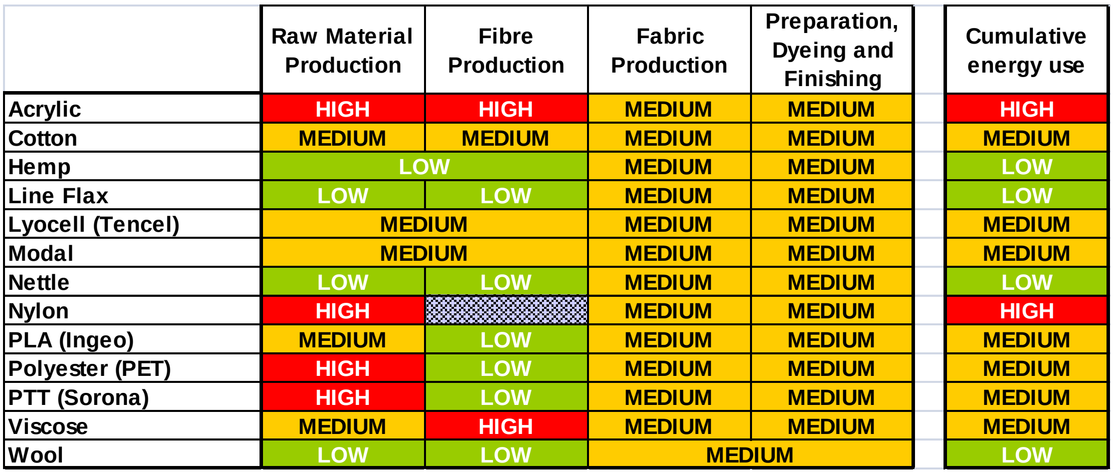
The sustainability assessment examined the energy, water, greenhouse gas, chemical, and land use implications of textile fibre production. Although evidence was lacking, the potential impacts of organic cultivation and GM varieties of natural fibre crops were examined. The issues surrounding social sustainability of textile fibre production were considered, but limited data were available. Information gathered on the energy use and water demands for individual fibres was used to produce summary impact tables for water and energy (Table 5 and Table 6 respectively). These provide a high-level indication only due to data and comparability limitations. The complete method used to calculate the band ranges is given in the full report along with a more comprehensive discussion of the environmental impacts.

6.2.1.1 Energy

Overall, the synthetic fibres acrylic and nylon are the most energy intensive, reflecting high inputs in terms of energy use and embodied energy in resources for polymer production. Pulping operations for regenerated cellulosic fibre production (viscose, lyocell and Modal) are energy intensive, but less so than for nylon and acrylic production, as a result, regenerated cellulosic fibres fall into the 'moderate' category for energy use in fibre production and processing.

Polyester, PLA and PTT have moderate energy demands in comparison to acrylic and nylon. Cotton also has a moderate energy demand, due to higher crop inputs , including artificial fertilisers, pesticides and fuel than the other natural fibres studied.

Table 5. Summary impact table for energy use.



	Raw Material Production	Fibre Production	Fabric Production	Preparation, Dyeing and Finishing	Cumulative energy use
Acrylic	HIGH	HIGH	MEDIUM	MEDIUM	HIGH
Cotton	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
Hemp	LOW		MEDIUM	MEDIUM	LOW
Line Flax	LOW	LOW	MEDIUM	MEDIUM	LOW
Lyocell (Tencel)	MEDIUM		MEDIUM	MEDIUM	MEDIUM
Modal	MEDIUM		MEDIUM	MEDIUM	MEDIUM
Nettle	LOW	LOW	MEDIUM	MEDIUM	LOW
Nylon	HIGH	▨	MEDIUM	MEDIUM	HIGH
PLA (Ingeo)	MEDIUM	LOW	MEDIUM	MEDIUM	MEDIUM
Polyester (PET)	HIGH	LOW	MEDIUM	MEDIUM	MEDIUM
PTT (Sorona)	HIGH	LOW	MEDIUM	MEDIUM	MEDIUM
Viscose	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
Wool	LOW	LOW	MEDIUM		LOW

Other natural fibres such as wool have relatively low energy use demands, with flax and hemp having the lowest overall demand on energy use. In the absence of sufficient available data, it is assumed that natural fibres such as Spanish broom, jute and Ramie would have an impact on energy use that would be similar to other non-cotton natural plant fibres, and the impacts of soy bean, and silk (protein-based fibres) on energy use are most likely to be similar to those of wool, where for example dye bath temperatures are lower.

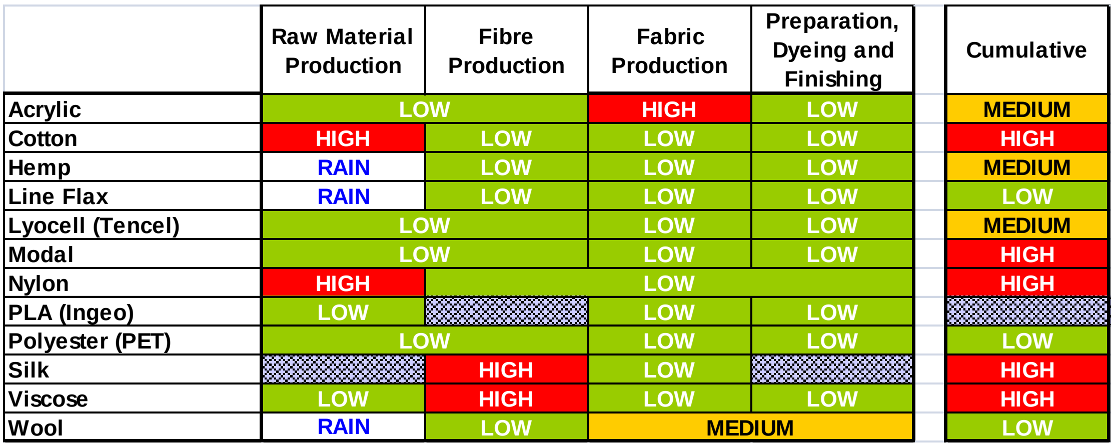
6.2.1.2 Water

Cotton is the most water demanding fibre, outstripping the water demands of all other fibres. Silk also uses very high volumes of water in the fibre spinning process (high enough to put it in the high impact category based on water use in this phase alone). Nylon also uses relatively high volumes of water, in polymer production and spinning operations, leading to a high overall impact on water use. The pulping operations involved in regenerated cellulosic fibre production result in overall, relative high water use for viscose and modal textile production. By comparison, water use for lyocell is moderate, which reflects appropriately on the modified 'closed' viscose process used for lyocell, which reduces steps in processing.

Acrylic has moderate water demands overall and polyester and PLA have relatively low water demands for most stages of production, but gaps in available published data for PLA fibre and fabric production mean that it is not possible to confidently allocate PLA to an overall relative impact category for water use in the absence of such data.

Excluding cotton, natural plant-based fibres all have relatively low water demands, with the exception of hemp production (medium impact), where water is used in retting processes to separate the fibres from the plant stems. Though a lot of water is used in wool production in cleaning and scouring operations, overall this has only a low impact on overall water use in wool textile production.

Table 6. Summary impact table for water demand.



	Raw Material Production	Fibre Production	Fabric Production	Preparation, Dyeing and Finishing	Cumulative
Acrylic	LOW		HIGH	LOW	MEDIUM
Cotton	HIGH	LOW	LOW	LOW	HIGH
Hemp	RAIN	LOW	LOW	LOW	MEDIUM
Line Flax	RAIN	LOW	LOW	LOW	LOW
Lyocell (Tencel)	LOW		LOW	LOW	MEDIUM
Modal	LOW		LOW	LOW	HIGH
Nylon	HIGH	LOW			HIGH
PLA (Ingeo)	LOW	▨	LOW	LOW	▨
Polyester (PET)	LOW		LOW	LOW	LOW
Silk	▨	HIGH	LOW	▨	HIGH
Viscose	LOW	HIGH	LOW	LOW	HIGH
Wool	RAIN	LOW	MEDIUM		LOW

6.2.1.3 Greenhouse gas emissions

Reliance on fossil fuels as the primary source of energy for all stages of textile fibre production means that greenhouse gas emissions are strongly linked to energy requirements. However, regenerated cellulosic fibres have low net greenhouse gas emissions due to the use of forestry feed stocks with low input demands and high carbon sequestration potential. In contrast, synthetic fibres have the highest impacts due to the use of both fossil fuels and fossil-based raw materials. Polyester recovery for recycling can reduce greenhouse gas emissions, but the small number of recycling plants currently mean that recycling is very limited in scale at present.

6.2.1.4 Chemical pollution

Waste water can become contaminated with dyes and finishing chemicals. Pesticides may also be present in waste water from crop cultivation. Cotton and wool blends generally use more basic chemicals during finishing operations than synthetic fibres. However, the use of dyestuffs and auxiliaries during the dying process is quite similar.

6.2.1.5 Land use

There is growing concern that the land area requirement of renewable raw materials will affect food production or increase the amount of land cultivated, with impacts on biodiversity. In addition, removal of biomass and the drainage, aeration, and disturbance of soils can lead to increased soil respiration and, consequently, increased carbon dioxide emissions. Any growth in natural or regenerated cellulosic fibre production will require increased yields and/or increased land area. Existing land use requirements of some of the fibres examined in this study are shown in Figure 4. Synthetic fibres derived from fossil resources have been excluded as their production typically has negligible immediate land area requirements.

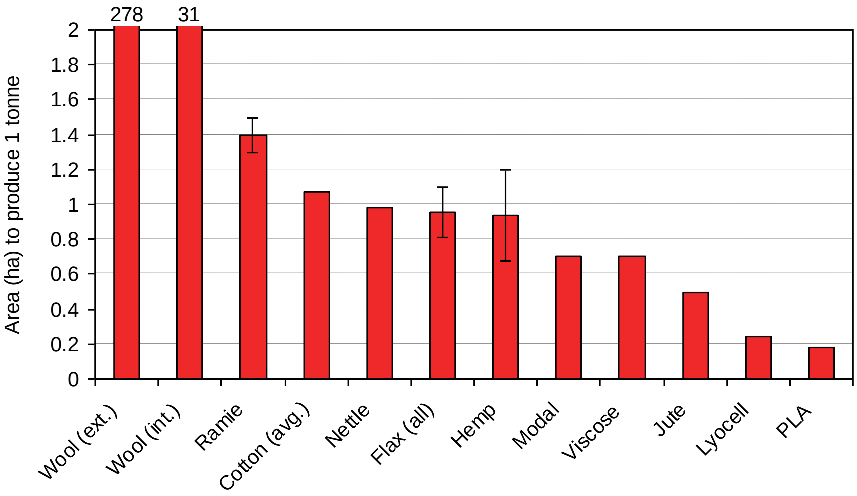


Figure 4. Land requirement for 1 tonne fibre production. Error bars indicate ranges of data. The bars for both extensive and intensive wool production have been truncated and their values given at the top of the graph.

Data on land requirements for fibre production are complex and scarce. Geography, climate, and cultivation techniques all affect crop yields and both environmental and economic factors lead to annual variability. However, several general conclusions can be drawn. Cotton has relatively high land requirements, while PLA and the regenerated cellulosic fibres viscose, modal, and lyocell require much smaller land areas. However, the biodiversity value of eucalyptus plantations may be comparatively low. Wool production appears to have enormous land area requirements but wool is by-product of meat production and grazing often takes place on land unsuitable for crop cultivation. In contrast, PLA and PTT (derived from sugar crops) and regenerated soybean fibres make use of existing food crops and so are in direct competition with food production.

6.2.2 Alternative cultivation techniques

GM cotton now accounts for approximately 50% of the global cotton area. Despite this, there has been very little detailed research into the environmental impacts of these novel varieties and so it is difficult to make conclusive statements about their sustainability. GM cotton is typically modified for pest-resistance or herbicide-tolerance and there is some evidence of increased yields and lower pesticide usage, suggesting a potential for lower environmental impacts. In contrast, organic cotton accounts for 0.2% of the current global cotton area. While there is the potential for higher revenues for growers, yields are thought to be lower and there may be increased processing costs and larger direct land requirements. However, standards and certification practices for organic production also impinge on downstream textile processing operations to reduce use of certain undesirable chemicals and processes, which should result in improvements in environmental performance, or at least ensure compliance with good environmental practice.

6.2.3 Social impacts

At present, cotton markets are distorted by subsidies paid to producers in industrialised nations, leading to lower incomes for farmers in developing countries. Low levels of safety awareness, poor enforcement of regulations, and lack of access to protective equipment also make pesticide use a major health concern in the developing world. Initiatives such as Fairtrade encourage sustainable economic development for farmers in poorer areas, but currently only reach a minority of cotton producers. Organic farming may increase product value and better access to GM varieties could increase yields and profits, but at present the two techniques are seen as mutually exclusive by buyers in industrialised countries.

6.2.4 Importance of use and end of life phases

The overall environmental consequences of a fibre are influenced by its impacts during laundering at the use phase and at end of life. It is not practical to assess environmental impacts during these stages on an individual fibre basis due to the prevalence of blended fabrics and also due to the wide range of uses for different garment types. Therefore, this section comprises a qualitative analysis to highlight key environmental issues. A thorough analysis of the environmental impacts of textile laundering in the UK has been conducted as part of a parallel Defra project "Reducing the Environmental Impact of Clothes Cleaning" (EV0419).

Washing accounts for 70–80% of the total life cycle energy use of an item of clothing, mainly due to the high energy requirement for heating water. The fibre manufacturing processes examined in this report can affect laundering energy demand in two broad ways. Firstly, the use of blended fabrics can increase garment longevity and improve drying characteristics. Secondly, antimicrobial coatings can be used to reduce odour and so reduce wash frequency, but the effectiveness of this is subject to consumer behaviour. Despite higher energy requirements for producing a polyester/cotton blend, taking both this and 'in-use' effects into account, pure cotton sheets result in 73% higher energy use over a 100 wash lifetime and a threefold increase in water use compared to cotton–polyester blend sheets.

The Defra project "Maximising Reuse and Recycling of UK Clothing and Textiles" (EV0421) has analysed the impacts of garment disposal. In terms of energy and greenhouse gas emissions, the impact of reuse is lower than that of recycling, which is lower than that of incineration for energy recovery or disposal in landfill. Efficient recycling requires effective identification of material composition and separation of different fibre types. Initiatives such as the Eco Circle system developed by Teijin Fibers Ltd aim to simplify the process with a common labelling system, consistent and homogeneous use of polyester, and an in-house recycling process. This can reduce energy consumption and carbon dioxide emissions by up to 84% and 77% respectively.

Minimising the impact of laundering may involve increased use of high-performance blends and coatings. However, efficient recycling depends on uniformity of fibre composition and minimal use of external applications. The dominant role of laundering in determining overall energy demand and greater scope for reuse may make more durable and easily cleaned blends a more sustainable option than single-fibre fabrics.

6.3 Summary and conclusions

This report has focused on the economic and environmental sustainability of fibre production and textile preparation. The results of this analysis have shown that current dominant fibres have relatively high environmental impacts but that their technical qualities and low cost make them appealing to both industry and consumers. Some niche and emerging fibres have considerably smaller environmental profiles but are incompatible with the existing industrial infrastructure (e.g. hemp) or are still under development (e.g. PLA). Consequently, niche fibres are expected to remain so for the foreseeable future.

The review has also revealed major knowledge gaps, particularly in the environmental profiles of niche fibres and in the social impact of textile fibre production. It is important to note that the environmental profiles presented in this report are a snapshot of current practices and the impact of fibre production will change with the adoption of new technologies and new raw material sources. Importantly, the report has also shown the importance of including use, reuse, and disposal in any assessment of sustainability.

6.4 Future directions

This study is a collation of the existing published information and expert consultation, pertaining to the cradle to gate environmental and social impacts of clothing fibres and influencing factors relevant to fibres associated with the use and end of life supply chain stages. This study has identified where relevant information is available in the public domain as well as the significant gaps that exist in current understanding.

The environmental impact tables for energy and water use in fibre production presented in this report provide a simple, high level indicator for identifying the key environmental impacts of a fibre, but is not intended as an accurate comparison, as the underlying data has significant gaps and comparability limitations. Further research to fill the data gaps in line with best practice LCA guidance and wider sustainable products initiatives are key next steps.

Credible LCA data development initiatives taking into account the need for global consistency in approaches across the textile sector should be utilised. For example the European Platform on LCA’s and its International Reference Life Cycle Data-System (ILCD) should be targeted to support the textile sector in improving data availability. The ILCD in particular is developing globally consistent independent peer-reviewed sources of LCA information using anonymised data collated from manufacturers. Similarly tools (e.g. Environmental Product Declarations (EPD 2009)) already available for several sectors should be developed for the textile sector as a means of developing a standard approach to conducting textile LCAs to help compare the environmental impacts of different products. To date, only one PCR on performance apparel exists. Several of the large fibre manufacturers and clothing Original Equipment Manufacturers (OEM's) have their own proprietary LCAs and sustainability material assessment tools that can contribute significantly to this. Many are participating in the Sustainable Clothing Roadmap which provides an industry framework to move forward with these next steps. In addition, industry support organisations and commercial consultancies have developed early tools to help identify the environmental impacts of fibres. These can be built upon.

Given the technical, cost and production barriers affecting the market development of emerging fibres such as hemp, soybean protein, PLA and cellulosic materials, that on-balance (and within the limited information currently available) may provide more sustainable alternatives to either dominant natural or synthetic fibres, priorities for further work in the short term should focus on textiles that are more widely represented in the market place (i.e. on cotton and polyester). Impacts on procurement decisions with regard to polyester and cotton are likely to have the greatest short-term impact to reduce fibre-related sustainability impacts across the textile industry.

If the gathering of more complete environmental data show benefits to switching to other textile fibres and technological developments ensure that emerging and niche fibres provide equivalent or better product performance, then measures may be necessary to promote the use of novel fibres or fabrics on a sustainability basis to overcome any cost barriers.

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