Ecological Footprint and Water Analysis of Cotton, Hemp and Polyester

Report prepared for and reviewed by
BioRegional Development Group and WWF Cymru

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Contents

Figures and Tables

Introduction

BACKGROUND TO THE STUDY

The BioRegional Development Group (BDG), supported by WWF-Cymru, commissioned the Stockholm Environment Institute to calculate the environmental burden of producing five textiles based products. The study was carried out as part of a wider research project into new technologies for hemp textile production undertaken by BioRegional in 2003–2004 (Blackburn et al., 2004) and building on BioRegional's previous work in this area (Riddlestone et al., 1995).

In a broader context, this study represents one of a number of investigations conducted by the Stockholm Environment Institute in the field of sustainable consumption. The World Summit on Sustainable Development (WSSD) in Johannesburg in 2002 called upon the international community to work toward improving global living conditions and to "encourage and promote the development of a ten-year framework of programs on sustainable consumption and production (SCP) in support of regional and national initiatives to accelerate the shift towards SCP." Sustainable consumption focuses on formulating equitable strategies that foster the highest quality of life, the efficient use of natural resources, and the effective satisfaction of human needs while simultaneously promoting equitable social development, economic competitiveness, and technological innovation. It is within this framework that a comparison is undertaken between the production of five textiles with regard to energy intensity, carbon dioxide (CO_2) emissions and water requirements.

This study therefore gathers information on the processes involved in textile production to perform an Ecological Footprint (EF) analysis and a water requirement analysis. The Ecological Footprint represents the amount of land area (measured in global hectares) required to provide all the necessary resources and absorb associated CO_2 waste to produce a given unit of textile, within the context of the Earth's biological capability to regenerate those resources. Although this measure does not take into account all the necessary conditions needed to achieve sustainable development, unless we recognise the ecological limits of the biosphere we cannot claim to be sustainable[1]. The study therefore compares, in Ecological Footprint terms, five textiles: cotton, organic cotton, hemp, organic hemp and polyester. Modern intensive cotton production has been associated with unsustainable water use and therefore this study will also investigate the water requirements of producing the cotton, hemp and polyester products from growth or synthesis of the raw material to the manufacture of the spun and woven fabric.

The production of any crop, including textile crops, results in some environmental degradation that can impact negatively on people's livelihoods and deplete biodiversity. However, crop production also has numerous human benefits. For example, in 1993 cotton production and manufacturing provided a livelihood for some 170 million workers in developing countries with approximately 125 million people directly dependent upon cotton growing (Doraiswamy, 1993).

This paper does not set out to provide all the necessary information for selection of fabrics based on alternative parameters to aesthetics, or to provide an argument for the selection of one fibre over another. The analysis presented should be regarded as a partial insight into the sustainability of textile production. However, what the paper does do is present estimates of the requirements, in terms of water and energy, for the production of five fibre types: conventional cotton, organic cotton, conventional hemp, organic hemp and polyester.

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[1] See Appendix E for details of the Ecological Footprint methodology

Structure of this report

The emphasis of this report is on the results rather than the methodologies employed. Firstly, we set the scene for textiles in the United Kingdom, in the context of the Ecological Footprint and water requirements, by providing a comparison to other goods. This is followed by a brief introduction to the three materials, including information on the industrial processes, trade patterns and significance in the textile market. The methodology section emphasises once again the boundaries of this study, along with its aims, data collection, sources and case studies. The results are presented in four sections: energy requirements, associated CO_2 emissions, Ecological Footprint and water requirements. These are explored further in the discussion section, and the report then concludes with a set of recommendations. Finally, the Appendix contains examples of input data, data sources, a description of the assumptions that were made and a short description of the Ecological Footprint calculation procedures.

TEXTILES IN THE UK

Textiles have been of great importance to humans throughout history and remain so to this day. The total value of textile imports into the United Kingdom (UK) is approximately £5,400 million per year, whilst total textile exports amount to some £3,700 million. In terms of customer expenditure, the UK population spends some £23 billion per year on textile and footwear products, equivalent to about 7 per cent of total retail expenditure (BTTG, 1999).

Ecological Footprint of textiles in the UK

The Ecological Footprint of textiles in the UK is shown in Table 1. Appendix E of this report provides a description of the Ecological Footprint technique, however, if a more detailed description is required please contact the authors. The data has been produced by combining an Input-Output approach with mass balance data collated from ProdCom (an EU database on production, imports and exports by industrial sectors).

Table 1. Ecological Footprint of textiles and other consumer items

Category	Total EF (000 gha.)	Energy Land (000 gha.)	Crop Land (000 gha.)	Pasture Land (000 gha.)	Built Land (000 gha.)	Sea (000 gha.)	Forest Land (000 gha.)
Clothing	1,706	1,415	90	15	50	31	105
Footwear	696	405	87	41	43	84	35
Household Textiles	791	639	60	11	16	20	45
Total	3,193	2,459	237	67	109	136	186
Total EF of UK	318,232	197,804	197,804	40,653	19,701	12,828	28,217
Textiles % of UK EF	1.0%	1.2%	0.1%	0.2%	0.6%	1.1%	0.7%
Alcholic Drinks	4,634	1,141	1,212	594	19	1,547	121
Insurance	2,738	2,106	100	48	121	95	267
Purchase of Cars	6,938	6,315	108	44	88	90	293

Source: Calculated by SEI using the "Resources and Energy Analysis Programme"

As Table 1 shows, it is estimated that the UK requires 3.2 billion hectares of land to provide its consumable items and absorb all the CO_2 produced. This equates to 5.35 hectares per capita. However, if we were to collect the world's available productive land and share it out amongst every person in the world, each individual would have two hectares. The UK is therefore consuming resources beyond the ecological capacity of the planet. This situation varies quite dramatically in different countries: the average per capita Ecological Footprint for India, for example, is 0.8 hectares, while at the other extreme, the average per capita Footprint for the USA is 9.5 hectares.

Table 1 also demonstrates the proportion of the UK Ecological Footprint that can be related to the consumption of textiles. Three categories have been considered: clothing, footwear and household textiles. Textiles will be used for other purposes but these three categories are considered the most significant. A number of random consumable items have been included in the list for comparison.

As a total of the UK Ecological Footprint, textiles consumed by households represent 1 per cent. The proportion is more significant in terms of energy land (1.2 per cent) compared to the other land types. Within textiles, it is clothing which has the most significant impact (accounting for 53 per cent), followed by household textiles, which includes soft furnishing and bedding.

When comparing textiles with consumable items and services, it is clear that the Ecological Footprint of textiles is higher than that of the insurance industry and lower than that of alcoholic drinks or the purchasing of cars. The Ecological Footprint of textiles includes all the intermediate demand by the industry sector to provide the final product.

Water requirements of textiles in the UK

This study represents one of the first attempts at capturing the water requirements of textiles consumed in the UK.

While not comparable with this study, some attempts have been made to identify the water requirements of consumer items imported into the UK. One such study, carried out for UNESCO by Chapagain and Hoekstra (2004), calculates the volume of water required to grow the cotton and produce the cotton goods imported into the UK in a typical year to be 1.7 per cent of the total per capita water footprint for the UK.

THE MATERIALS

To add context to the discussion in the report a short description of the industrial processes, trade patterns and significance in the textile market has been included for each of the three materials.

COTTON

Cotton fibres are the seed hairs from a wide variety of plants of the 'Gossypium' family (Laursen and Hansen, 1997), representing one of the oldest known fibres, dating back at least 5,000 years. Today, cotton provides 30–40 per cent of all global fibre requirements and it is grown in over 90 countries, 75 of which are developing nations (Soth and de Man, 1999). Since 1990, global cotton fibre production has been constant at around 20 million tonnes per year. The latest figures for the 2003 season show world raw cotton production at 19.78 million tonnes with five countries: China, USA, India, Pakistan and Brazil, accounting for 72 per cent of total production (Figure 1). The remainder is spread across a large number of much smaller producers in Africa (10 per cent), the rest of Asia and Latin America.

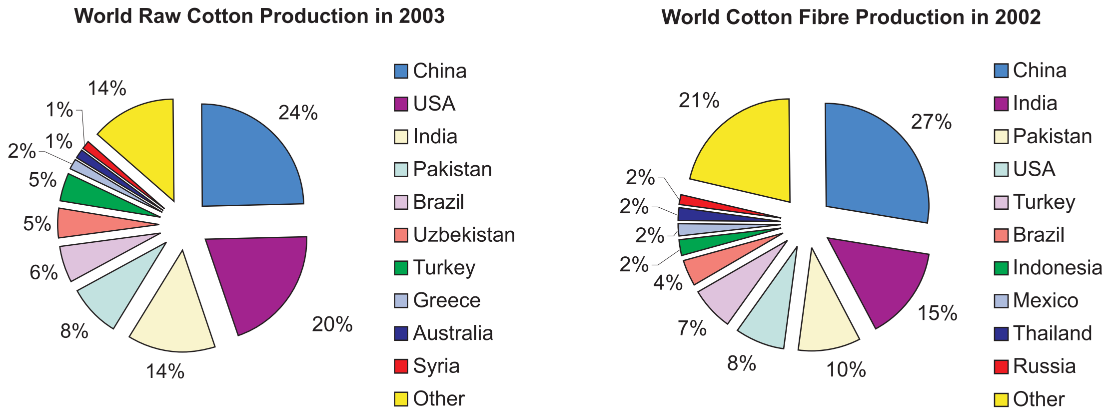


Figure 1. Global cotton production in 2003, for raw cotton, and 2002, for cotton fibre
(Source: USDA, 2004 and ICAC, 2003)

In 2002, UK cotton imports totalled an estimated 167,766 tonnes (121,222, 26,863 and 19,660 tonnes respectively of cotton products, raw cotton and waste cotton). This figure relates solely to the import of raw cotton and does not include the import of cotton in products. The majority is recorded as arriving in the UK from the EC (40 per cent), Asia and Oceania (35 per cent), and Western Europe (9 per cent) (see Appendix A for a list of countries in the EC and Western Europe) having been processed in, or traded through, these countries.

Cotton is of sub-tropical origin but has a broad production base across both the humid-warm temperate and semi-arid warm temperate zones, and is therefore grown in a very broad range of climates, soils and cultural practices, even within a given district. The type of cotton grown and the local soil and climate conditions are the major factors governing the choice of cultivation and processing methods, which will in turn impact on the Ecological Footprint and water requirements.

The steps involved in producing yarn from raw cotton are highlighted in Box 1.

BOX 1. MAIN PROCESSESS INVOLVED IN PRODUCING YARN FROM COTTON

1. **Cultivation**: following the preparation of the land the seeds are sown, shallow and thickly so the early weak plants can support each other. These plants are later thinned.
2. **Harvesting**: after flowering, a boll (segmented pod containing immature seeds from which the cotton fibres will grow) appears. Eventually the fibres grow and thicken, splitting the boll open ready for harvesting.
3. **Ginning**: following harvesting the cotton fibre is separated from the cotton seed in a process known as ginning, leaving the clean cotton fibre, now called lint, for baling.
4. **Cleansing**: at the textile mill, the bales are opened and the cotton is mixed and cleaned further by blowing and beating.
5. **Carding**: the cleaned fibre then enters a carding system, which combines and pulls the fibres together into a continuous length called a sliver.
6. **Combing**: these slivers continue to a combing machine where impurities are removed and the fibres are pulled and twisted to produce a smooth and uniform yarn.
7. **Roving**: the sliver is twisted and drawn out further to improve strength, then wound on bobbins. Having completed this process it is now called rove.
8. **Spinning**: the last process in yarn manufacturing. The roving is twisted into a yarn and placed on cones where it is stored until needed for the weaving process.

Source: Cotton's Journey (2004)

ORGANIC COTTON

Organic cotton production demands a radical change in production practices, processing and manufacturing systems. Cotton sold as organic must be grown according to established standards, which prohibit the use of toxic and persistent agro-chemicals, as well as GM organisms. Conventional practices are therefore replaced by a more holistic approach. Soil fertility practices typically include crop rotation, with the use of leguminous plants, cover cropping, animal manure and compost additions, and the use of naturally occurring rock powders. Weeds play an important part, creating ideal microclimates and harbouring or even attracting pests away from the crop. Weed management is mainly determined by crop rotation, which over time reduces the need to weed. Pests are not a major issue, with the focus of management techniques directed at enhancing and restoring natural balances between pest and natural enemy populations. These include trap cropping, strip cropping and the revival of traditional and cultural methods. Pre-harvest defoliation techniques that meet organic certification are limited to citric acid, flamers and frost, and unless the farm is highly mechanised, all cotton is hand-picked, thereby ensuring high quality fibres. The growing of organic cotton therefore not only enhances natural ecosystems but also increases human participation and a healthy lifestyle.

The first organic cotton projects were initiated by European and USA clothing companies in the 1980s, and by the early 1990s the first certified organic cotton was brought to market. Today, organic cotton is grown in 10–15 countries. In 2001, traded volumes of organic cotton fibre were estimated to be about 6,000 tonnes, representing only 0.03 per cent of cotton production worldwide (PAN UK, 2002). Most organic cotton is grown in Turkey (29 per cent) and the USA (27 per cent). Other major producers are India (17 per cent), Peru (9 per cent), Uganda (5 per cent), Egypt (3 per cent), Senegal (3 per cent) and Tanzania (3 per cent) (PAN UK, 2002).

Europe is by far the largest market for organic cotton (3,500 tonnes of cotton fibre), followed by the USA (2,000 tonnes). Within Europe, Germany (around 1,750 tonnes) and Switzerland (750 tonnes) are the most important markets for eco-textiles (PAN UK, 2002).

However, various factors have impeded wide scale adoption of organic cotton agriculture and consumer demand for organic cotton products. Firstly, the absence of synthetic fertilisers and the adoption of crop rotation programmes results in yields which are 20–50 per cent lower (Boon, 1999). For production of organic cotton to replace production of all conventional cotton, a greater land area would therefore be required. There are also additional costs at each stage of processing. Boon et al. (1999) report organic fibre costs in the USA to be: 37–65 per cent greater at the cultivation level due to increased labour, machinery and fuel costs; 1–2 per cent greater at the ginning stage; 20–50 per cent greater at the cleaning, carding, spinning and handling stage; and 5–10 per cent greater at the finishing stage. The average price for organic cotton lint in the USA is therefore 37–65 per cent higher than for conventional lint. These added costs are reflected in the price of the final product, which not all consumers are willing to pay.

HEMP AND ORGANIC HEMP

Industrial hemp (*Cannabis sativa*) is native to Central Asia. It is, however, a robust crop which grows readily in most temperate or subtropical climates (Weindling, 1947) and is even capable of growing in climates ranging from the Arctic to the equator. It is a low maintenance crop requiring low inputs, including agro-chemicals, during the growing season. Hemp grows rapidly, faster than weeds, and it has to date not been plagued by pests. Therefore the changes required in the cultivation of hemp to produce organic hemp are minimal.

Hemp is a multi-use annual crop cultivated for fibre, animal feed and seed. It was a traditional European fibre crop which, for centuries, played an important role in meeting demand for textiles, rope and paper. During the first 40 years of the 20th Century around 2.5 million acres of land were devoted to hemp production but this dramatically reduced as a result of the two World Wars. Production ceased in the USA and the UK because the crop was made illegal due to its association with narcotics. Low narcotic varieties have been developed allowing cultivation in Europe once again, although hemp remains an illegal crop in the USA. Total world hemp fibre production in 2003 was approximately 77,450 tonnes (representing only 0.15 per cent of world fibre production) with five main producers: China (45 per cent), Spain (19 per cent), Peoples' Republic of Korea (16 per cent), Russia (8 per cent) and Chile (5 per cent) (FAO, 2004).

In the UK the ban on hemp was lifted in 1993, and 1,620 hectares were cultivated in 1994, the figure rising to 3,000 hectares in 2003. In 2003, the area under hemp cultivation in the EU had increased to around 17,500 hectares. The average yield of dry hemp stalks in the EU is about 12–15 tonnes per hectare, yielding approximately 3 tonnes per hectare of the final fibre product (Karus, 2003). In 2002, the UK also imported an estimated 51 tonnes of hemp of which 25 tonnes arrived from France, 13 tonnes from Germany, 12 tonnes from Israel and 1 tonne from Switzerland (Figure 2). This hemp came in two forms: raw, or retted; and broken, scutched, combed (for details see Appendix B).

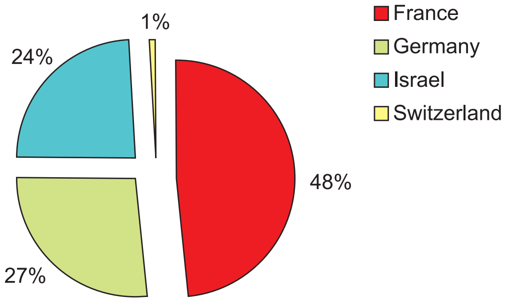


Figure 2. Total UK hemp imports by country in 2002
Source: Uktradeinfo, 2002

In the UK hemp is mainly used for animal bedding, paper and non-woven textiles. Historically its use as a fibre for clothes was more widespread but it has been replaced by cotton and wool. Hemp rope and rigging for ships have been replaced with wire rope, which is more lasting and rigid.

Hemp textile fabric and clothes made in China and Eastern Europe are currently exported around the world in small quantities. According to BioRegional, the methods used to produce hemp textile fibre in China involve only human labour up to the point of fibre for spinning. In Eastern Europe some machines are used and the process is similar to that used in the production of linen from flax all around the world. This is the method detailed in Box 2. However, overall, hemp plays a very small part in the global textile industry and if this were to change it would need to overcome a series of technical constraints, involving the entire sequence of production and utilisation (Liberalato, 2002). At present, the traditional processing of hemp is still at the same technological level it was at fifty years ago and consequently it is only viable in countries where labour costs are low. The important process of retting (see Box 2) is highly dependent on weather conditions, which when not ideal can result in crop failure and subsequent economic losses. This is one process in the hemp production chain that can, with technical help, be overcome. This area is explored in the research project carried out by BioRegional during 2003–4 the findings of which were used in this report. The steps involved in producing hemp are highlighted in Box 2.

BOX 2. TRADITIONAL METHOD OF TEXTILE PRODUCTION FROM HEMP

1. **Cultivation**: sowing the seed densely to produce tall, slender stems that contain a greater amount of finer fibre.
2. **Harvesting**: takes place after flowering but before the seeds set (the fibre content is reduced and becomes coarser toward seed formation).
3. **Retting**: the process whereby naturally occurring bacteria and fungi, or chemicals, break down the pectins that bind the hemp fibres to be released. One of two methods are generally used:
    - a) **water retting**, involves soaking the stems in water in tanks, ponds or in streams for around ten days; more effective if water warm and laden with bacteria; in the past potash or soap was added to accelerate retting;
    - b) **dew retting**, entails laying the crop on the ground for three to six weeks turning as necessary to allow even retting.
4. **Breaking**: the stems are then broken by passing them through a breaker or fluted rolls.
5. **Scutching**: the broken stems are then beaten in a process known as scotching, which allows the fibre to be separated from the woody core.
6. **Hackling**: the fibres are then hackled (combed) to remove any remaining woody particles and to further align the fibres into a continuous sliver.
7. **Roving**: the sliver is twisted and drawn out further to improve strength, then wound on bobbins. Having completed this process it is now called rove.
8. **Spinning**: generally to produce a better, finer yarn the fibres are then thoroughly wetted in a small trough of water as part of the spinning process, known as wet spinning. Though fibres can also be dry spun with a resulting coarser yarn.

Source: Riddlestone et al., 1995

POLYESTER

In 1941, the first polyester fibres were developed in the UK. Polyester (polyethylene terephthalate or PET) is manufactured from mineral oil (see Box 3) and is now the world’s major man-made fibre for textiles and industrial applications. In 2001, polyester represented 32 per cent (17 million tonnes) of the world fibre production (Stepanski and Rutti, 2003). This popularity can be attributed to the textiles’ properties which make it stretch resistant with thermal stability and low moisture absorption. The steps involved in producing polyester are highlighted in Box 3.

BOX 3. POLYESTER (PET) TEXTILE PRODUCTION

1. **Cracking:** is the process of breaking down long chain hydrocarbons produced during petroleum refining into lighter more useful short chain products. Ethylene are the starting compounds for the commercial production of PET and are produced by cracking either natural gas or the naphtha fraction of crude oil.
2. **Separation:** the cracking process also produces small quantities of xylenes including ortho-xylene, meta-xylene and para-xylene. Before being used in the production of terephthalic acid, the different isomers of xylene are separated, with para-xylene retained for use in the production of PET.
3. In practice, there are two routes used in the production of PET precursors from para-xylene:
   a) **Oxidisation:** is the process through which a substance undergoes a chemical reaction with oxygen. Para-xylene is oxidised to terephthalic acid (TPA) which is then purified.

      Esterification: is the process of making something into an ester. An ester is an organic chemical compound formed by the reaction of an alcohol with an organic acid, with the loss of a water molecule.

      The purified terephthalic acid (PTA) is then reacted with ethylene glycol to produce bishydroxyethyl terephthalate (BHET) with water as a by-product.

   b) The alternative route is **Oxidation**: para-xylene is oxidised to terephthalic acid but then immediately reacts the acid with methanol to produce dimethyl terephthalate (DMT).

      Esterification: the DMT is reacted with ethylene glycol and the result is bishydroxyethyl terephthalate, as in the alternative route, but there is a liberation of methanol rather than water. The methanol is recovered and re-used.
4. **Melt Polymerisation:** polymerisation is a chemical reaction in which two or more monomers are joined together in a chain to form a polymer. In this instance the monomer from either route is then polymerised in the liquid phase to produce amorphous polyethylene terephthalate (PET). The polymerisation reaction is sometimes carried out on the site where the fibres are produced but some fibre producers buy in polymer resin.
5. **Solid State Polymerisation**: the second polymerisation in the solid state increases the molecular weight of the polymer and produces a partially crystalline resin.
6. **Spinning Preparation**: if the polymer resins are bought in, they will need to be reheated prior to spinning, otherwise direct melt spinning of molten PET from the polymerisation equipment will take place.
7. **Spinning:** carried out almost exclusively with extruders which feed molten polymer under pressure through the tiny holes of a device called a spinneret. Filament solidification is induced by blowing the filaments with cold air at the top of the spin cell. The filaments are then led down the spin cell through a fibre finishing application, from which they are gathered into tow, hauled off and coiled into spinning cans.

Source: Boustead, I. (1995) and (1997)

In 2002, the UK imported 208,428 tonnes of polyester in both yarn and woven fabric form (for details on types see Appendix C). The majority of this polyester came from five countries: Germany (43,300 tonnes), Irish Republic (40,246 tonnes), Spain (16,601 tonnes), Turkey (15,332 tonnes) and India (13, 923 tonnes). Polyester textile production no longer takes place in the UK, however there are a couple of plastic manufacturers producing PET resin which is mostly used for the production of PET bottles.

The production of polyester is not without problems. Firstly, it is produced from oil, a non-renewable resource, making the long term production of this fibre uncertain. Secondly, the manufacturing process involves high energy inputs which, unless sourced from renewable energy, generate large amounts of particulates, CO_2, nitrogen oxides, hydrocarbons, sulphur oxides and carbon monoxide subsequently released as atmospheric emissions (Laursen and Hansen, 1997). Major water-borne emissions from polyester production include dissolved solids, acids, iron and ammonia (Franklin Associates Ltd, 1993). In terms of world consumption of chemical feedstock, the production of man-made fibres accounts for about 5 per cent of the total.

Methodology

PUTTING THIS STUDY INTO CONTEXT

This study provides a water requirement and Ecological Footprint analysis of different materials. These calculations have been made in isolation and not placed within the context of the socio-economic issues that surround the production of textiles, particularly in developing countries, and all the complexities that this would add to the analysis.

For example, cotton has become a means of considerable economic development and enhancement in some of the poorest regions of world, such as the Sudan, where the Gezira Scheme was established in the area between the Blue and White Niles. The backbone of the scheme was the cultivation of cotton and one of the major consequences of the scheme is one of the highest standards of living and education for the workers in the whole of Africa (Gaitskell, 1959). However, such prolific developments are often overshadowed by reports of the negative environmental, social and economic impacts, including the large water requirements of cotton in already water stressed nations and the impact of agro-chemical use.

The issue of agrochemical use in the production of cotton is connected with specific environmental impacts which are not captured in this analysis. As is the case with most other crops, agrochemicals, including fertilisers, insecticides, herbicides, growth regulators and defoliants, have become an integral part of cotton production practices (consuming 11 per cent of the world's agrochemicals) and are a crucial factor in realising an optimum yield under any set of agroclimatic conditions and practices (Chaudhry, 1995). Although fertilisers form the bulk of agrochemicals used to grow cotton, the use of pesticides is considered the most serious problem. Extensive domestication, widespread cultivation and monocropping, expose commercial cotton to a range of environments which harbour alien pests and diseases with which it has no inherent ability to compete. Large quantities of the most acutely toxic pesticides are used in the production of conventional cotton, insecticides alone accounting for about 24 per cent of the global insecticides market in 1994 (Myers and Stolton, 1999). At the same time, cotton acreage amounts to only 2.4 per cent of the world's arable land (Soth and de Man, 2000).

The most prevalent socio-economic impacts associated with agrochemical use documented have been: fatalities, short term illnesses, increased medical costs and the build up of pesticides in human and animal food chains. Contamination of drinking and ground water, the evolution of insect resistance/resurgence, pest/predator cycle disruptions, biodiversity and soil fertility reduction have also been documented. Such effects are not cotton specific, but may be prevalent where there is widespread intensive application of agrochemicals.

In addition, the issue of environmental impacts associated with water availability has not been addressed in this study. The production of cotton across regions with Mediterranean, desert or near desert climates where freshwater is in short supply (e.g. Uzbekistan, Australia or Egypt) has been made possible through irrigation. Typically, 7,000 to 29,000 litres of water (averaging about 10,000 l) are required to grow one kilogram of cotton and in most areas, where there is insufficient rainwater, the shortfall must be made up with irrigation water. Soth and de Man (2000) estimate that approximately 73 per cent of global cotton is harvested from irrigated areas.

Most irrigation systems in cotton production rely on the traditional technique of flood irrigation in which freshwater is extracted from a river, lake or reservoir and transported through an open canal system to the place of its consumption. Losses of freshwater occur through evaporation, seepage and inefficient water management. Worldwide, irrigation efficiency is lower than 40 per cent (Gleick, 1993). In addition, irrigation of cotton is associated with negative impacts on the regional freshwater resources including eutrophication, salinisation, pollution, wildlife contamination, raising water tables and habitat destruction. The shrinking of the Aral Sea, the world's fourth largest lake, following the diversion of rivers for cotton irrigation, is the most cited environmental disaster associated with cotton production.

The water stress and vulnerability of a region is difficult to characterize in a generally accepted way. There is no agreed measure of water sustainability. This fact was emphasized by the Comprehensive Assessment of Freshwater Resources of the World (SEI, 1997). Data for country sub-divisions frequently do not exist as they are usually collected (or, at least generally recorded) on a national basis. A use to resource ratio – annual water withdrawals divided by annual renewable water resources – is probably a realistic indicator. A related indicator is water quantity – an indicator of internal renewable water per capita and per capita water inflow from other countries.

Apart from CO_2, this study does not take into account any other atmospheric emissions associated with the production of any one textile.

Consequently, any use of the figures presented in this report must also consider such factors as socio-economic benefits and impacts, pollution factors, the availability of raw materials including energy and water sources, and product disposal.

AIMS OF THIS STUDY

This study therefore aims to:

1. make a preliminary estimate of the environmental burden, in Ecological Footprint terms, of five textiles: cotton, organic cotton, hemp, organic hemp and polyester;
2. identify which processes undertaken throughout the documented life cycle components of the five textiles are responsible for contributing the greatest to the Ecological Footprint; and
3. calculate the average water requirement for the production of fabric from cotton, hemp and polyester, from crop cultivation or synthesis to the woven un-bleached and un-dyed product.

DATA COLLECTION

Ecological Footprint

Sources of information and data availability

The fibre production data used in the Ecological Footprint calculations varied both in terms of availability and quality for the five textiles (Table 2). The data on cotton production was the most variable and it therefore had to be based on literature from several information sources, thus enabling the cross-checking of data, and at the same time avoiding the deriving of an average figure, thereby ensuring that more than one practice of cotton production was accounted for.

Table 2. Fibre production data sources

Textile	Case Study Data Sources
Cotton and Organic Cotton	BioRegional Development Group (2004) Larson and Fangmeier (1978) Singh et al., (2000)
Hemp and Organic Hemp	BioRegional Development Group (2004) Blackburn et al (2003) Bridge Mackie Textile International Ltd (2004) Depoortere Ltd (2004) Hemcore Limited (2004) J.L. Brierley Spinners Ltd (2004) Macart Textiles (Machinery) Ltd (2004) R. Gledhill Ltd (2004)
Polyester	Franklin Associates Ltd (1993) Boustead (1995) Kalliala and Nousiainen (1999)

Research problems and limitations

Due to the great differences in cotton production practices throughout the world it was not considered helpful to estimate an average Ecological Footprint figure. In an attempt to overcome this problem we tried to find case study specific data for both the agronomic production (e.g. Punjab, India) and manufacturing processes (e.g. UK textile mills), although the data were not from the same study. It was therefore not possible to calculate a complete Ecological Footprint of cotton from one case study alone; a combination of sources had to be used.

Initially we had hoped to collect data down to the level of each process involved in producing the fibre, from the sowing of the seed (or extraction of the mineral oil in the case of polyester) through to the spinning of the fibre. It quickly became evident that this would not be possible, because some studies had the information in the detail we had expected (Singh et al., 2000) and others did not (Franklin Associates Ltd, 2003). Again, these various sources were combined in order to enable a comparison and analysis of the textiles.

Research parameters

In view of data limitations twelve scenarios were developed and explored: two for both cotton and organic cotton; three for both hemp and organic hemp; and two for polyester (see Table 3). For both cotton types, the scenarios represent different cultivation practices of varying energy intensity in different parts of the world but with the same manufacturing process. Hemp and organic hemp scenarios involve the same cultivation practices with three forms of manufacturing processes and two spinning methods. Two case studies, one set in Europe and the other in the USA represent polyester.

Table 3. The twelve Ecological Footprint scenarios of this study: location and type of cultivation practice with manufacturing process

Scenario Number	**Textile (abbreviation for charts in brackets)**	**Case Study***
1	Cotton Punjab (Cotton–Punjab)	Low energy use in medium-sized farms: Punjab, India
2	Cotton USA (Cotton–USA)	High energy use in medium-sized farms: USA
3	Organic Cotton, Punjab (Org Cotton–Punjab)	Low energy use in medium-sized farms in Punjab, India
4	Organic Cotton, USA (Org Cotton–USA)	High energy use in medium-sized farms in the USA
5	Hemp, experimental process (Hemp–exp)	Experimental processing using Fibrenova technology green decortication and a non-aligned system with chemical de-gumming (UK)
6	Hemp, semi-experimental process (Hemp–semi-exp)	Cultivated by Hemcore, dew retted and processed through a non-aligned system with experimental chemical de-gumming (UK)
7	Hemp traditional process (Hemp–trad)	Cultivated by Hemcore, dew retted and processed through an aligned scutch mill system as used by the linen industry (UK)
8	Organic Hemp experimental process (Org Hemp–exp)	Organic hemp experimental processing using Fibrenova technology green decortication and non-aligned system with chemical de-gumming (UK)
9	Organic Hemp semi-experimental process (Org Hemp–semi exp)	Cultivated organically by Hemcore, dew retted and processed through a non-aligned system with experimental chemical de-gumming (UK)
10	Organic Hemp traditional process (Org Hemp–trad)	Cultivated organically by Hemcore, dew retted and processed through an aligned scutch mill system as used by the linen industry (UK)
11	Polyester Europe (Polyester Europe)	Polyester manufacturing in Europe
12	Polyester USA (Polyester USA)	Polyester manufacturing in USA

*Assumption is that all cotton and hemp is spun in a UK textile mill except Hemp 7 and Hemp 10 which are wet spun using the linen system and polyester which is not spun but rather extruded.

Details of the data collected, conversion factors and calculations adopted can be viewed in Appendix E.

WATER ANALYSIS

To assess the water demand of cotton and hemp production and its subsequent processing in relation to imports into the UK, it was initially proposed that this assessment would distinguish between an agronomic phase and a manufacturing phase. It was proposed that the agronomic phase would investigate not only crop growth water requirements but also water use in cultivation, pesticide and fertiliser application and harvesting. The manufacturing phase would distinguish between water use in ginning, baling, spinning, weaving, finishing, dying and printing. However, this has been simplified into the calculation of mean overall values for the two broad phases (agronomic and processing) due to the dominance of water use by irrigation and rainfall to the crop, and the lack of data for water use at individual steps in cultivation and processing.

The second constraint was on the availability of data on the percentages of water provided by rainfall and irrigation to cotton and hemp, and the mode of irrigation, and hence transmission and evapo-transpiration losses. It is evident that this will vary greatly according to the geographical location and associated rainfall patterns, the availability of technology and traditional practices. Accordingly, the water requirements of cotton and hemp have been calculated as a global average.

Polyester is a considerably different fibre in terms of its production process, and its water requirement calculation is therefore based on the water input to the synthesising process.

The data used for all calculations (except for the water requirement for cotton dyeing in Bangladesh) is from secondary resources and where possible more than one source has been used. However, as will be seen in the calculations, this was not always possible and there is considerable disparity in published figures from different sources, as a result of the variety of cultivation and irrigation techniques mentioned above.

Results

The results are presented for all the analyses undertaken in this study. Firstly, the results of the energy analysis are given, followed by the CO_2 emissions, the Ecological Footprint analysis and finally the water requirement analysis.

ENERGY REQUIREMENTS

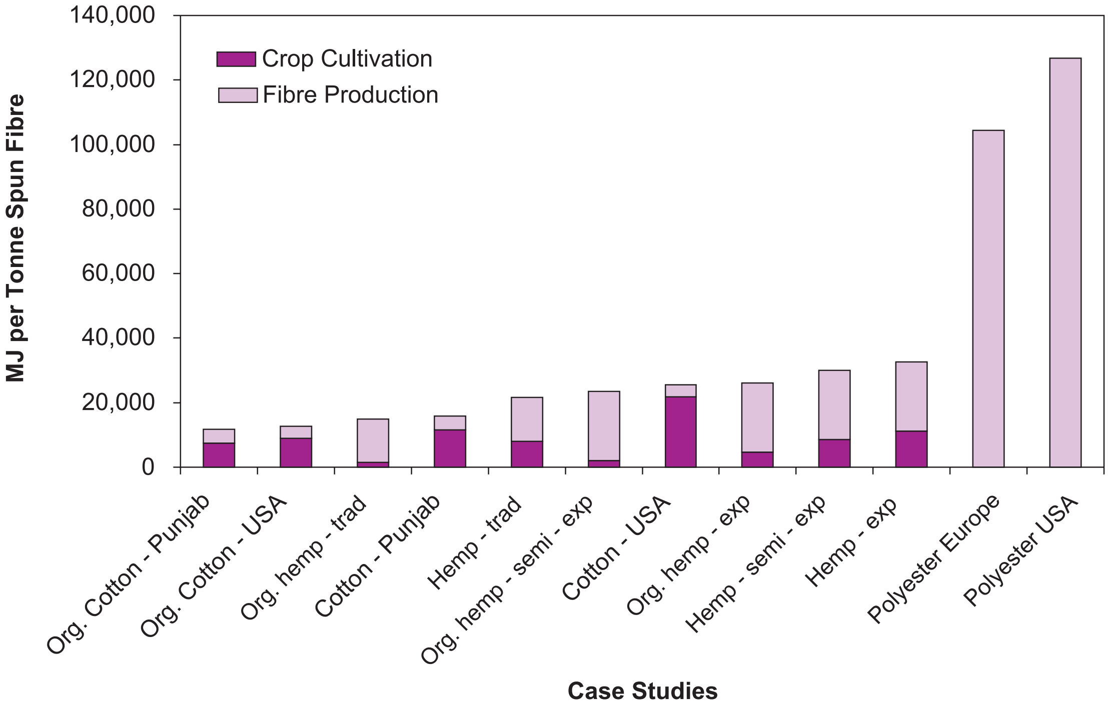


Figure 3. Total energy (in megajoules) required to produce one tonne of spun fibre

As presented in Figure 3, total energy required for the production of one tonne of spun fibre varies significantly in the twelve case studies with polyester consuming the most (104,479 and 126,706 MJ). It is suggested that the difference between the two polyester studies could be attributed to a difference in the PET processing method due to geographical location or an improvement in technological efficiency during the time between which the two studies were conducted. The "Polyester 1" study is more recent and represents a consistent methodology developed by Boustead (1995) for all plastics.

Despite the existing variation (22,227MJ) between both polyester studies, they clearly demonstrate the considerably larger energy requirement for production of synthetic fibre in comparison to hemp and cotton. It is important to note that the energy required for production includes the feedstock, or raw material. If the feedstock is not included, the energy requirement of polyester drops by approximately 36 per cent. However, the energy requirement of polyester is significantly greater than that of cotton and hemp, which require between 11,000 and 32,000MJ, even when allowing for large error margins.

The range of energy required for cotton varies from 11,711MJ for organic cotton grown in a low energy use system in Punjab, to 25,591MJ for conventional cotton grown in a high energy use system in the USA. Figure 3 demonstrates that conventional cotton requires greater energy inputs into the crop cultivation stage and highlights the potential energy savings (a total of 12,929MJ in the USA study) that could be made by omitting synthetic fertilisers, herbicides, and in the case of the USA study, energy intensive irrigation schemes.

A similar range of energy requirements exists for hemp, from 15,009MJ for traditionally processed organic hemp to 32,622MJ for conventionally grown hemp processed through a green decortication system. In contrast to cotton, the greatest energy requirements for hemp are in the fibre production stage, as the cultivation of the crop requires fewer inputs. However, energy savings of 6,596MJ are still achieved when hemp is cultivated organically instead of conventionally.

The hemp fibre production process that requires the least energy at 13,500MJ is the traditional system of scutching, hackling, roving, drawing and wet spinning.

The experimental green decorticated non-aligned fibre production process which was the subject of the wider research project carried out by BioRegional – which involves scouring, drying, carding and dry spinning – is much more energy intensive requiring 21,449MJ per tonne of spun fibre. A large proportion of this energy (13,863MJ) is required to heat water to temperatures up to 110°C.

CARBON DIOXIDE EMISSIONS

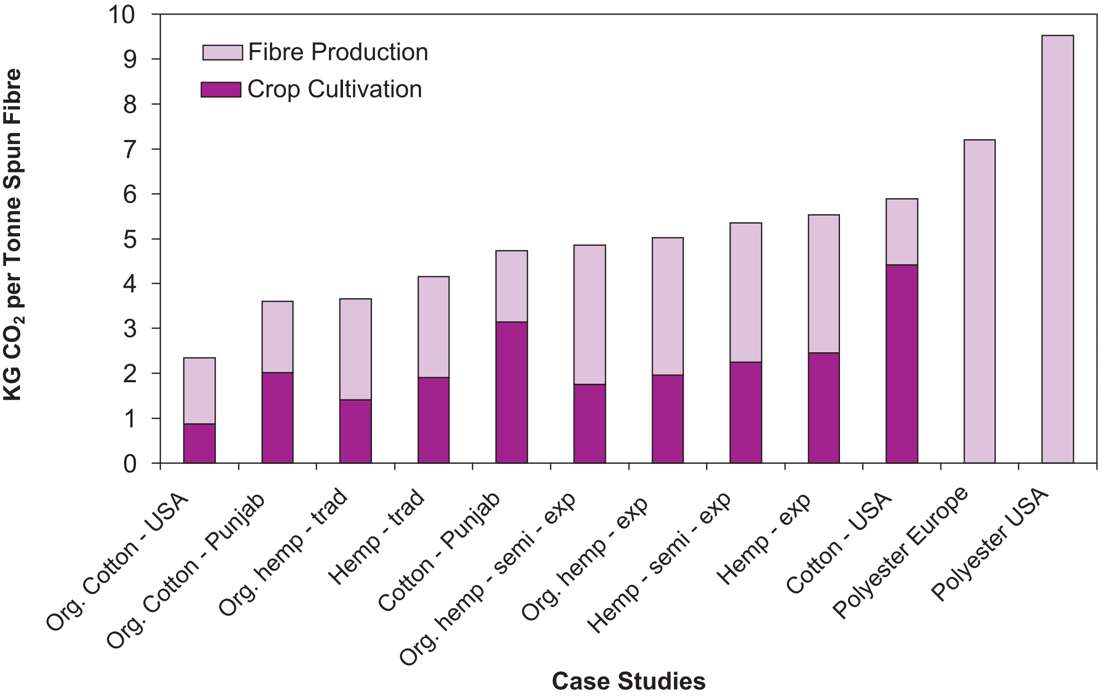


Figure 4. CO_2 emissions (in kilograms) associated with the production of one tonne of spun fibre

The CO_2 emissions associated with the production of one tonne of spun fibre are closely linked to the energy requirements of producing that fibre (Figure 4). As described in Appendix E, the fuel mix variation between countries has been taken into account; therefore different conversion factors for MJ/CO_2 were adopted according to the location of production. This is the only factor distinguishing the CO_2 analysis from the energy analysis.

Polyester production emits the greatest CO_2 emissions, ranging from 7.2 to 9.52kg of CO_2 per tonne of fibre. Again, CO_2 emissions associated with cotton range widely from 2.35 to 5.89 kg of CO_2 per tonne of fibre. In this case, however, organic cotton grown in the USA has the lowest value despite less energy being used in the organic cotton system employed in Punjab. This discrepancy reflects the different fuel mix used by the two countries, implying that the proportion and type of fuel used to generate energy in India produces greater CO_2 emissions per unit of fuel than that used in the USA, which in turn produces greater CO_2 emissions than that used in the UK. This is further supported by the fact that the conventionally grown cotton system in the USA produces more CO_2 emissions per tonne of spun fibre than conventional hemp processed through the green decortication system in the UK, even though the latter requires 7,032 MJ/tonne more energy to produce than the cotton system in the USA.

As all the hemp case studies were based in the UK, CO_2 emissions follow the same pattern as the energy requirements outlined in the section above.

ECOLOGICAL FOOTPRINT

Summary of all results

Finally, the Ecological Footprint, represented in global hectares (gha), of producing one tonne of spun fibre is presented in Figure 5.

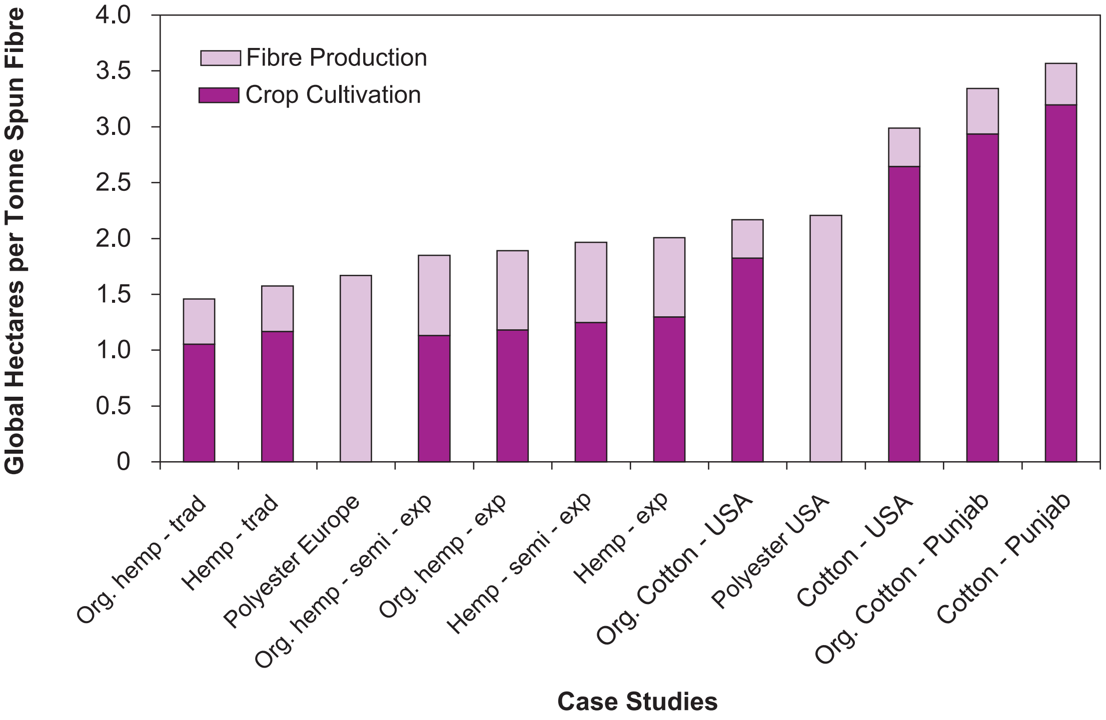


Figure 5. The Ecological Footprint (in global hectares) of producing one tonne of spun fibre

In this instance polyester occupies the middle ground with an Ecological Footprint of 1.67 and 2.21 gha. Although polyester requires the greatest quantities of energy per tonne of spun fibre, it does not require the land area for cultivation that cotton and hemp do.

Cotton represents the higher end of the Ecological Footprint results ranging from 2.17 gha for organic cotton in the USA to 3.57 gha for conventional cotton in Punjab. Crop cultivation represents the greatest proportion of the Ecological Footprint in the cotton case studies. These results highlight that the cotton system, particularly in Punjab, is the least productive, especially when the inputs are reduced at the cultivation stage to grow organic cotton. This means that a greater land area is required to attain cotton yields equal to those of the USA, and indeed hemp. This productivity factor contributes significantly to the size of the Ecological Footprint, as the energy requirements are relatively low for this system compared to the other case studies (see Figure 3).

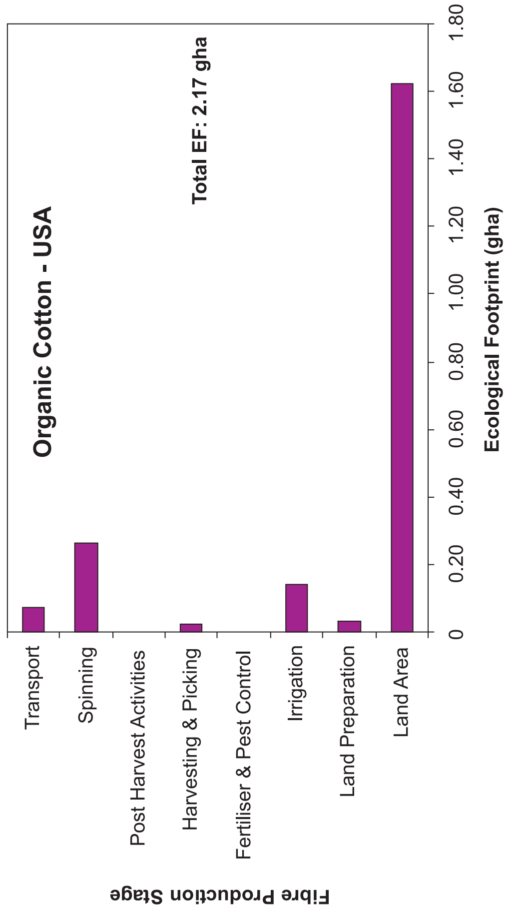
Hemp represents the lowest Ecological Footprint of the three textiles. The Footprint of hemp does not vary significantly in the different case studies, starting at 1.46 gha and reaching 2.01gha. As with cotton, crop cultivation represents the greatest proportion of the Ecological Footprint in the hemp case studies. Again, this can be attributed to the land area required to grow the crop. However, unlike cotton, in the case studies presented hemp productivity levels are much greater with yields of up to 3 tonnes of dry fibre per hectare compared to 1.35 tonnes of cotton lint per hectare.

Snapshot of individual results

Figures 6 and 7 provide a detailed snapshot of the results from four case studies. The case studies represent the Ecological Footprint extremes for cotton and hemp. These figures provide an example breakdown of the processes included in the crop cultivation and fibre production stages of cotton and hemp.

They also explicitly indicate the stages which contribute to the greatest Ecological Footprint, crucial information that cannot be determined otherwise. As Figure 5 shows, crop cultivation is responsible for a huge proportion of the Ecological Footprint of ‘Organic Cotton–USA’ (84 per cent) and ‘Cotton–Punjab’ (90 per cent). A detailed look at the crop cultivation components, as provided by Figure 6, shows that the land area required for cotton cultivation is alone responsible for 75 per cent (‘Organic Cotton–USA’) and 69 per cent (‘Cotton–Punjab’) of the Ecological Footprint. For ‘Organic Cotton–USA’, the spinning process plays the next greatest role at 12 per cent of the total Ecological Footprint, while in ‘Cotton–Punjab’, fertilisers and pest control make up 11 per cent of the total.

In the ‘Traditional Organic Hemp–UK’ and ‘Green Decortication Hemp’ case studies, crop cultivation is also the largest component of the Ecological Footprint. Although the land area required for hemp cultivation is not as great as it is for the cotton case studies, it is still responsible for 50 per cent (‘Traditional Organic Hemp–UK’) and 36 per cent (‘Green Decortication Hemp’) of the Ecological Footprint. However, the stage contributing the next greatest proportion is different for the two hemp case studies: harvesting and picking represents 22 per cent of the ‘Traditional Organic Hemp–UK’ total, while the drying process makes up 27 per cent of the ‘Green Decortication Hemp’ total. This snapshot is therefore able to determine and highlight the key points within a case study as well as the key differences between case studies.



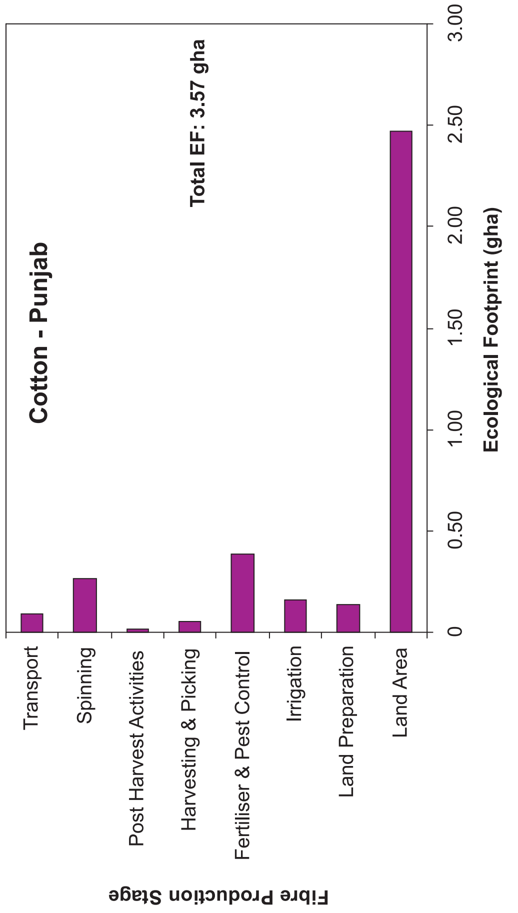
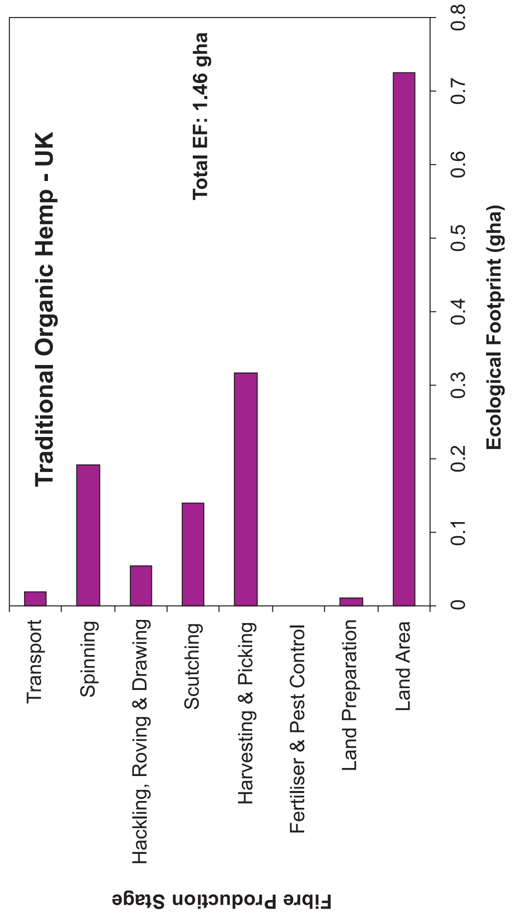


Figure 6. The Ecological Footprint (in global hectares) of each stage involved in producing 1 tonne of spun cotton fibre for 'Organic Cotton–USA' (above) and 'Cotton–Punjab' (below)



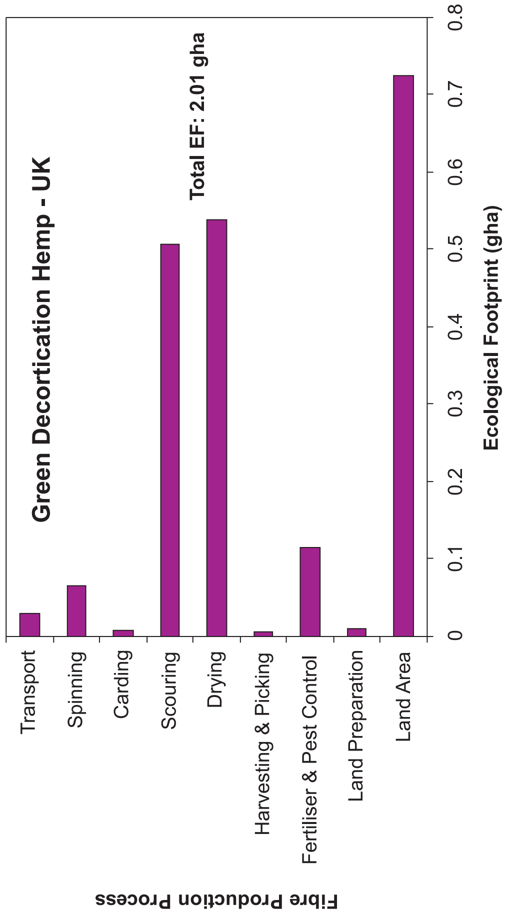


Figure 7. The Ecological Footprint (in global hectares) of each stage involved in producing 1 tonne of spun hemp fibre for 'Traditional Organic Hemp Aligned' (above) and 'Green Decortication Hemp' (below)

WATER ANALYSIS

Cotton

About 53 per cent of the global cotton area is irrigated and mainly located in dry regions: Egypt, Uzbekistan and the province Xinjiang of China are entirely irrigated; and in Pakistan and the North of India most crop water is supplied by irrigation, with 70 per cent of the cotton grown in India grown on irrigated land (Silvertooth, unknown). Irrigated fields provide around 73 per cent of the world's cotton, producing a yield of 854 kg per ha, while the remaining 27 per cent produced on rainfed land has a yield of just 391 kg per ha (Soth, 1999).

Cotton is recorded as requiring between 763 and 915 mm of water (rainfall and/or irrigation) per growing season. At the higher value this amounts to 9,150 m^3 of water per ha or 9.15 million litres (Myers and Stolton, 1999). In Arizona, USA, an extreme 1040 mm of irrigation water is delivered (Silvertooth, unknown).

UK cotton imports

In a typical year, the United Kingdom imports 167,766 tonnes of cotton fibre. As previously stated, this figure only includes include raw cotton. Of this, 121,222 tonnes are represented by the final product, 26,883 tonnes are raw material and 19,660 tonnes are waste cotton. The single largest source of these imports is Germany, which accounts for about 10 per cent of total imports (17,303 tonnes). Germany obtains 21.52 per cent of its cotton from the USA, 14.4 per cent from Turkey and 10.47 per cent from Bangladesh, but for certain countries, such as Bangladesh, the cotton has been imported from elsewhere. The supply chains are long, inter-connected and sometimes additive. In view of the overall very high amounts of water involved in cotton growth and processing it is not thought possible to disaggregate the estimates. Average yield values and water demand volumes have therefore been used.

WATER COMMITMENT TO UK COTTON IMPORTS

Based on an average yield of 599 kg lint per ha, 202,374 ha of land would be required to produce the total weight of cotton imported into the UK. At 9.15 million litres of water per ha, 1.8517x1012 litres would be required to grow the cotton, equivalent to 9,758 litres per kilogram.

Research in Bangladesh suggests that the water requirement for processing one kilogram of knitted cotton fabric is between 72 litres for bleached fabric, based on a 1:8 ratio of fabric to bath liquor, to 200 litres for scouring, bleaching and dyeing, based on a 1:10 recipe. Woven fabric, although requiring an extra processing stage of de-sizing, generally requires less processing water than knitted fabric because it is dyed as a continuous piece of cloth, in a process called "continuous dyeing" in which the cloth is channelled through a series of liquor baths. The volume of the baths is kept to a minimum and is almost entirely used up in the process, which limits the effluent. Knitted cotton by contrast is generally dyed using winch or jet dyeing machines, and requires several dye baths and rinses. Approximately 70 per cent of cotton garments exported from Bangladesh to Europe and North America are dyed. These figures are supported by estimates by Myers and Stolton (1999) that between 30 and 200 litres of water are needed to process one kilogram of woven or knitted dyed cotton fabric.

If the minimum quantity of water used to process one kilogram of cotton fabric is 30 litres and the maximum is 200 litres then 121,222 tonnes of fabric would require between 3.6x109 and 24.2x109 litres of water in addition to that required during crop growth. In terms of the overall water requirement for growing and processing, it is suggested that for one kilogram of cotton lint between 9,788 litres and 9,958 litres of water are required.

It should be noted that these estimates of water demand for growth of the cotton imported into the UK have not subtracted the rainfall and/or irrigation water that replenishes groundwater reserves and soil moisture capacity, possibly as much as 35 per cent of the delivered water (Tennekoon and Milroy, 2003). This water would remain and benefit the location where the cotton is grown. The 1.8x1012 litres of water used to grow the cotton imported to the UK might therefore be reduced to 1.2x1012 litres. In addition, no reduction has been made for the processing of the cotton fabric, and neither has a correction been made for the water that has been processed in water treatment plants and then made suitable for re-use or other local uses. This is more difficult to calculate as the process baths contain pollutants including mineral salts, dyes, bleaching agents and alkalis, and are characterized by high COD, BOD and pH, but the drop from each process bath in winch dyeing of knitted fabrics can have very different characteristics and some rinse waters will only contain very small levels of pollutants, often within national and international standards.

The estimates given above for the growth of cotton and its processing into the mean importation of cotton goods to the United Kingdom are summarized in Table 4.

Table 4. A summary of the parameters relating to water requirements for the cotton fibre and cotton goods imported annually to the United Kingdom (only including raw cotton imports)

Parameter	Estimate	Unit
Litres of water required to produce 1kg of cotton	9,788–9,958	litres
Total cotton fibre imported to the United Kingdom	1.6777x108	kg cotton fibre
Raw cotton imported to the United Kingdom	0.2688x108	kg cotton fibre
Waste cotton imported to the United Kingdom	0.1966x108	kg cotton fibre
Total cotton products imported to the United Kingdom	1.2122x108	kg cotton fibre
Cotton yield	599	kg lint.ha–1
Area required to grow imported cotton products	202,374	ha
Seasonal irrigation requirement	9.15x106	l.ha–1
Total water requirement for imported cotton products	1.8517x1012	l
Proportion of water retained on site	0.35	
Total water demand for growth of cotton goods	1.2158x1012	l
Water demand for growth of imported cotton goods	10,030	l.kg–1
Total water required to process imported cotton goods	24.2x109	l
Total water required to grow and process cotton goods	1.24x1012	l
Water for growth and processing of cotton goods	10,229	l.kg–1
United Kingdom per capita water demand for goods	21,754	l
Percentage of estimated UK water footprint3	1.7	

As displayed in Table 4, the volumes of water required to grow the cotton and produce the cotton goods imported into the UK in a typical year are quite considerable but they represent a very small percentage of the total per capita water footprint for the UK (only 1.7 per cent) as calculated by Chapagain and Hoekstra (2004).

Hemp

Hemp grown in the UK requires around 500–700 mm of precipitation per growing season (Bosca and Karua, 1998) which is met entirely by rainfall. Research has shown that on average 300–500 litres of water are required for the production of 1 kg of dry matter, of which 30 per cent is suitable for fibre production (Bosca and Karua, 1998).

In the UK, the experimental trials in hemp production using green decortication mechanical processing followed by scouring with sodium hydroxide (NaOH) resulted in a further loss of 30 per cent of the fibre, and carding an additional 30 per cent. Consequently, the amount of usable fibre produced from 1 kg of hemp dry matter is 343g. Therefore, the quantity of water required to grow 1 kg of usable fibre is 2,041–3,401 litres. In addition to this, scouring requires 40 litres of water per 1 kg. Assuming a 30 per cent loss from the raw fibre, then 1 kg of final product requires 82 litres of water for scouring. The overall water requirement to produce 1 kg of usable fibre from a hemp crop in this experimental method is therefore 2,123 litres. The experimental trials by BioRegional of the Fibrenova green decortication method and subsequent scouring have shown that this method is too costly. Therefore this method might not be representative. These figures are summarised below in Table 5.

Traditional hemp processing requires 343 litres per kg of useful hemp fibre.

Table 5. A summary of the parameters relating to water requirements for hemp production

Parameter	Estimate	Unit
Hemp precipitation requirement per growing season	500–700	mm
Water requirement to produce 1kg of dry matter	300–500	l
Usable fibre from 1kg of dry matter	343	g
Water required to grow 1kg of useful matter	2041–3401	l
Water requirement for scouring of useful matter	82	l/kg
Overall water requirement for 1kg useful fibre	2123	l

Polyester

Natural and synthetic fibres cannot really be compared as polyester and cotton are not interchangeable materials, due to their differing technical, physical and chemical properties. Furthermore, the annual production volumes of these materials are so high that it is not possible to substitute one for the other (Kalliala and Nousiainen, 1999). This caveat aside, a hypothetical comparison shows that the water use in polyester production is less than 0.1 per cent of that required in cotton growing (Kalliala and Nousiainen, 1999). Water is not an input in the polyester production process and the chemistry is in fact such that water is produced as a by-product of one of the polycondensation processes in which molecules containing a different double bond at either end, for example an alcohol and an acid group, react to form an ester (http://www.ivc-ev.de/englisch/pdf/man_made_fibres.pdf, date unknown). Water is used in the production process but its major use is for cooling and it is therefore largely unused and returned to the system.

Water stress and vulnerability

In most of the regions where cotton is grown rainfall is insufficient to provide the necessary moisture for the growth of the crop to give commercially viable yields. Therefore, the available rainfall must be supplemented by additional moisture from irrigation. The amount of water supplied through various methods of irrigation, most commonly surface methods (flooding, furrow and corrugation) represents a huge demand on what are often very limited total water resources. Thus the irrigation demand is often met to the detriment of other competing demands such as domestic, municipal and industrial supplies, although the quality of water for competing uses is not identical.

The USA has a relatively low level of water withdrawals as a percentage of availability and hence the use-to-resource ratio is also relatively low (SEI, 1997). However, this figure is forecast to rise by 2025, and “water sustainability” is ranked as relatively low in the USA, at just above the world average (Esty and Cornelius, 2002). The Southern States, where cotton is grown, are undoubtedly at the higher end of water stress for the USA. For example, California, a cotton growing state, has attracted a large and growing population. Subsidized water maintains irrigated agriculture. Groundwater aquifers which supply irrigation water are heavily over-exploited. The system experiences both water quantity and water quality problems and there is now reliance on exogenous water. There is considerable competition for available water between traditional agricultural users, who operate a “first in time, first in right” rule, and the newer urban populations (Gleick, 1993). Rainfall provides only about 30 per cent of the water demand of the cotton crop in many cotton growing areas of the USA leaving the rest to be supplied by irrigation.

Discussion

The application of the Ecological Footprint to assess the environmental burden of the five textiles highlights interesting factors in the cultivation and fabric production processes represented in the twelve case studies.

It shows that polyester production is the most energy intensive, requiring approximately ten times more energy than ‘Organic Cotton–Punjab’, which consumes the least energy. Consequently, polyester emits the greatest quantity of CO_2 emissions but in this case it is only four times that of ‘Organic Cotton–USA’, the smallest emitter of CO_2 emissions. However, the overall best performer in the Ecological Footprint context is ‘Traditional Organic Hemp–UK’ (1.46 gha/tonne of spun fibre), two times better than the worst performer ‘Cotton–Punjab’ (3.57 gha/tonne of spun fibre). In terms of water consumption, cotton requires 9,758 kg of water per kg, while hemp requires between 2,401 and 3,401 kg of water per kg.

As hemp represents a tiny fraction (0.15 per cent) of world textile production it seems a highly unviable option for consumers. The feasibility of hemp textile production on a broad scale is compounded by constraints, namely technological ones (see section 2.4), as well as the limited land area needed for cultivation. Agriculturally productive land in the UK is largely concerned with the cultivation of food crops, with a lower emphasis on non-food crops. The UK simply does not have enough land to cultivate all the necessary food crops and animal based foods, as well as non-food crops, such as hemp, to meet local demands. As the results show, transportation contributes less than 1 per cent to the total Ecological Footprint of textile production, thereby reducing the pressure on textile goods to be produced locally. However, it is important to note that it is possible to produce three times the amount of hemp fibre as cotton from the same amount of land.

As it is currently not feasible to produce hemp on a broad scale and thereby increase its proportion of the global textile market, it is possible to identify areas within the production of the three textiles where energy efficiency improvements can be made.

Firstly, in terms of energy requirement and associated CO_2emissions, it is not enough to simply measure the amount of energy needed to produce a said amount of fibre. It is crucial to establish the proportion and type of fuel used to generate that energy which, as the analysis showed, varies significantly from one country to another. For example, electricity generated by a renewable resource will have virtually zero CO_2 emissions associated with it, a huge contrast to electricity generated by coal. It is important to remember that polyester will always have an input of oil in its manufacturing process. This represents about one third of the total impact of the product.

In conventional cotton production the greatest energy requirements are at the crop cultivation stage. This is shown by the difference in energy requirements between cotton grown conventionally and organic cotton. The production of synthetic fertilisers and herbicides, along with their application, represents 40 per cent of total energy requirements in the crop cultivation stage for the Punjab case study and 59 per cent for the USA study. Organic agriculture therefore presents itself as a way of reducing energy requirements in the cultivation of cotton. The same opportunity exists for hemp where savings of 81 per cent, 59 per cent and 76 per cent of total energy requirements in the crop cultivation stage for traditionally processed hemp, green decortication processed hemp, and Hemcore hemp respectively can be achieved.

An opportunity also exists for reducing the energy requirements of hemp in the fibre production process. Processing hemp through the aligned system consumes 7,949MJ less energy per tonne of spun fibre than the processing of hemp through the experimental non-aligned system.

Secondly, the Ecological Footprint highlights the issue of yield factors and the real land area required for crop cultivation. Taking the example of cotton grown in the USA, on the one hand organic cultivation reduces the amount of energy required to cultivate a said quantity of crop, but on the other it reduces the yield. This means that a greater land area is needed to grow an amount of cotton equal to that grown in non-organic conditions. The analysis has also further emphasised the variety of crop cultivation techniques and yield factors in different nations.

There are some important factors which determine the environmental burden and long-term sustainability of producing the five textiles that have not been addressed by the Ecological Footprint analysis.

Production of polyester, even if the energy requirements are met by renewable sources, cannot be sustained indefinitely. The raw material, oil, is a non-renewable resource which will, in time, run out. However, it is suggested that it is a wiser use of oil than simply burning it for energy production. The other toxic emissions associated with the production of polyester have also not been accounted for. This also applies to cotton and, to a limited extent, hemp.

The analysis also fails to recognise the important role of crop cultivation and fabric production processes at the social and economic level. While for polyester this may not be such a focal factor, it certainly is crucial for cotton, especially cotton grown in developing nations.

Limitations

- This study only looks at one part of the textile chain. The results may be strikingly different if the analysis were to include the complete life cycle of the five textiles (e.g. consumer use stage may have a greater impact). Environmental impact is also related to cultural factors, product type (e.g. clothing, which requires regular washing versus furnishing which does not), length of product life and disposability. However, we have ensured to the best of our ability that the case studies are comparable and all represent the production of the fibre to the same stage.
- The Ecological Footprint and water results only provide a limited picture of the environmental pressure associated with the production of the five textiles. To capture a much wider picture of other environmental problems other analyses are necessary (i.e. air and water pollution, biodiversity etc).
- There are issues outside of the environmental setting which need to be addressed. Social and economic factors must also be taken into account. The study does not look at the feasibility

of hemp production in the UK. It has merely concentrated on the environmental pressure of producing the different fibres.

- Fashion and aesthetic qualities may dominate final consumer choice. The study does not look at markets, cultural and consumer issues in relation to the demand for different products.
- The study did not focus on the limitation of the methodologies employed. Several critiques of the Ecological Footprint exist (notably VROM-Council (1999), Van Kooten and Bulte (2000), van den Bergh and Verbruggen (1999) and Pearce (2000)). These reviews contain a mix of positive and negative comments relating to the application of the methodology as well as suggestions for improving its structure.

Recommendations and Next Steps

A detailed understanding of the energy and water requirements and their related impacts, in terms of CO_2 emissions and the Ecological Footprint, allows the exploration of potential options to reduce the environmental impacts of the different materials. A number of options are available: increasing the efficiency of production, changing composition of material used in products and an absolute reduction in consumption. At the same time, any measures adopted should meet the environmental, as well as social and economic, needs of those whose livelihoods depend on it.

There was a marginal reduction in the Ecological Footprint of organic production (in most cases) for cotton and hemp. In the UK there has also been a substantial increase in the demand for organic products. This increased demand allows the further development of organic agriculture and economies of scale to play an important role. With the introduction of “bio-dynamic approaches” which use the surrounding environment to its benefit, further increases in yields could be achieved, as well as reductions in the water requirements of crops.

As fertiliser input was responsible for a significant proportion of CO_2 emissions and the Ecological Footprint, organic production could play a vital role in improving the ecological efficiency of production.

In terms of material substitution, hemp had a lower impact in terms of water, energy and the Ecological Footprint. However, the full potential of the technologies identified in this study has not yet been realised. The most promising technologies for transforming hemp into a usable product are still at the pilot stage and it is currently not in the position to replace cotton and polyester.

Finally, future research would benefit from understanding the market potential of organic cotton while continually exploring technologies for different materials.

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Appendix A

Table 6. List of countries classified under the EC, Western Europe (excl. the EC) and Eastern Europe

European Community	Western Europe (excluding EC)	Eastern Europe
Austria	Andorra	Albania
Belgium	Switzerland	Armenia
Denmark	Faroe Islands	Azerbaijan
Finland	Gibraltar	Belarus
France	Iceland	Bosnia & Herzegovina
Germany	Liechtenstein	Bulgaria
Greece	Malta	Croatia
Irish Republic	Norway	Czech Republic
Italy	San Marino	Estonia
Luxembourg	Turkey	Fyr Macedonia
Netherlands	Vatican City	Georgia
Portugal		Hungary
Spain		Kazakhstan
Sweden		Kyrgyzstan
		Latvia
		Lithuania
		Moldova
		Poland
		Romania
		Russia
		Slovakia
		Slovenia
		Tajikistan
		Turkmenistan
		Ukraine
		Uzbekistan
		Yugoslavia

Appendix B

Table 7. Hemp Comcode data category and description

	Hemp Comcode Category and Description
53021000	TRUE HEMP, RAW OR RETTED:TRUE HEMP,RAW OR RETTED BUT NOT O/W PROCESSED
53029000	TRUE HEMP O/T IN 265.21:TRUE HEMP, BROKEN,SCUTCHED,COMBED OR O/W PROC BUT NOT SPUN;TOW & WASTE (INC YARN WASTE & GARNETTED STOCK)

Appendix C

Table 8. Polyester Comcode data category and description

	Polyester Comcode Category and Description
54021010	HIGH TENACITY YARN OF NYLON. OTHER POLYAMIDESOR OF POLYESTERS, NOT PUT UP FOR RETAIL SALE:SYN FILAMENT YARN (O/T SEWING THREAD) NOT FOR RETAIL SALE-HIGH TENACITY YARN OF ARAMIDES
54021090	HIGH TENACITY YARN OF NYLON. OTHER POLYAMIDESOR OF POLYESTERS, NOT PUT UP FOR RETAIL SALE:SYN FILAMENT YARN (O/T SEWING THREAD) NOT FOR RETAIL SALE-HIGH TENACITY YARN OF POLYAMIDES O/T ARAMIDES
54022000	HIGH TENACITY YARN OF NYLON. OTHER POLYAMIDESOR OF POLYESTERS, NOT PUT UP FOR RETAIL SALE:SYN FILAMENT YARN (O/T SEWING THREAD) NOT FOR RETAIL SALE-HIGH TENACITY YARN OF POLYESTERS
54023300	POLYESTER FILAMENT YARN (O/T SEWING THREAD),TEXTURED, NOT FOR RETAIL SALE,INC MONOFIL OF L/T:SYNTHETIC FILAMENT YARN (O/T SEWING THREAD) NOT FOR RETAILSALE-OF POLYESTERS,TEXTURED - M/T 50 TEX
54023990	SYN FIL YARN, NES,(O/T SEWING THREAD),TEXTURED,NOT PUT UP FOR RETAIL SALE, INC MONOFIL OF L/T 67:SYN FILAMENT YARN (O/T SEWING THREAD) NOT FOR RETAIL SALETEXTURED O/T POLYPROPYLENE POLYAMIDE POLYESTER
54024200	SYN FILAMENT YARN OF HDG 651.60: OTHER YARN SINGLEUNTWISTED OR TWIST N/E 50 TURNS P/M NOT FOR RETAI:SYN FIL YARN (O/T SEWING THREAD) NOT FOR RETAIL SALE-NON TEXOF POLYESTERS PARTIALLY ORIENTED (POY)
54024300	SYN FILAMENT YARN OF HDG 651.60: OTHER YARN SINGLEUNTWISTED OR TWIST N/E 50 TURNS P/M NOT FOR RETAI:SYNTHETIC FILAMENT YARN (O/T SEWING THREAD) NOT FOR RETAILSALE, OF POLYESTERS, OTHER - L/T 50 TURNS
54025200	SYN FILAMENT YARN OF HDG 651.60:OTHER YARN,SINGLEWITH A TWIST EXD 50 TURNS PER METRE, NOT FOR RETA:OTHER SYN FIL YN,SINGLE (O/T SEWING THREAD) NOT RETAIL SALE -M/T 50 TURNS PER MTR - OF POLYESTERS
54026200	SYNTHETIC FILAMENT YARN OF HEADING 651.60: OTHERYARN, MULTIPLE (FOLDED) OR CABLED, NOT FOR RETAIL:OTHER SYN FIL YN , MULT/CABLED (O/T SEWING THREAD)NOT FOR RETAIL SALE - OF POLYESTERS
54071000	WOVEN FABRICS OBTAINED FROM HIGH TENACITY YARN OFNYLON OR OTHER POLYAMIDES OR OF POLYESTERS:WOVEN FABRICS OF SYN FIL YARN OF NYLON OR OTHER POLYAMIDES OROF P/ESTER -HIGH TENACITY
54075100	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF TEXTURED POLYESTER FILAMENTS:OTHER WOVEN FABRICS WITH NLT 85% BY WGT OF TEXTURED POLYESTERUNBLEACHED OR BLEACHED
54075200	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF TEXTURED POLYESTER FILAMENTS:OTHER WOVEN FABRICS WITH NLT 85% BY WGT OF TEXTURED POLYESTER-DYED
54075300	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF TEXTURED POLYESTER FILAMENTS:OTHER WOV FAB WITH NLT 85% BY WGT OF TEX POEST FILAMENTS OFYARNS OF DIFF COLOURS (TEXT 035)

54075400	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF TEXTURED POLYESTER FILAMENTS:OTHER WOVEN FABRICS WITH NLT 85% BY WGT OF TEXTURED P/ESTERFIL-PRINTED
54076110	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF NON-TEXTURED POLYESTER FILAMENTS:OTHER WOV FAB WITH NLT 85% BT WGT OF NONTEX POEST FIL UNBLCHD/BLCHD(TEXT 035)
54076130	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF NON-TEXTURED POLYESTER FILAMENTS:OTHER WOV FAB WITH NLT 85% BY WGT OF NONTEX POEST FIL DYED(TEXT 035)
54076150	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF NON-TEXTURED POLYESTER FILAMENTS:OTHER WOVEN FABRIC WITH NLT 85% BY WGT OF NONTEXT POEST FIL-YARNSOF DIFF COLOURS (TEXT 035)
54076190	OTHER WOVEN FABRICS, CONTAINING 85% OR MORE BYWEIGHT OF NON-TEXTURED POLYESTER FILAMENTS:OTHER WOVEN FABRIC WITH NLT 85% BY WGT OF NONTEX POEST FIL PRINTED(TEXT 035)

Appendix D

Table 9. Hemp processing, comparison between traditional method and experimental Fibrenova system

Harvest Process	Traditional Method (Dew Retting)	Experimental Fibrenova System
Stem cutting	Mowing (conventional machinery)	Cutting head on machine (existing technology)
Crop transport	Baling or other conventional machinery	On machine
Separation of bast fibres from hurd	Retting process followed by scutching	Direct – D7 type decorticator
Separation of fibre bundles	Occur naturally during retting process	Primary separation element : involved boiling in caustic soda

(Source: Brighton et al., 2003)

Appendix E – Calculating the Ecological Footprint

The Ecological Footprint as a sustainability indicator

What is an Ecological Footprint?

The Ecological Footprint of a region or community is defined as the bio-productive area (land and sea) that would be required to maintain current consumption, and to absorb waste and emissions. Probably the most important dimension of the Ecological Footprint is the fact that impact is related to the population of the city or region that consumes the goods and services. Traditionally, environmental pressures were mostly local or national, meaning the consumer was affected by the environmental consequences of the production. Today, however, the geographic location of environmental pressures has little relation to the location of consumption. The Ecological Footprint takes on the task of re-allocating the environmental pressures to the consumer. The Ecological Footprint of both a community and of a specific product or material can be calculated.

The Ecological Footprint essentially accounts for the use of the planet's renewable resources. Non-renewable resources are accounted for only by their impact on, or use of, renewable, bioproductive capacity. The Ecological Footprint deals only with demands placed on the environment. It does not attempt to include the social or economic dimensions of sustainability.

Measuring the Ecological Footprint

For the purposes of the Ecological Footprint calculation, land and sea area is divided into four basic types: bioproductive land (sub-divided into arable, pasture and forest), bioproductive sea, energy land (forested land and sea area required for the absorption of carbon emissions) and built land (buildings, roads etc). A fifth type refers to the area of land and water that would need to be set aside to preserve biodiversity.

The Ecological Footprint is measured in a standardised area unit equivalent to a world average productive hectare (abbreviated to global hectares or gha). This 'demand' on land area can be compared with the productive area available on the planet (the 'supply') to estimate the sustainability of current resource consumption. Globally, the average personal Ecological Footprint was 2.4 gha/cap in 2001 – as opposed to an available capacity of 1.9 gha/cap (excluding biodiversity considerations) – suggesting that humanity is using more natural resources than can be sustained in the long term.

To date, Ecological Footprint studies have been carried out at levels ranging from global and national (WWF, 2002), to regional (Barrett et al., 2003), and local (Birch et al., 2003). However, one area the Footprint has failed to exploit fully is the product level. This study represents an early attempt at not only calculating the Footprint of one product, but that of a number of products which will enable a comparison and analysis to take place. The five textile products considered in this study are complex in the sense that their life cycles and supply chains do not have defined boundaries but represent dynamic interrelationships between agricultural resources, industrial activities, livelihoods and the environment, all of which vary dramatically through time and space. These attributes contributed greatly to the challenges faced when attempting to conduct a rigorous study at such a detailed level.

STEP 1

The first step in calculating the Ecological Footprint of the various textiles involved identifying the various stages of crop production and fibre processing all the way through to the spinning stage. Table 10 below shows the processes taken into consideration for the six hemp case studies.

Table 10. List of processes identified for each of the six hemp case studies

	Green Decortication (with experimental Fibrenova Technology)	**Green Decortication Organic (with experimental Fibrenova Technology)**	**Hemcore**	**Hemcore Organic**	**Traditional Aligned**	**Traditional Aligned Organic**
Land area	•	•	•	•	•	•
Land Preparation (plough and tractor)	•	•	•	•	•	•
Land Preparation Secondary Cultivation (harrow, mechanical)	•	•	•	•	•	•
Sowing (mechanical)	•	•	•	•	•	•
N fertiliser production	•		•		•	
P fertiliser production	•		•		•	
K fertiliser production	•		•		•	
CaO production	•		•		•	
Fertilizer Application (mechanical)	•	•	•	•	•	•
Herbicide Production	•		•		•	
Herbicide Application	•		•		•	
Harvesting (Fibrenova harvester/ decorticator)	•	•				
Harvesting, Turning and Baling	•	•	•	♦	•	•
Decortication (in factory)			•	•		
Drying (mechanical)	•	•	•	•		
Transport (stage 1)	•	•				
Transport (stage 1 and 2)			•	•	•	•
Scouring (25% fibre loss):	•	•	•	•		
NaOH	•	•	•	•		
Softener	•	•	•	•		
Acid	•	•	•	•		
Heated Water	•	•	•	•		
Scutching					•	•
Hackling					•	•
Roving					•	•
Drawing					•	•
Wetspinning					•	•
Drying (mechanical)	•	•	•	•		
Carding (mechanical - 35% fibre loss)	•	•	•	•		
Transport (stage 2 and 3)	•	•				
Transport (stage 3 and 4)			•	•	•	•
Spinning	•	•	•	•		

STEP 2

The second step involved collating the data from the various sources to determine the energy requirement for each stage in crop cultivation and fibre processing. Energy requirement is expressed in Megajoules per tonne of fibre. Once established, a material multiplier was applied to take into account the various fibre losses incurred after each processing stage. It was then possible to apply the relevant conversion factors and ascertain the associated CO_2 emissions and Ecological Footprint for each stage, and hence each case study. See Table 11 below for hemp examples.

Table 11. Compilation list of data provided, sources, calculations and final energy, carbon dioxide and Ecological Footprint results for the hemp case studies

	Data Provided	**Source**	**Calculation**	**Total Energy in MJ per Tonne of Fibre**	**Material Multiplier**	**CO_2 Emissions per Tonne of Fibre**	**Ecological Footprint (Global Hectares per tonne of Fibre)**
Land area	3 tonnes per hectare	•	•	•		•	0.73
Land Preparation	Plough and 100hp tractor 286 KJ/Kg	Cranfield University (2003)		286	1.00	0.02	0.00
Land Preparation Secondary Cultivation	Power harrow 143.2 KJ/kg	Cranfield University (2003)		143	1.00	0.01	0.00
Sowing	Power harrow and drill combination 179 KJ/Kg	Cranfield University (2003)		179	1.00	0.01	0.00
Fertiliser Production	Nitrogen 0.125 t/ha.	Hemcore Limited (2004)	0.125*36 (GJ/t) = 4,485MJ per tonne fibre	4,485	1.00	0.34	0.08
Fertiliser Production	Phosphate 0.07 t/ha	Hemcore Limited (2004)	0.07*14 (GJ/t) = 926 per tonne fibre	926	1.00	0.07	0.02
Fertiliser Production	Potassium 0.07 t/ha	Hemcore Limited (2004)	0.07*15 = 1117 per tonne fibre	1,117	1.00	0.08	0.02
Fertiliser Application (conventional and organic hemp)	Top dressing by tractor and fertiliser spreader 35.8 KJ/Kg	Cranfield University (2003)		35.8	1.00	0.00	0.00

Herbicide Production	Glyphosate 2 litres/ha.	Hemcore Limited (2004)	0.002*12 (GJ/t)= 44 per tonne fibre	44	1.00	0.00	0.00
Herbicide Application	Pre-emergence, pre-tillage application of Glyphosate 23.9 KJ/Kg	Cranfield University (2003)		23.9	1.00	0.00	0.00
Harvesting - Fibrenova	Fibrenova technology harvester/ decorticator 333.3KJ/Kg	Cranfield University (2003)		333.3	1.00	0.03	0.01
Harvesting, Turning and Baling	23 litres diesel/tonne fibre (based on 57.6 litres/hectare and 3 tonnes fibre/hectare)	Cranfield University (2003)	23*37.6 = 864.8MJ per tonne fibre	865	21.00	1.36	0.32
Decortication	Machine running at 540 MJ/tonne (in factory).	Cranfield University (2003)		540	8.40	0.34	0.08
Drying	3600KW/kg water removed mechanically (2.3kg water per 1kg dry fibre)	Cranfield University (2003)		3,600	7.00	1.89	0.44
Transport (stage 1)	Bishops Stortford, Essex to Manchester (300.80km)	Hemcore Limited (2004)	(300.8*0.1790)/1000 = 0.05 CO_2 emissions per tonne. 0.05 *Material Multiplier = Total CO_2 emissions per tonne		2.10	0.11	0.03
Transport (stage 1 and 2)	Southend to Bishops Stortford (75.2km) Bishops Stortford to Manchester (300.8km)	BioRegional Development Group (2004)	(376*0.1790)/1000 = 0.067 CO_2 emissions per tonne. 0.065* Material Multiplier = Total CO_2 emissions per tonne.		2.10 8	0.14 0.57	0.03 0.02
Scouring: NaOH	0.2litres/kg fibre	R. Gledhill Ltd, Dye House, Delph, Nr. Oldham (2004)	0.002*9 (GJ/t) = 15 MJ per tonne fibre	15	2.10	0.00	0.00

Scouring: Softener	0.01kg/kg fibre	R. Gledhill Ltd, Dye House, Delph, Nr. Oldham (2004)	0.01*100 (MJ/t) = 1 per tonne fibre	1	2.10	0.00	0.00
Scouring: Acid	0.01kg/kg fibre	R. Gledhill Ltd, Dye House, Delph, Nr. Oldham (2004)	0.01*100 (MJ/t) = 1 per tonne fibre	1	2.10	0.00	0.00
Scouring: Heated Water	Pressure dye vat, 15 minutes at 110C; hot wash at 80C; further boil for 15 minutes at 110C; second rinse at 80C. 40 litres water per kg of fibre. (25% fibre loss)	R. Gledhill Ltd, Dye House, Delph, Nr. Oldham (2004)	13,863 (See Appendix F for details)	13,863	2.10	2.19	0.51
Scutching	150–250 KW processing line, estimated 70–80% power usage, 3000kg baled straw resulting in 750kg fibre per hour	Depoortere, Belgium (Scutching machine manufacturers) (2004)	200 * 3.6 = 720MJ per 0.75 tonne fibre. 720/0.75 = 960MJ per tonne of fibre.	960	8	0.61	0.14
Hackling	30KWh per 150kg fibre	Bridge Mackie, N. Ireland (Machinery Manufacturers) (2004)	30*3.6 = 108MJ per 0.15 tonne fibre. 108/0.15 = 720MJ per tonne of fibre	720	2	0.11	0.03
Roving	15KWh per 150kg fibre	Bridge Mackie, N. Ireland (Machinery Manufacturers) (2004)	15*3.6 = 54MJ per 0.15 tonne fibre. 54/0.15 = 360MJ per tonne fibre.	360	2	0.04	0.01

Drawing	27.5KWh per 150kg fibre	Bridge Mackie, N. Ireland (Machinery Manufacturers) (2004)	27.5*3.6 = 99MJ per 0.15 tonne fibre. 99/0.15 = 623MJ per tonne fibre.	660	2	0.08	0.02
Wet Spinning	450KWh per 150kg fibre	Bridge Mackie, N. Ireland (Machinery Manufacturers) (2004)	450*3.6 = 1,620MJ per 0.15 tonne fibre. 1,620/0.15 = 10,800 MJ per tonne fibre	10,800	1	0.83	0.19
Drying	3600KW/kg water removed mechanically (2.3kg water per 1kg dry fibre)	Cranfield University (2003)		3,600	1.58	0.43	0.10
Carding	15 KW motor processing 200kg of fibre an hour (35% fibre loss).	Macart Machinery Manufacturers, Bradford (2004)	15*3.6 = 54MJ per 0.2 tonnes fibre. 54/0.2 = 270MJ per tonne fibre.	270	1.58	0.03	0.01
Transport (stage 2 and 3)	Manchester to Bradford (62.4km). Bradford to Huddersfield (25.6km).	BioRegional Development Group (2004)	(88*0.1790)/1000 = 0.0158 CO_2 emissions per tonne. 0.0158*Material Multiplier = Total CO_2 emissions per tonne.		1.02	0.02	0.00
Transport (stage 3 and 4)	Manchester to Bradford (62.4km) Bradford to Huddersfield (25.6km)	BioRegional Development Group (2004)	(88*0.1790)/1000 = 0.0158 CO_2 emissions per tonne. 0.0158*Material Multiplier = Total CO_2 emissions per tonne.		1.58 1	0.02 0.02	0.01 0.00
Spinning	3.7KW per 1Kg of yarn	J.L. Brierley Spinners, Huddersfield (2004)	3.7*1000 = 3.700MJ per tonne yarn.	3,700	1.02	0.28	0.07
Wet Spinning	450KWh per 150kg fibre	Bridge Mackie, N. Ireland (Machinery Manufacturers) (2004)	1000/150 = 6.6kg 6.6 * 450 = 3,000KWh 3,000*3.6 = 10,800MJ	10,800	1	0.83	0.19

Embodied Energy Data

SEI has obtained a considerable number of studies on life cycle analysis which provide data on the embodied energy of a vast number of materials and products. This information is available on request from SEI.

Material Multiplier

Most production systems, including that of textiles, generate waste and incur material losses. These losses have been taken into account in the calculations by the use of a Material Multiplier. Two methods were devised: the first accounted for the inputs required per tonne of final product, while the second only accounted for the material input at each stage. Details of how these two methods were applied are provided in the following example:

Case Study: 'Traditional Hemp Aligned'

For all cultivation processes, including 'Land Area' through to 'Herbicide Application', the first method 'Inputs Required per Tonne of Final Product' was employed. From 'Harvesting, Turning and Baling' through to 'Wetspinning' the second method 'Material Input at Each Stage' was adopted. See Table 12.

Table 12. Applying the material multiplier. The case study of 'Traditional Hemp Aligned–UK

Process	Input	Output	Losses Incurred (%)
Harvesting, Turning and Baling	21.00	8.40	7 tonnes of hemp harvested per hectare. Following drying 70% of weight is lost, leaving 30% to be turned and baled.
Transport (stage 1 and 2)	8.40	8.40	30% of total yield is transported from field to manufacturing factory.
Scutching	8.40	8.40	No losses
Hackling	8.40	2.10	Following the scutching process 25% usable fibre is left.
Roving	2.10	1.58	25% fibre loss
Drawing	1.58	1.58	No losses
Wetspinning	1.58	1.02	2% fibre loss
Transport (stage 3 and 4)	1	1	No losses

STEP 3

Conversion Factors

The third step involved converting the energy requirement for each stage in crop cultivation and fibre processing into associated CO_2 emissions and the final Ecological Footprint result.

Carbon Dioxide

Total energy consumption (in MJ per tonne of fibre) is converted into associated carbon dioxide emissions, expressed in tonnes of CO_2 per tonne of spun fibre. To add depth to the study it was crucial to take into account the global variation of fuel composition (e.g. different proportions of gas, oil, coal, nuclear, biomass) used to generate electricity. The conversion factors used to determine associated CO_2 emissions by fuel mix used within the UK, USA and India, the location of the case studies, are presented in Table 13.

Table 13. Country specific conversion factors

		United Kingdom	**India**	**United States**
		Conversion factors	Conversion factors	Conversion factors
		Agriculture	Agriculture	Agriculture
Energy		MF factor	MF factor	MF factor
Carriers	t/GJ	0.033	0.129	0.023
Hidden		HF factor	HF factor	HF factor
Flows	t/GJ	0.039	0.516	0.0002
Carbon		CO_2 factor	CO_2 factor	CO_2 factor
Dioxide	t/GJ	0.075	0.273	0.067
	t/MJ	0.00008	0.00027	0.00007

Worked Example 'Cotton – Punjab'

Seedbed preparation required 1,527MJ:

1,527 x 0.00027 = 0.42t CO_2/tonne spun fibre

Standard distances were established for different world regions (see table X). CO_2 emissions vary according to transport mode, and are calculated per kilometre. Transport therefore has separate conversion factors to energy fuel. The transportation of cotton and polyester was assumed to involve two main modes, lorry and ship. Associated Vehicle CO_2 Conversion Factors were used (taken from the UK Government Greenhouse Gas Inventory). These being 0.179 kg/CO_2 per tonne km for lorries and 0.01 kg/CO_2 per tonne km for ships.

Table 14. Estimated transport distances for different world regions

Origin of UK Imports	**Stage 1 (Road Movement within Country of Origin**	**Stage 2 (Shipping from Country of Origin)**	**Origin of UK Imports**	**Stage 1 (Road Movement within Country of Origin) - Proportional**	**Stage 2 (Shipping from Country of Origin)- Proportional**
EC	786	880	21%	165	189
W Europe exc EC	451	1,961	2%	9	39
Eastern Europe	1,000	3,358	2%	20	67
North America	600	9,594	2%	12	192
Other America	600	11,273	5%	32	596
M East & N Africa	500	7,790	2%	10	156
Sub-Saharan Africa	700	11,955	2%	14	239
Asia & Oceania	600	15,853	63%	377	9,973
Total			**100%**	**639**	**11,451**

Ecological Footprint

The most recent detailed description of conversion factors used in the calculation of the Ecological Footprint can be found in the following paper:

Wackernagel, M., Monfreda, C., Moran, D., Goldfinger, S., Deumling, D., Murray, M., (2004b). National Footprint and Biocapacity Accounts 2004: The underlying calculation method. Global Footprint Network, Oakland, CA, USA. Download at: http://www.footprintnetwork.org

Appendix F

SCOURING RECIPE

1. Using pressure dye vat, 15 minutes at 110°C, using 2 per cent sodium hydroxide solution (NaOH),
2. hot wash at 80°C, followed by
3. further boil for 15 minutes at 110°C at 4 per cent sodium hydroxide solution,
4. second rinse at 80°C, and neutralisation.

This process is estimated to use 40 litres water per kg of fibre treated. Source: (R. Gledhill Ltd, 2004)

ENERGY REQUIRED TO HEAT WATER

Where: 0.00116 KWh are needed to heat 1 litre of water up by 1C.
Average start temperature of water is 12C.
Each of the four stages requires equal quantities (10 litres) of water

110 – 12 = 98°C
0.00116 * 98 = 0.11368KWh
0.11368 * 20 = 2.2736 KWh required to heat water to 110°C.
(2.2736*3.6)*1000 = 8,184MJ/tonne

80 – 12 = 68°C
0.00116 * 68 = 0.07888KWh
0.07888 * 20 = 1.5776 KWh needed to heat water to 80°C.
(1.5776*3.6)*1000 = 5,679MJ/tonne

8,180 + 5,680 = **13,863 MJ/tonne**

This final result is an underestimate as it does not take into account the extra energy required to maintain the desired water temperature over time.

The Stockholm Environment Institute (SEI)

SEI is an independent, international research institute specializing in sustainable development and environment issues. It works at local, national, regional and global policy levels. The SEI research programmes aim to clarify the requirements, strategies and policies for a transition to sustainability. These goals are linked to the principles advocated in Agenda 21 and the Conventions such as Climate Change, Ozone Layer Protection and Biological Diversity. SEI along with its predecessor, the Beijer Institute, has been engaged in major environment and development issues for a quarter of a century.

Mission

SEI's mission is to support decision-making and induce change towards sustainable development around the world by providing integrative knowledge that bridges science and policy in the field of environment and development.

The SEI mission developed from the insights gained at the 1972 UN Conference on the Human Environment in Stockholm (after which the Institute derives its name), the work of the (Brundtland) World Commission for Environment and Development and the 1992 UN Conference on Environment and Development. The Institute was established in 1989 following an initiative by the Swedish Government to develop an international environment/development research organisation.

Sustainable Development Studies Programme

The Sustainable Development Studies programme conducts research on sustainable society, development and planning. The programme expands upon ongoing and previous work on integrated future assessment studies at national and regional level, the concepts of urban and regional sustainability, socio-economic analysis, gender issues and environmental ethics. The tools and methods used in the programme include PoleStar, GIS, Global Scenario Group, participatory techniques, strategic and sustainability impact assessment and indicators.

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