



Energy Consumption in the UK Jeans Supply Chain

Transport Studies Group
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Energy Consumption in the UK Jeans Supply Chain

1. Introduction

This document is the final report produced as part of a study examining the energy consumption associated with the production and distribution of jeans sold in the United Kingdom (UK). The UK study, which is funded by the Institut National De Recherche sur les Transports et Leur Securite (INRETS), has been completed by the Transport Studies Group (TSG) at the University of Westminster.

The research approach to the study has been agreed between INRETS and TSG although there have been some differences in data collection. The data gathered for the UK study has been collected from published sources and a major UK retailer who has assisted with providing contacts to garment manufacturers. This retailer had also permitted its own supply chain to be the basis of the study.

This report presents a description of the UK market for jeans and the generic and more specific supply chains that exist for production and distribution of jeans sold in the UK.

Although the project was concerned with the entire supply chain for jeans from cotton growing through to the retailing of jeans to customers, the main focus of the study was on freight transport activity in the supply chain and the associated transport energy use.

The ways in which the supply chain structure and shop location affected transportation and energy consumption was examined as part of the project.

2. Approach

The research approach we have used in the project included:

- Literature review
- Interviews
- Supply chain mapping and description
- Data gathering (primary and secondary data)
- Data analysis

A *literature review* was carried out into: (i) material about the cotton and jeans supply chain and the activities involved in their production and transport, and (ii) research into energy consumption in the supply chain in other sectors.

Interviews were held with the UK multiple retailer selling the jeans and their suppliers. These interviews were used to obtain a detailed understanding of the supply chain, how it is organised and the range and sequence of activities that take place. Data concerning the transport activities and locations was also obtained during these interviews.

Supply chain mapping and description – using information obtained during the interviews it has been possible to produce detailed descriptions and visual representations of the supply chain for the jeans studied. These descriptions and mapping exercises are of the entire supply chain for jeans, including non-transport and transport activities from the cotton plantation to the final customer's home.

Data gathering - primary and secondary data were gathered in order to analyse energy consumption and CO₂ emissions in the jeans supply chain. Secondary data was obtained from the literature review and from companies participating in the project that had existing information from previous research.

Representatives from the participating companies validated secondary data obtained from published sources. Primary data about transport activities was obtained through the interviews as well as through subsequent contacts provided by the interviewees. It should be noted that the supply chain data used and analysed in the project is intended to reflect generic jeans supply chains rather than the specific supply chains of particular companies.

Data analysis was carried out using an Excel spreadsheet. Energy consumption was calculated from the point at which cotton is grown to the jeans arriving at the customer's home. The effect of variations within the supply chain was investigated using this spreadsheet approach. The analysis was intended to demonstrate:

- the relative importance of energy consumed by transport activities compared with other non-transport activities in the supply chain;
- the proportion of total transport energy consumed in each transport leg of the supply chain;
- the effect of cotton sources, different retail outlet locations and supply chain strategies on freight transport energy consumption.

3. Literature review

3.1 Previous studies of transport activity and energy use in supply chains

There have been a number of studies of freight transport activity and energy use in product supply chains since 1990. Previous studies have examined one or more of the following:

- the distance over which products have been transported from point of growing/production to point of retail or consumption
- the energy used in producing and transporting products in the supply chain
- the pollutants emitted in producing and transporting products in the supply chain

In the second and third points listed above (energy use and pollutant emissions) some studies have considered energy used in the entire supply chain, while others have limited themselves to particular parts of the chain or to specific activities such as production or transport. A chronological summary of published and relatively widely referred to studies is provided below.

In 1993, Stefanie Boge from the Wuppertal Institute published a report about the transport activity involved in producing strawberry yogurt sold in Germany (Boge, 1995). This piece of research is explained in some detail below as it provides an example of the typical content of such studies. The research showed that a small glass jar of strawberry yogurt for sale in Stuttgart required the following inputs:

- strawberries transported from Poland to west Germany for processing into jam and then transported to southern Germany;
- yogurt cultures transported from north Germany;
- corn and wheat flour transported from the Netherlands;
- sugar beet transported from east Germany;
- and the labels and aluminium covers for the jars transported 300 km;
- only the glass jar and the milk were produced locally.

The study calculated that to bring one lorry-load of yogurt pots to a southern German retail outlet a 'theoretical' lorry had to be moved 1005 km, using approximately 400 litres of diesel fuel. This was expressed as being equivalent to 9.2 metres of lorry movement for each 150g strawberry yogurt pot.

This research by Boge (1995) did not include consideration of a range of products required to make yogurt and their transport including:

- fossil fuels used by the farmer to plant, spray and harvest the fruit;
- the production of the sprays used by the farmer;
- the aluminium for the yogurt jar lids transported from mines many thousands of miles from the packaging plant;
- the machinery used for packaging the yogurt, which had to be transported internationally;
- the commuter transport of the workers in the yogurt processing plant going to and from their homes every day;
- the transport of shoppers from their homes to the shops, in order to buy the yogurt.

The issue of what to include and what to leave out of the analysis is faced in all such LCA studies.

The Food Miles report (Paxton, 1994) studied food products transported internationally, together with the social and ecological implications of this food trade. It was this report that coined the phrase "food miles" that has become commonly used in the UK. Case studies included: apples, oranges, salad vegetables (lettuce, tomato and cucumber), milk, meat, chocolate, fish, and bread. The report considered the distances over which these products were being imported to the UK, and the energy

and economic effects of these trade patterns. The case studies did not analyse each product in detail in terms of each stage of transport activity and energy use but provided a summary discussion of existing arrangements.

Greenpeace published a report in 1994 (Whitelegg, 1994) which included case studies of what were referred to as “absurd freight transport movements” in the UK and elsewhere in Europe. The supply chains discussed included: bananas, tomatoes, chocolate bars, underwear, car production and Italian ham. The case studies were primarily descriptive rather than containing quantified transport distance and energy use calculations.

FMS, a research group in Stockholm University, published a report containing the results of a survey to collect data that could be used for estimating energy requirements in the food sector (Carlsson-Kanyama and Faist, 2000). It contained data about the energy required for crop farming, animal husbandry, food processing, storage, transportation and food preparation. It was the authors’ intention that this data could be used to estimate the energy use for various food items over their lifecycle. The authors applied this data to the case of a hamburger containing bread, lettuce, onions, cucumbers and cheese. They also discussed ways in which the energy use for hamburger production and supply could be reduced. The report indicated that transport accounted for between 5-9% of the total energy used in producing, supplying and cooking a hamburger in a fast-food restaurant.

In 2001, FMS published a report about energy use for cooking wheat, spaghetti, pasta, barley, rice, potatoes, couscous and mashed potatoes from potatoes mashed powder in the home using different types of cooking appliances and for different numbers of servings (Carlsson-Kanyama, and Boström-Carlsson, 2001). The measurements of energy used in cooking were compared with the energy use in the life cycle stages prior to cooking (including production and commercial transportation). The results showed that, for the food products studied, energy used to cook the food in the home was greater than the energy used for industrial food processing (including crop production, sorting, processing, storage and transportation). When food was cooked in the home by the most efficient means studied (generally on a hotplate for four people) the energy used in commercial transport of the food ranged from approximately 7% of the total energy used to produce, supply and cook the food in the case of mashed potato, to 32% in the case of rice. Transport from the shop to the home by the final consumer was not included in the analysis.

In 2001, SUSTAIN published a report (Jones, 2001) that included case studies of three different meals, and imported organic vegetables. For the case studies of meals, the transport activity and energy consumption involved in supplying them was calculated. For the imported organic vegetables case studies the transport activity and associated CO₂ was provided. It was calculated that the transportation of a sample basket of imported organic produce could release as much CO₂ into the atmosphere as an average household does through cooking meals for eight months. The 26 products in the sample basket had collectively travelled a distance of 241,000 kilometres.

In 2002 Marks and Spencer, a major British clothing and household goods and food retailer, published a life cycle assessment carried out for them into their polyester trousers and men’s cotton briefs (Environmental Resources Management, 2002). This study considered the entire supply chain from cotton growing/polyester fibre production to the retail shop and the consumer’s home. Commercial freight transport was calculated to represent 2% the total energy used in producing a pair of polyester trousers and 6% of the total energy for a pack of cotton briefs. Car transport by the final consumer was calculated to use between two and five times as much energy per item as commercial freight transport. By extending the analysis to include the energy used by the consumer to wash the products after purchase and its ultimate disposal, the results indicated that approximately 75% of the total energy consumption in each of these supply chains is used by the consumer during the washing of the product.

The Wise Moves project by Transport 2000 (Garnett, 2003) examined the relationship between food, transport and carbon dioxide emissions. Within the scope of the project several food supply chains

were studied including: cherries, apples and lettuce (Francis, Simmons and Partners, 2002) and slab cheddar cheese, chicken carcass, and white bread (Eco-Logica, 2003).

The Francis, Simmons and Partners (2002) work quantified the carbon dioxide emissions associated with the transport activity for the current supply chain for the products studied. Cherries, apples and lettuces were found to have an average supply chain distance of 7,751 km, 8637 km and 907 km respectively. The ratio of supply chain CO₂ to product shipped (expressed in tonnes of CO₂ per tonne of product shipped) for cherries, apples and lettuces was calculated to be 3.128, 0.109 and 0.044 respectively. The result for cherries reflects the use of airfreight for a high proportion of shipments. The research also compared the base cases with two alternative distribution strategies (higher load factors and shared distribution networks), and two alternative sourcing strategies (international and local sourcing). Cherries have an average

The Eco-Logica (2003) work referred to above analysed the energy used and carbon dioxide produced during the transport legs between the point of production and the consumer's home. Data from other studies was used to reflect the energy and CO₂ associated with the production of this food. In this analysis, the supply chain of two large supermarkets, one regional supermarket and seven local shops are compared. The results showed that the kilogrammes of CO₂ from commercial freight transport per kilogramme of product delivered to the shops studied ranged from 0.01 to 0.14 for cheese, 0.08 to 2.71 for chicken, and 0.001 to 0.06 for bread. CO₂ from shopping trips was found to vary widely by shop and product type. In the case of bread, shopper trips produced between approximately 10% and 500% of the CO₂ emitted by commercial freight transport per kilogramme of product.

Jespersen (2004) investigated the transport activity involved in the production and retailing of rye bread. This work shows that the transport used to deliver all the inputs to the bread factory is equivalent to 18 km per tonne delivered (these inputs include rye flour and grain, linseed, yeast, vinegar, salt, and barley malt syrup). Most of this transport is carried out in relatively well-loaded, large goods vehicles. Jespersen (2004) notes that the transport of bread from the factory to retail outlets is rather less efficient using smaller goods vehicles, with some bread being delivered direct to retailers, while others is distributed via warehouses. This transport stage from factory to retail outlets is equivalent to 36 km per tonne delivered. The transport used by final consumers buying rye bread in retail outlets and taking this to their homes in their cars is the most transport intensive, representing 70 km per tonne of rye bread. This is explained by the typically low total weight of products transported in these trips made by final consumers. However, as Jespersen (2004) notes the consumer transport calculations are the most uncertain due to the lack of good quality information about whether trips are dedicated to shopping or not, and the total weight of goods purchased.

The studies reviewed in section 4 used different system boundaries and units of analysis. This is shown in Table 1.

The literature review has demonstrated that previously the transport activity and energy use in the jeans supply chain has not been widely studied. Also, the goals of this project are broader than several of the studies summarised above as this project intends study and quantify the energy consumption associated with:

- the entire supply chain from cotton growing to the shop and consumers' home;
- two different sources of cotton and their impact on the supply chain;
- different retail outlet locations and supply chain strategies (multiple retailer and independent retailer);
- consumer transport compared with home delivery.

By studying the entire supply chain from cotton growing to the shop and consumers' home it is possible to quantify the relative importance of transport activity in terms of energy consumption compared with other activities in the jeans supply chain.

Table 1: Summary of studies into freight transport activity and energy use in product supply chains

| Author/organisation | Products studied | Parts of supply chain included in analysis | Units of analysis | Comments |
|--|---|--|---|---|
| Stephanie Boge, paper in World Transport Policy & Practice, Vol. 1 No. 1, (1995) | Strawberry yogurt | Study of all transportation processes in life cycle of strawberry yogurt Study included milk, jam, sugar, glass container, paper label, aluminium cover, cardboard box and sheets, glue and foil | <ul style="list-style-type: none"> • Metres of lorry movement per 150g yogurt purchased in supermarket in southern Germany • Km “theoretical” truck must be moved to bring one truckload of yogurt to distribution outlet in southern Germany | Does not include energy use, only distance over which products are transported. |
| Food Miles Report - SAFE Alliance (1994) | Case studies included: apples, oranges, salad vegetables (lettuce, tomato and cucumber), milk, meat, chocolate, fish, and bread. | Includes transport only | <ul style="list-style-type: none"> • Miles | Considered the distances over which products being imported to the UK were transported |
| Energy Use in the Food Sector: A data survey – FMS (2000) | An estimation of energy used during life-cycle of a hamburger with bun and other ingredients | The project included analysis of: <ul style="list-style-type: none"> • Crop farming • Animal husbandry • Food processing • Storage • Transportation • Food preparation | <ul style="list-style-type: none"> • Megajoules (MJ) per hamburger (with bun, meat, cheese, cucumber, onions and lettuce). | |
| Energy Use for Cooking and Other Stages in the Life Cycle of Food - FMS (2001) | The following foods were studied: Wheat, spaghetti, pasta, barley, rice, potatoes, couscous and mashed potatoes from powdered potatoes. | <ul style="list-style-type: none"> • Farm production with production of farm inputs • Drying of crops • Processing, storage and transportation up to the retailer • Cooking in the home | <ul style="list-style-type: none"> • Megajoules (MJ) per portion of food. | Excluded from analysis: <ul style="list-style-type: none"> • Production of capital goods such as machinery and buildings. • Packaging material • Waste treatment • Transportation from the retailer to the consumer • Dishwashing. |
| Eating Oil – SUSTAIN (2001) | Case studies include: <ul style="list-style-type: none"> • 3 different meals • Imported organic vegetables | Case studies include: <ul style="list-style-type: none"> • Transport activity and energy involved in producing 3 different meals • Transport activity and CO₂ associated | For 3 different meals: <ul style="list-style-type: none"> • Total transport distance (miles) • Total transport energy consumption (megajoules) | Only deals with transport distance and transport energy |

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| | | with imported organic vegetables | For organic veg: <ul style="list-style-type: none"> • Total transport distance (miles) • Total transport CO₂ emissions (grammes) | |
| Wise Moves – Francis, Simmons and Partners (2002) | Cherries, apples and lettuce | Study models the current baseline scenario, two alternative distribution strategies, and two alternative sourcing strategies. Only transport activity and CO ₂ emissions are quantified. Other activities described/estimated. | <ul style="list-style-type: none"> • Total transport (annual tonne-km), and • Total tonnes of CO₂ from transport activity emissions from the farm gate to the retail store. • Ratio of Supply Chain CO₂ to Product Shipped (tonnes of CO₂ per tonne of product shipped) | Compares baseline transport system with: <ul style="list-style-type: none"> • Efficient transport system (higher load factor) • Shared network (less distance from distribution centre to store) Compares international and local sourcing options. |
| Streamlined Life Cycle Assessment of Two Marks and Spencer Apparel Products – ERM (2002) | Polyester trousers & men's cotton briefs | Includes: <ul style="list-style-type: none"> • Extraction of resources and production of materials; • Manufacture of materials; • Transport; • Consumer transport; • Use and disposal. | <ul style="list-style-type: none"> • Kwh per pair of polyester trousers and cotton briefs. | Includes kwh/tonne-km data for ship and 40t truck Only one destination per product studied. |
| Wise Moves – Ecologica (2003) | Slab cheddar cheese, chicken carcass, and white bread | <ul style="list-style-type: none"> • Analyses commercial transport legs between point of production and point of sale. • Also includes shopper transport leg. • Does not analyse non-transport activities (e.g. production, packaging, warehousing etc.) but provides data from other studies for embodied energy. | <ul style="list-style-type: none"> • Mass CO₂/mass of product | Compares supply chains of: <ul style="list-style-type: none"> • Two large supermarkets • One regional supermarket • And 7 local shops |
| Jespersen (2004) | Rye bread | Calculates the “transport content” for each transport leg in the supply chain from seed corn, fertilizer and pesticides, to flour and grain delivered to bakery, to bread distributed to shops, to consumers shopping trips | <ul style="list-style-type: none"> • Km/tonne of product delivered | Only deals with transport distance and vehicle load factor on each leg in the supply chain. |

3.2 Other work consulted about the jeans and cotton supply chains

In addition to the transport and supply chain energy consumption studies reviewed as part of this study (see Section 4.1), we also consulted a range of other published material about jeans and cotton. This included papers concerned with production issues as well as supply chain issues.

The supply chain for jeans involves many stages and activities. It is important to understand these stages and the levels of activity that take place within them in order to assign the associated levels of energy consumption. The approach adopted to broaden understanding of the cotton garment supply chain was to review a variety of relevant literature, which is summarised in Table 2.

Table 2: Literature consulted about the cotton garment supply chain

| Subject area | Publication summary |
|---|--|
| General overview of facts and figures about the cotton industry | <ul style="list-style-type: none"> - <i>About Cotton (Cotton Australia, 2004)</i> - Internet based statistics and information concerning the production of cotton throughout the world. - <i>Top 100 Agriculture: Cotton Production (Nationmaster.com, 2004)</i> - Information about countries producing the raw cotton. |
| The stages of raw cotton production through to fabric weaving | <ul style="list-style-type: none"> - <i>Bradmill PTY Ltd, 2004</i> - detailed description of the various production processes used to produce cotton garments extending from the field to the garment machine room. - <i>Cotton: From Field to Fabric (Cotton Counts, 2004)</i> - Overview of the processes that cotton has to pass through to become a usable fabric. |
| The production of garments and jeans | <ul style="list-style-type: none"> - <i>Jeans (50megs.com, 2004)</i> - An overview of the fabrics styling, construction and sizing of jeans. - <i>How Jeans are Made (50megs.com, 2004)</i> - A summary of the manufacturing processes involved in making jeans. |

| | |
|--|--|
| <p>Technical data related to cotton and the energy consumption associated with the production of cotton, fabrics and jeans</p> | <ul style="list-style-type: none"> - <i>U.S. Cotton Bale Dimensions (National Cotton Council of America, 2004)</i> - information about size and weight of baled cotton. - <i>Cotton versus Polyester (American Science Journal, 1978)</i> - A paper that discusses the energy consumption associated with the production of cotton and polyester at their primary preparation stages - i.e. during cultivation and manufacturing. - <i>Textile Processing Techniques (BTTG, 1999a)</i> - technical report about how cotton is processed into fabric, with indications of levels of waste and technology used. - <i>Textile Mass Balance and Product Life Cycles (BTTG, 1999b)</i> - technical report about the comparable levels of resources consumed in the production of textiles. - <i>Waste Minimisation and Best Practice (BTTG, 1999c)</i> - technical report discussing how to minimise waste during textile production. - <i>Life Cycle Analysis - a Finland United Kingdom comparison (Binkley)</i> - technical paper discussing the energy consumption associated with the production of textiles in the UK and Finland. - <i>From the Cradle to the Gate (Sundin, 2002)</i> - An MSc dissertation that documents a study examining the energy consumption associated with the supply chain of a pair of cotton trousers being distributed in Sweden. - <i>From Cotton to Clothes (Zeander, 2002)</i> - An MSc dissertation that documents a study examining the energy consumption associated with the supply chain of a pair of cotton trousers being distributed in Sweden. - <i>Environmental assessment of Textiles (Laursen et al, 1997)</i> - An in-depth life cycle screening study of the environmental impacts, including energy consumption, associated with the total production of a selection natural fibre and man-made textiles. - <i>e-textile toolbox</i> - developed in a project co-financed by the European Commission's EuropeAid ASI@ITC program. Its intention is to facilitate a more efficient and cleaner textile industry. It aims to help companies become more competitive (through reduced raw material and energy costs, and improved product quality) and to meet environmental regulations. The e-textile website containing the toolbox was consulted as part of the literature review (www.e-textile.org). |
|--|--|

All of the material referred to in sections 4.1 and 4.2 is listed in the references at the end of this report.

3.3 UK Jeans Market

Denim jean trousers are one of the most widely worn garments in the world. Traditional 'denims' or 'jeans' are made from 100% cotton, although modern variations may be made from fabrics that include fibres or yarns such as polyester or lycra to provide other characteristics - i.e. more stretchy fabric. Jeans are manufactured globally by companies that either specialise in the product (e.g. Levi Strauss, Lee, Wrangler), or are general garment manufacturers working for specific brands or retailers.

3.3.1 Jeans sales in the UK

The sale of denim jeans in the UK is an important part of the clothing market. During 2002, UK retail volume sales of jeans were approximately 61 million units, with a value of approximately €1,751

million (Mintel, 2003a). To place this into context, in 2002 consumer expenditure on clothing in the UK was approximately €52,240 million, which means that jeans sales represented around 4% of the clothing market (Mintel, 2003b).

The market for jeans in the UK has continued to grow over the past six years. In 1998, UK retail volume sales of jeans were around 44 million units. This figure rose to an estimated 63 million units in 2003 (Mintel, 2003b).

The jeans market is split into three broad segments: men, women and children. While the men's segment is the most dominant in the market, sales of women's jeans have risen rapidly in recent years. Table 3 indicates the changing market for sales of jeans in the UK by volume.

Table 3: Sales of jeans in the UK by volume for main market segments, 1999 – 2003

| | 1999 | | 2001 | | 2003 (est) | | % change 1999-2003 |
|--------------|-----------|------------|-----------|------------|------------|------------|-----------------------|
| | Mn pairs | % | Mn pairs | % | Mn pairs | % | |
| Men | 25 | 58 | 26 | 50 | 30 | 48 | +20 |
| Women | 11 | 26 | 18 | 35 | 25 | 40 | +127 |
| Children | 7 | 16 | 8 | 15 | 8 | 13 | +14 |
| Total | 43 | 100 | 52 | 100 | 63 | 100 | +46 |

Source: Mintel, 2003a

3.3.2 Supply of jeans in the UK

The production of jeans in the UK has declined from 33 million pairs in 1997 to 9 million pairs in 2001 (Mintel, 2003a). Over the same period imports of jeans have risen from 33 million pairs to 54 million pairs (Mintel, 2003a). Table 4 shows the changes in production, and import and export of jeans for the UK.

Table 4: Apparent consumption of jeans in the UK, 1997-2001

| | UK Jeans - million of pairs | | | |
|------|-----------------------------|--------|--------|-------------------------|
| | Domestic Production | Import | Export | Apparent Consumption |
| 1997 | 33 | 33 | 17 | 49 |
| 1998 | 24 | 30 | 11 | 43 |
| 1999 | 18 | 34 | 8 | 44 |
| 2000 | 12 | 40 | 10 | 42 |
| 2001 | 9 | 54 | 9 | 54 |

Apparent consumption = Domestic production + import – export

Source: Mintel, 2003a

The main reason cited for this change is that overseas production costs are lower than those which can be achieved in the UK. Mintel suggests that the typical manufacturer selling price of a pair of jeans manufactured in the UK is €13.32, while imported jeans have a typical manufacturer selling price of €8.65 (Mintel, 2003a).

The final distribution of jeans in the UK occurs through a variety of different retail channels. Table 5 illustrates the range of channels and volume of sales.

Table 5: Volume sales of jeans in the UK by type of outlet, 2000 and 2002

| | 2000 | | 2002 | | % Change 2000-02 |
|-----------------------------|---------------|-----|---------------|-----|---------------------|
| | Million pairs | % | Million pairs | % | |
| Clothing multiples | 13.5 | 29 | 19.5 | 32 | +44.4 |
| Specialist jeans outlets | 6.5 | 14 | 7.3 | 12 | +12.3 |
| Clothing independents | 7 | 15 | 8.5 | 14 | +21.4 |
| Department & variety stores | 4.6 | 10 | 5.8 | 10 | +26.1 |
| Market stalls | 2.8 | 6 | 3 | 5 | +7.1 |
| Mail order/home shopping | 2.3 | 5 | 2.7 | 4 | +17.4 |
| Others | 9.7 | 21 | 14 | 23 | +44.3 |
| Total | 46.4 | 100 | 60.8 | 100 | +31.3 |

Source: Mintel, 2003a

Clothing multiples such as Marks and Spencer, Arcadia, Next Retail and GAP dominate the market, selling a mix of own brand and specialist brand jeans. Over the two years illustrated in Table 4, it can be seen that these clothing multiples companies have strengthened their position in the market and in 2002 controlled over 30% of the total sale of jeans in the UK by volume.

In terms of actual brands being purchased, specialist labels, which include names such as Levi's and Lee, dominate the market. Mintel (2003a) suggests that only Marks and Spencer has been successful in breaking into this market with its own brand labels (i.e. Per Una and Blue Harbour). Some of the makers of specialist labels have their own retail outlets (e.g. Levi Stores, Diesel), but other such as Wrangler do not run such shops and are only sold through other companies' clothing stores. Table 6 shows the market share of different brands in the UK.

Table 6: Brand shares by value in the UK jeans market, 2000 and 2002

| | 2000 | | 2002 | |
|-------------------------|------|-----|------|-----|
| | £m | % | £m | % |
| Levi's | 134 | 15 | 167 | 15 |
| Marks & Spencer | 80 | 9 | 98 | 9 |
| Lee | 46 | 5 | 61 | 5 |
| Wrangler | 49 | 6 | 56 | 5 |
| Diesel | 40 | 5 | 56 | 5 |
| Pepe | 40 | 5 | 52 | 5 |
| Next | 34 | 4 | 45 | 4 |
| CK Jeans | 36 | 4 | 45 | 4 |
| Gap | 31 | 3 | 39 | 3 |
| Easy | 29 | 3 | 36 | 3 |
| Falmer | 22 | 2 | 30 | 3 |
| Lee Cooper | 19 | 2 | 23 | 2 |
| Other own/private label | 151 | 17 | 187 | 17 |
| Other brands | 177 | 20 | 220 | 20 |
| Total | 888 | 100 | 1115 | 100 |

Source: Mintel, 2003a

4. Generic supply chain for jeans

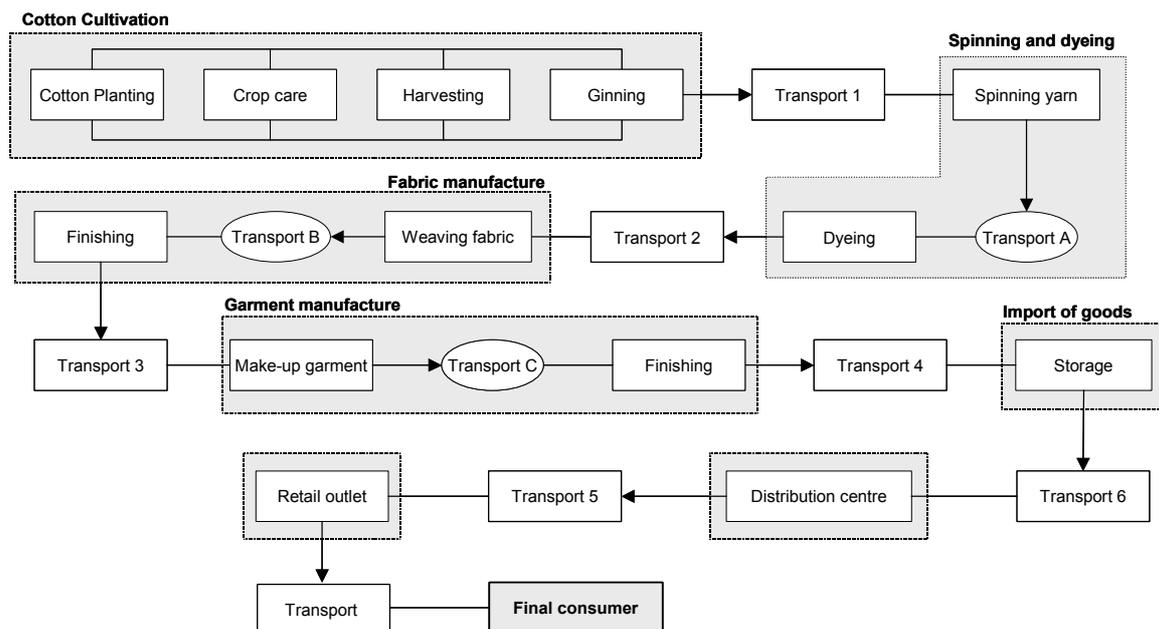
4.1 Introduction

The production of jeans can be broken down into seven main operations. These are:

- Cotton cultivation
- Spinning and dyeing of cotton
- Fabric manufacture (making denim)
- Garment manufacture (making jeans)
- Importation of jeans to UK
- National and regional distribution
- Sale of jeans at retail outlet

Within some of these operations there are a variety of processes that influence the levels of energy consumption. Transportation typically takes place between each of the operations listed above. In addition, transport of partly finished jeans and other constituent materials can also take place during these main manufacturing operations as the product is moved between different factories (e.g. transporting the cotton from a spinning to a dyeing facility, or transporting the jeans to another site for embroidering). Figure 1 illustrates the processes and transport stages that can be included in the supply chain. These are discussed in more detail in the following sections.

Figure 1: Stages of jeans production and distribution



The transport stages in Figure 1 have been divided into two types: i) transport takes place when a movement of materials is carried out between one major operation and another (e.g. between cotton plantation and spinning facility - this is shown as 'Transport' followed by a number in a rectangular box), and ii) transport that occurs within one a major operation (e.g. between weaving and finishing the denim – this is shown as 'Transport' followed by a letter in an oval box). In some cases a transport stage involves a single transport leg by one mode. In other cases a transport stage could involve several transport legs using more than one mode (e.g. road-sea-road).

4.2 Cultivation of cotton

Global quantities and sources of cotton

Cotton is a natural fibre, which has been grown and harvested for thousands of years. Today it is cultivated throughout the world, both north and south of the equator, meaning crops are delivered year round. During 2002/03, world production of cotton was about 84 million bales, each weighing 227 kg. The five major cotton producing countries are: the United States, Uzbekistan, China, India and Pakistan. Other countries producing cotton include, Australia, Syria, Turkey, Spain, Egypt, Greece and Brazil (Cotton Australia, 2004).

Cotton yields can be affected by a variety of factors including weather patterns, levels of mechanisation used by growers, and the cotton crop's economic attractiveness to farmers. The world average yield of cotton per hectare is 638 kg. The most efficient country producing cotton in 2002/03 was Australia, with a yield of 1,672 kg per hectare. The lowest yields in 2002/03 were in Pakistan are were 625 kg per hectare (Cotton Australia, 2004).

Cotton production and energy consumption

The growing of cotton comprises four main activities: sowing of seed, crop care during the growing period (e.g. pest control and irrigation), harvesting and ginning (the separation and cleaning of cotton lint from cotton seed and baling of the lint). Typically, each of these activities requires the use of mechanisation that will draw energy either from combustion engines or electrical sources. In addition there is often an element of transport that takes place between the harvest location and ginning facility.

4.3 Spinning and dyeing

Processing the baled cotton lint is the first manufacturing stage in producing garments. At this stage two main processes take place: spinning the lint into yarn and dyeing the yarn. The spinning of yarn involves a number of preparations to bring the lint to a ready state for spinning. This includes using agitating machines and blowers to remove dust and mixing the cotton fibres (and where necessary, adding other fibres such as polyester) into a mass ready for spinning. Machines at this point draw the fibres into continuous lengths which are fed into the spinning equipment. There are two forms of spinning, chemical and mechanical spinning, both of which have different preparations.

After the yarn has been produced it is ready for dyeing, which may or may not be carried out at the same site. Yarn for jeans is predominantly coloured with indigo (blue) dye, although where fashion dictates black and other colours are used. Modern indigo dyes are synthetically produced and do not use the original *isatic tinctora* or *indigofera* plants or ancient methods of manufacture. The dyeing process requires the yarn to be dipped into the dye solution and dried at least 5 to 6 separate times in order to obtain a sufficiently dark indigo coloured dyed yarn. At this point the yarn is ready for use in the production of the denim fabric and will be transported to a weaving mill, which can be located locally, or much further a field.

4.4 Fabric manufacture

The manufacture of denim fabric involves two main processes, the weaving of the material and finishing - e.g. softened by washing, left untouched, etc. These processes are not necessarily carried out at the same site, in which case the fabric is transported between the two factories. The fabric will be produced to different weights and grades to suit the various jeans markets that exist. Branded products from companies such as Levi Strauss tend to use higher-grade fabrics than material destined for own brand or cheap brand jeans. The fabric finally produced will be shipped to the garment manufacturer, who could be located in the same country in which the cotton is grown or in another country.

4.5 Garment manufacture

The manufacture of jeans involves three main processes: pattern cutting, sewing the garment and finishing. This overall manufacturing process can range from being relatively simple, (e.g. making jeans that use a base material, have five pockets and do not require a washing finish), to jeans that are quite complex to make. These latter versions are for the fashion market and can involve a variety of finishing processes and are discussed later. In terms of materials used in the manufacture of jeans, Levi Strauss state that a typical pair of Levi's® 501® jeans takes about 1.75 yards (1.4m) of denim (this is a linear measurement and the denim would be 60cm wide on the roll), 213 yards (195m) of thread, five buttons and six rivets. There are 37 separate sewing operations involved in making a single pair of Levi's® 501® jeans (Levi Strauss, 2004).

Pattern cutting: modern pattern cutting for jeans and most garments is carried out by computerised cutting machines that are able to calculate the optimal arrangement of garment components on an area of fabric. This ensures that fabric wastage is minimised. Mechanical blades carry out the actual cutting. Pattern cutting may or may not be completed at the same site as the sewing. The machinery is powered by electricity.

Sewing garments: as noted above in the information from Levi Strauss, jeans require a number of separate sewing operations. Whether a pair of jeans is fabricated in one operation or whether the sewing is completed in stages, depends on the final finish of the product. For example, a pair of jeans may be sewn together, but the waistband is left off while the jean and the waistband undergo a finishing process - e.g. washing. The waistband will be sewn in place after this treatment has taken place. Importantly the washing and sewing might not be completed at the same site and the part-finished products will be transported between the two locations. In other cases, the final finishing of the product might be carried out at a different factory, where zips, buttons and studs are added. It is worth noting that these sites can also be a considerable distance apart and may require long shipping movements - i.e. garment made in China and final finishing completed in Hong Kong

Finishing: many of today's jeans are, as a minimum, given a wash in order to fade the denim material. Washing times can range from 15 minutes to 3 hours, depending on the desired effect. Furthermore, the washing may involve using a variety of additives or agents, such as pumice and/or enzymes, to achieve different effects. The finishing process may also involve giving the fabric a 'well worn' look, whereby the material is reduced to being threadbare or even have holes made in it by abrasive machines. In other instances once the jeans have been sewn the fabric is printed with different finishing effects (e.g. made to look like it has been splashed with paint) or pressed to give a creased look. All these finishes require energy to be used to achieve the effect and in many cases the finishing is carried out at different sites and jeans have to be transported between locations.

After the jeans have completed the manufacturing process they are checked for quality and stored for a short time in warehouses awaiting distribution.

The current innovations that make new jeans look old clearly have energy consumption implications, given that they are subject to a number of processes in order to achieve a certain 'look'. Conversely, base product jeans that do not require special treatments and finishes are not so energy consuming during manufacture.

4.6 Import of goods

There are a number of distribution routes that jeans can take when being imported into the UK. These very much depend on whether the company is a manufacturer or importer of a particular brand or if the importing is being organised by or on behalf of a retailer. Most jeans arrive in the UK by sea or road, the mode being determined by the original point of manufacture or whether the jeans are being redistributed throughout Europe from a central distribution hub located in another country - e.g. the Netherlands.

When arriving by sea jeans are typically carried in ISO containers and as a result there will be handling at the port of entry to unload containers from the ship and to move and store the container until it is collected. The packing of jeans into the container can vary between being hanging garments (bundles of jeans on hangers suspended from rails covered in polythene bags), or flat packed into cardboard boxes and stacked on top of one another. Jeans transported by road will be arriving from a Continental or Irish based warehouse or factory and will enter the country by one of the North Sea, Irish Sea or Channel ports. This does not normally involve additional handling unless the trailer is ferried to Britain as an unaccompanied movement (i.e. a lorry tractor unit and driver does not accompany the trailer onboard the ferry and different vehicles move the trailer each side of the sea crossing). As with jeans in containers, jeans in heavy goods vehicles trailers will be either hanging garments or flat packed in boxes.

4.7 National and regional distribution

Jeans will normally be distributed to a warehouse operated by the manufacturer, retailer or a third party logistics provider, where they will be unpacked and consolidated with other stock for the client. The unpacking may involve revitalisation of the garment (i.e. steaming to remove creases) and this is more the case where the initial transportation was as a flat packed consignment.

From this point the jeans may be forwarded to a retailer's national or regional distribution centre for storage and final distribution to a retail outlet, or may be sent directly to a retail outlet. Transport movements between warehouses and from the final warehouse to the retail outlet will typically take place by road.

4.8 Retail outlet

The quantity of jeans stored at a retail outlet depends on the type of retailer (e.g. multiple store retailer with large shops, multiple store retailer with small shops, or an independent retailer). The larger companies with many shops (that have both large and small shop space) tend to opt for a minimum amount of storage space and rely on frequent stock replenishment from their regional distribution centres (RDCs). Independent shops or small chains that do not have their own RDCs are likely to have larger shop-based stockrooms in which they store larger quantities of goods. However, even in these cases the retailers are moving towards holding less stock and ordering more frequently from the jeans suppliers. Ordering jeans on a more frequent basis will lead to a higher number of vehicle deliveries of jeans to retailers.

4.9 To customer's home

Consumers may either purchase a single pair of jeans, they may buy several items of clothing, or they may buy clothing and other products such as groceries during their shopping trip. They will then transport the jeans home either by car, using public transport or by walking or cycling.

Department for Transport data for 1999-2001 shows that 62% of non-food shopping trips in Britain take place by car, 8% by bus, 26% on foot and 4% by other modes (Department for Transport, 2003).

5. Case study: Jeans supply chain for a major UK retailer

5.1 Introduction and approach

The case study examined the supply chain for a pair of ladies five-pocket Western jeans sold by a major multiple clothing retailer. These jeans were chosen for study during discussions with the retailers as they are relatively “basic” jeans (i.e. they require little processing and finishing in comparison with jeans aimed at the fashion market). As described in section 3, we worked closely with the retailer and its suppliers in order to build up a detailed understanding of the activities and locations involved in the supply chain for these jeans from the field in which the cotton is grown through to the sale of the jeans in a retail outlet in the UK.

The information obtained from these companies was used to produce a detailed description and to map the supply chain for the jeans, this included non-transport and transport activities from the cotton plantation to the retail outlet. The distances over which the jeans were transported between each location in the supply chain was also determined (see section 6.2).

In order to carry out the transport energy consumption and CO₂ emissions analysis in the case study it was necessary to gather primary and secondary data. Secondary data was obtained from the literature review and from companies participating in the project that had existing information from previous research. Representatives from the participating companies validated secondary data obtained from published sources. Primary data about transport activities in the jeans supply chain was obtained through the interviews as well as through subsequent contacts provided by the interviewees. This involved the companies supplying the following information about each of the transport legs in the supply chain:

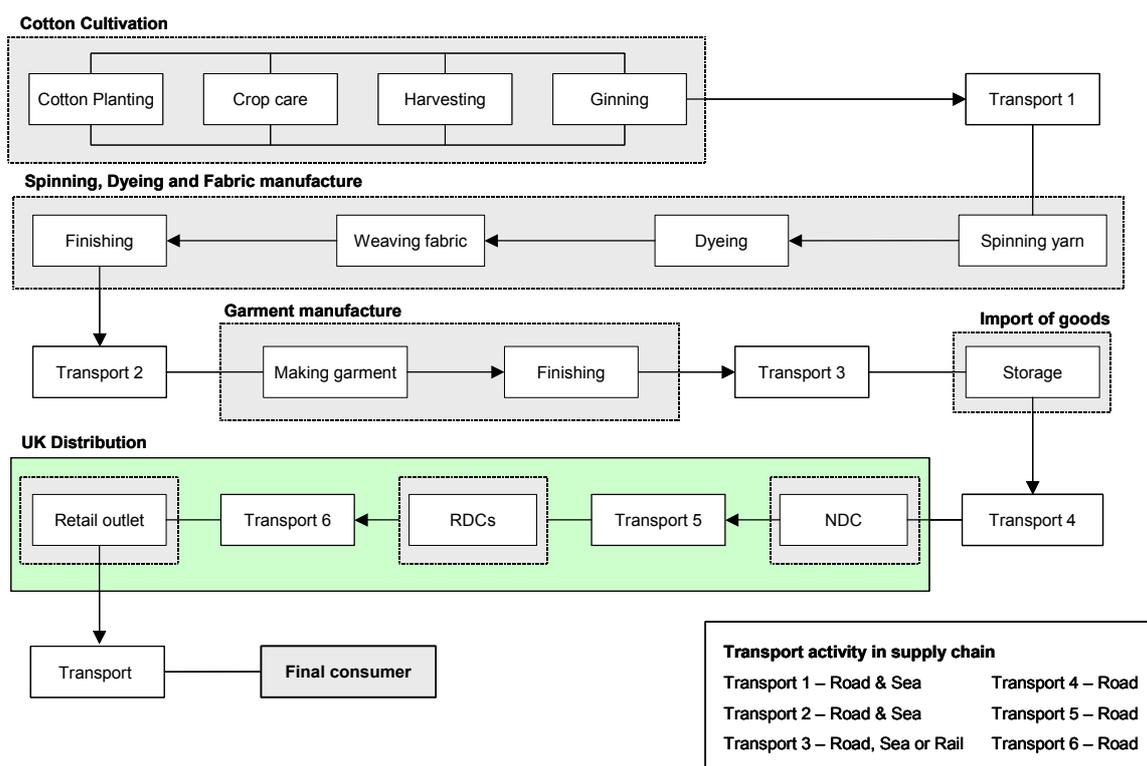
- Transport mode
- Type/weight of vehicle
- Quantity of product carried
- The distance between the point of collection and delivery
- Whether or not the vehicle returns empty

It is important to note that the supply chain data used and analysed in the project is intended to reflect generic jeans supply chains rather than the specific supply chains of particular companies. The data was analysed using a spreadsheet.

5.2 Description and mapping of case study supply chain

The supply chain for the ladies five-pocket Western jeans considered in this study included all the stages of the production and transportation that begin at the cotton plantation through to the final retail outlet in the Great Britain.

From the interviews with the retailer and suppliers it was possible to produce a supply chain map for the jeans. This is shown in Figure 2, the different stages of production and distribution and the various transport activity are depicted. In some cases a transport stage involves a single transport leg by one mode. In other cases a transport stage could involve several transport legs using more than one mode (e.g. road-sea-road). In this case study no transport takes place within a major manufacturing stage (e.g. garment manufacturing).

Figure 2: Supply chain of a pair of jeans

Cotton sources can vary from year to year and are dependent upon factors such as the price and quality of cotton in the market. Major sources of raw cotton used to manufacture the jeans that have been analysed in the case study are the USA and Turkey. At these sources the cotton is grown, picked, ginned and baled before it is transported to a processing factory in Malataya in Turkey where denim is produced from the cotton.

The cotton from both the USA and Turkey is transported to this processing factory in Turkey in a baled form in standard ISO containers (both 20-foot and 40-foot units). A 40-foot container will hold approximately 20.5 tonnes of baled cotton. The standard cotton bale weighs 227 kg and 90 bales can be loaded into a 40-foot container.

The transport of the baled cotton from the USA to the processing factory in Turkey is carried out in three legs: two road journeys (from the cotton growing area [e.g. South Carolina, Mississippi] to Port of Charlotte, USA and from Iskenderun port in Turkey to Malataya, a distance of 350 km) and a sea leg (Port of Charlotte to Iskenderun). The baled cotton from Turkey is transported by road from the growing areas in Anatolia or the Mediterranean Sea coast to Malataya, a distance of 400 km. Once at the processing factory, the cotton bales are manufactured into denim fabric. In this case the spinning, dyeing, weaving and finishing are all carried out on one site.

The rolls of denim fabric are then transported in containers to the garment manufacturing plant, which is located in Tangiers in Morocco. Approximately 29 tonnes of fabric are carried in each container, equivalent to 290 rolls. The transport involves two legs, a road journey from Malataya to Iskenderun (350 km) and a sea leg to Tangiers (distance of 3,800 km). The jeans manufacturing plant is located immediately next to the port (400 metres), so there is only a very short journey by road vehicle from the port to the manufacturing plant.

Both the production and finishing of jeans takes place on the same site in this example. Consequently, there is no other off-site transport activity involving the movement of partly finished jeans to different processes, such as washing. Finished jeans are packed as hanging garments into articulated good

vehicles - 10,000 to 12,000 garments in a lorry, bundled in three pairs and covered with a polythene bag (referred to as a 'polybag').

The journey from the manufacturing plant in Tangiers to the manufacturer's UK warehouse is entirely by road and involves a ferry crossing from Tangier to Algeciras in Spain (35 km); a road journey to the Channel port of Cherbourg in France (2,000 km); another ferry crossing to Poole/Southampton, England (120 km); and a road trip to South Wales (280 km).

At the manufacturer's warehouse the garments are unloaded and stored for a short period. They are supplied to the retailer's distribution system as requested by the retailer (based on customer demand). The manufacturer sends the jeans by lorry to the retailer's sortation depot in Leicester, a journey of 320 km. From this depot the jeans are distributed to 10 regional distribution centres (RDCs), the closest of which is 135 km and the furthest 500 km, with an average distance of 200 km. The average load size of jeans on a vehicle is 9,600 pairs, comprising 800 sets of 12 single pairs of jeans. These are transported on an articulated lorry that has a gross vehicle weight (GVW) of 28 tonnes.

The jeans are unloaded and stored at the RDCs and sent out to the retail outlets by road to replace stock that has been sold from the display rails as demand dictates. The closest retail outlet to an RDC is 3 km, the furthest 260 km and the average distance for deliveries from RDCs to retail outlets is 101 km. Delivery vehicles going to retail outlets carry mixed loads. The average number of garments carried on these deliveries is 6,500. These goods are transported on an articulated lorry that has a GVW of 23 tonnes.

After customers have purchased the jeans they transport them home either by car, using public transport or by walking or cycling. Research by the retailer has shown that car transport is common among its customers, with a typical round trip distance of 11.3 km.

5.3 Transport activity in the case study supply chain

From the interviews and discussions with the retailer and its suppliers we were able to determine the distances involved in each transport leg between points in the supply chain. The results are shown in summarised form for transport between major activities in the supply chain in Table 7.

Table 7: Summary of transport leg distances and mode used in the case study

| From | To | Distance (km) | Vehicle (s) |
|------------------------------------|------------------------------------|---------------|-------------------|
| Cotton plantation (USA) | Spinning mill (Turkey) | 10750 | Lorry & ship |
| Cotton plantation (Turkey) | Spinning mill (Turkey) | 400 | Lorry |
| Spinning mill (Turkey) | Garment make up (Morocco) | 4150 | Lorry & ship |
| Garment make up (Morocco) | Manufacturer's warehouse (UK) | 2,450 | Lorry & sea ferry |
| Manufacturer's warehouse (UK) | Retailer's national warehouse (UK) | 300 | Lorry |
| Retailer's national warehouse (UK) | Retailer's regional warehouse (UK) | (Average) 200 | Lorry |
| Retailer's regional warehouse (UK) | Retail outlets (UK) | (Average) 100 | Lorry |

The American and Turkish supply chains studied both involved six major transport stages from the cotton field to the retail outlet, with each stage involving up to three transport legs (e.g. road-sea-road). The supply chains only differ in terms of the source of the cotton. Once the cotton has been delivered to the spinning mill in Turkey the chains are identical. When US cotton is used, the supply chain comprises 13 transport legs (i.e. individual trips using different transport modes). Ten of these trips take place by road vehicle and three by sea. In the case of cotton from Turkey, the supply chain consists of 10 transport legs, eight of which take place by road vehicle and two by sea.

On average, the total journey distance from cotton field to UK retail outlet when using American cotton is 17,950 km, and when using Turkish cotton is 7,600 km. In addition, the road vehicles used in the supply chain are often not provided with a return load at the point of delivery, so there is

additional transport activity associated with the supply of jeans in which the vehicles have to travel to their next collection point (either to carry out more work associated with the supply of jeans or to work in a completely different supply chain).

6. Case study: Results of transport energy and CO₂ emissions in all supply chain activities

6.1 Energy use and CO₂ emissions in all supply chain activities

The energy consumption for the cotton cultivation, manufacturing and transport stages in the jeans supply chain from the cotton field to the consumer's home was calculated. All transport stages were included that involved cotton or jeans being carried between locations by road, water or sea, from cotton harvested in the field to transport by the final consumer to their home. As explained in the section 6.2, primary data was collected from the retailer and manufacturer about transport energy use. Vehicle fuel consumption formulae and data were supplied by INRETS.

Information concerning the transport carried out by the final consumer was less readily available due to a lack of existing survey work about transport mode and distance and whether these trips have one or more purposes. It was therefore assumed in the base case that the consumer travelled by car, with an average round trip distance of 11.3 km (this data was taken from previous work carried out by the retailer), purchased goods with a total weight of 5 kg and that the trip had two purposes (shopping and one other). Therefore half the distance (5.6 km) was attributed to the shopping trip in the base case.

Some transport activities that involve the supply of inputs to the cotton and jeans producers, as well as internal transport in factories and distribution centres, have been omitted from the analysis. The transport associated with the supply of zips, buttons, hangers, plastic covers, price labels and printed tickets, and carriers bags have also been omitted from the analysis due to lack of data. Materials handling activities that take place within industrial and retail facilities (using forklift trucks and other conveyance systems) have not been explicitly included in the analysis due to the difficulty of obtaining sufficiently detailed descriptions and the relevant data for these activities.

In the case of non-transport activities, energy consumption data from other published reports and studies was used (Environmental Resources Management, 2002; van Winkel, 1978). The companies participating in the study validated this data. A small number of non-transport activities were omitted from the analysis due to a lack of data. These include:

- energy used during storage activities prior to the finished jeans being manufactured (e.g. storage of baled cotton, rolled denim fabric etc.)
- energy used to carry out pre-retail activities including the attaching of the pricing and information ticket to the jeans

Energy data was expressed in terms of the extracted energy for each supply chain activity. Extracted energy refers to the energy consumed directly by machinery together with the energy required in order to produce this consumed energy, including losses in generation and transmission. Energy calculations have been calculated in grammes of oil equivalent (GOE), and have been expressed per kilogram (kg) of jeans. Carbon dioxide (CO₂) emissions were also calculated for the jeans supply chain using secondary data about the emissions associated with the use of different fuel sources.

Table 8 shows the results of the energy consumption analysis for each part of the supply chain for the jeans studied.

Table 8: Energy consumption in the jeans supply chain studied

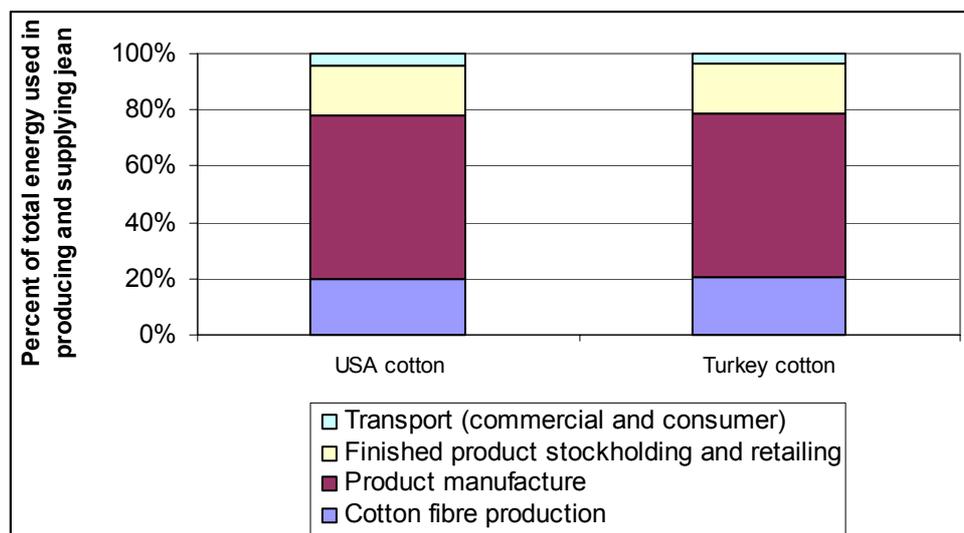
| | Energy consumption in producing and supplying jeans to UK retailer (grammes of oil equivalent per kg of jeans & % of total) | | | |
|--|--|------------|--------------------|------------|
| | Cotton from USA | | Cotton from Turkey | |
| | Goe/kg jeans | % of total | Goe/kg jeans | % of total |
| Cotton fibre production | 1863 | 20% | 1863 | 20% |
| Transport from plantation to product manufacture point | 70 | 1% | 70 | 1% |
| Product manufacture | 5362 | 59% | 5362 | 59% |
| Transport from product manufacture to UK port | 227 | 2% | 227 | 2% |
| Finished product stockholding and retailing | 1621 | 18% | 1621 | 18% |
| Transport from UK port to retail outlet | 10 | 0% | 10 | 0% |
| Total | 9155 | 100% | 9155 | 100% |

Figure 3 shows the same energy consumption results grouped into a smaller set of activity categories for cotton sourced from America and Turkey.

The results indicate that product manufacture is the most energy intensive procedure in the jeans supply chain studied (approximately 60% of total energy use in the supply chain), followed by cotton fibre production (20%) and finished product stockholding and retailing (i.e. the energy used to run the warehouses and shops in which jeans are stored and displayed) which is responsible for 18% of energy use. The transport activities (i.e. commercial freight transport from field to shop, and consumer transport to home) can be seen to account for 3% of the total energy used per kg of jeans supplied.

The results also indicate that the use of local cotton (i.e. from Turkey) has only a very small effect on the total energy consumed in the supply chain.

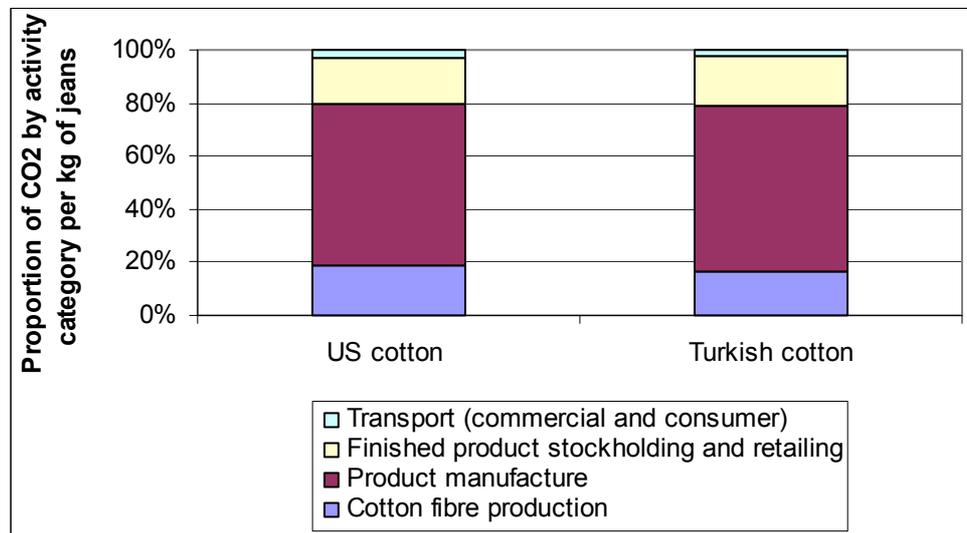
Figure 3: Energy used in the production and supply of jeans using cotton from USA (percentage of total energy consumption)



Using more locally produced cotton from Turkey can be seen to have virtually no impact on the proportion of energy used for total transport activities. Commercial freight transport alone (i.e. not taking into account the consumer transport from shop to home) accounts for 2.7% of total energy use in the supply chain using Turkish cotton and 3.4% in the supply chain using American cotton.

Figure 4 shows the results of the CO₂ analysis for each part of the supply chain for jeans. The results are similar to those for energy consumption, with the majority of CO₂ emissions produced as a result of the jean manufacturing activities (approximately 60% of total CO₂ emissions in the supply chain per kg of jeans for cotton from America and Turkey).

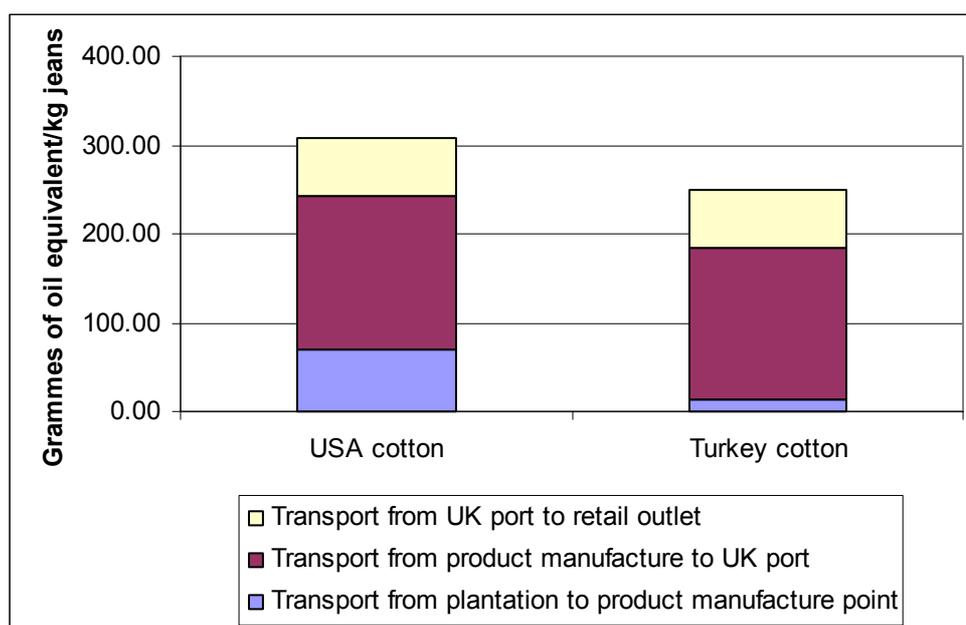
Figure 4: CO₂ emissions from supply chain activities in the case study



The results indicate that transport related CO₂ emissions (commercial freight transport and consumer transport) represent 3% of CO₂ emissions in the supply chains for cotton from Turkey and the USA. The majority of CO₂ emissions are generated during the manufacture of the jeans (60% of total CO₂ emissions in the supply chain).

6.2 Energy use in different stages of freight transport

If the commercial freight transport is considered in isolation, then it can be seen that the transport stages from the point of product manufacture to UK port is responsible for the greatest proportion of transport energy use per kg of jeans in the UK supply chain (see Figure 5). Most of this energy is consumed in the transport stage in which the product is moved from the factory where the jeans are finished to the UK port (this accounts for approximately 55% of commercial transport energy consumption when using US cotton, and approximately 70% when using Turkish cotton). Transport from the cotton source to the point of jeans manufacture accounts for approximately 5% and 25% of commercial transport energy consumption for Turkish and US cotton respectively.

Figure 5: Transport energy consumed from cotton field to retail outlet in the UK

Transport from the UK port to the store accounts for approximately 20% of the total commercial transport energy in the case of cotton from the USA, and 25% in the case of cotton from Turkey. The transport leg from the retailer RDC to the shop (the final commercial transport leg in the supply chain with an average distance of 101 km) accounts for approximately 4% of total commercial freight transport energy use.

6.3 Impact on energy use of variation in RDC and shop distances

The results presented in figures 3 to 5 are based on the average distance that jeans are transported from the retailer's national distribution centre (NDC) to their RDC (221 km) and from RDC to their shops (101 km). The minimum and maximum distances involved in these two transport stages were therefore analysed in order to examine its effect on commercial freight transport energy consumption. The maximum and minimum distances from NDC to RDC are 507 km and 95 km respectively. The maximum and minimum distances from RDC to shop are 263 km and 2 km respectively.

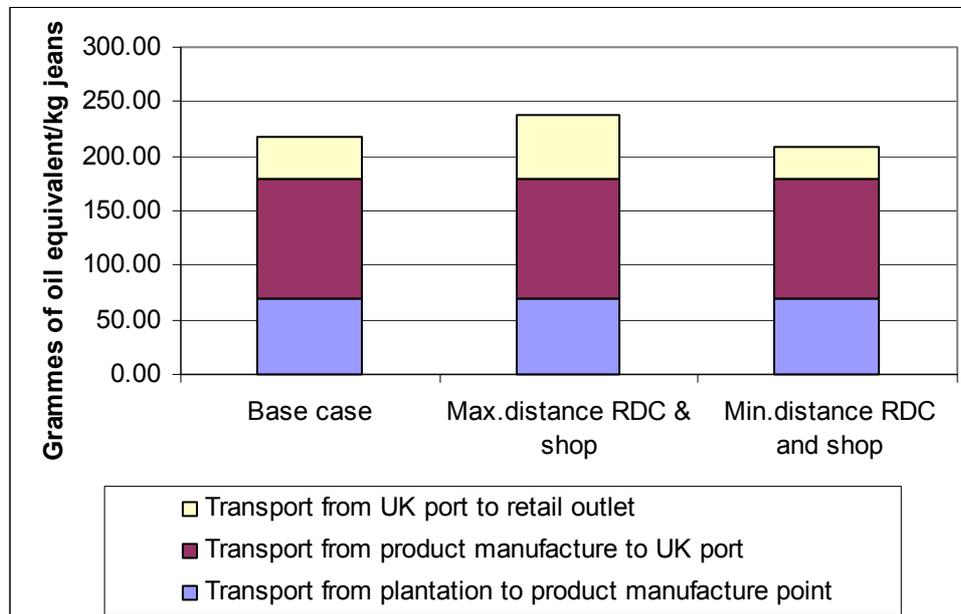
Figure 6 compares the effects of average (i.e. base case), maximum and minimum distances for these two transport stages on total commercial freight transport energy use. Further analysis of the results shown in Figure 6 shows that the maximum distance from NDC to RDC results in energy consumption are more than twice as much as in the base case (i.e. using average transport distances) for this transport stage. The minimum distance from NDC to RDC produces results that are less than half the base case for this transport stage.

Similarly, the maximum distance from RDC to shop uses approximately two and a half times as much energy for this transport stage than the base case. The minimum distance from RDC to shop uses a fraction of the energy used in the base case (given the journey distance of 2 km).

However, as Figure 6 indicates, because these two transport stages are responsible for a relatively small proportion of the total energy used in commercial freight transport, the effect of the maximum and minimum distance scenarios on total commercial freight transport energy use are relatively modest. The maximum distance scenario results in a 10% increase in total commercial freight transport energy use per kg of jeans supplied compared with the average distance base case. The

minimum distance scenario results in a 5% decrease in total commercial freight transport energy use compared with the average distance base case.

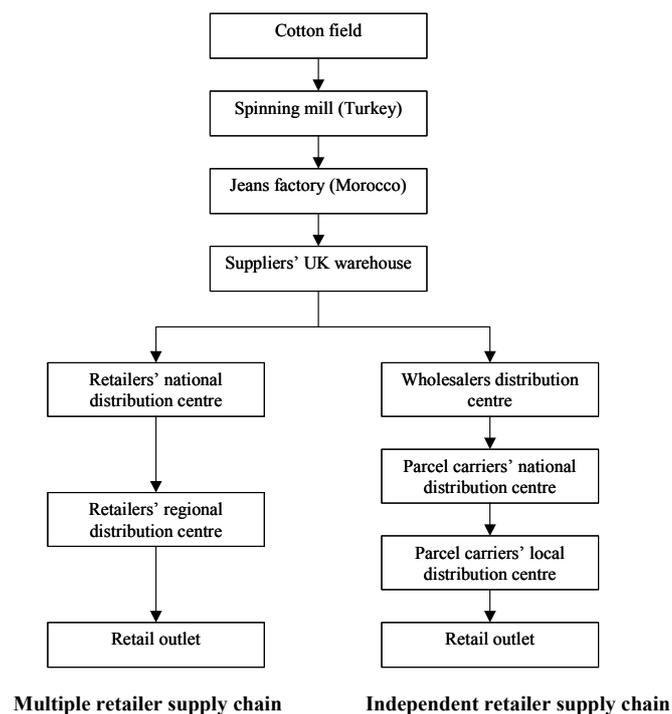
Figure 6: Effects of variations in the distance to RDC and retail outlet (using US cotton)



6.4 Impact on energy use of product supply to an independent shop

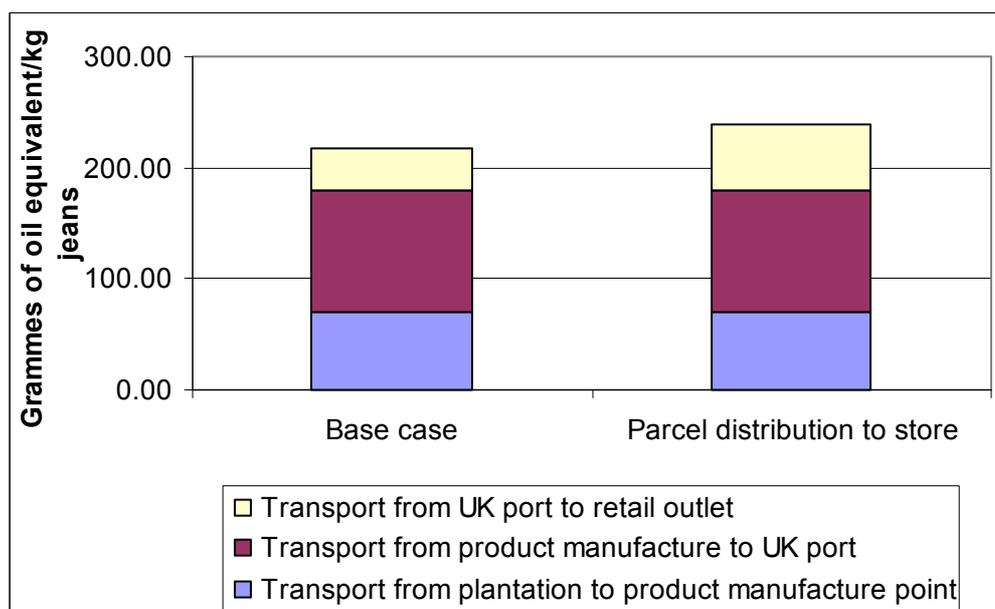
The results of an alternative supply chain in which the jeans are sold by an independent clothes retailer rather than a national multiple retailer have also been considered. It has been assumed that the jeans destined for an independent clothes shop will be the same as in the multiple retailer base case up to the point that they arrive in the supplier’s distribution centre in the UK. From this point they are then distributed to the wholesaler’s distribution centre and are then transported by parcel carrier via their national distribution centre to their urban distribution centre (the distance from supplier’s DC to wholesaler’s DC to parcel carriers urban DC is assumed to be the same distance as the journey from supplier’s distribution centre to the retailer’s NDC and then to the retailer’s RDC). A van is then used to transport the jeans from the urban distribution centre to the store. This trip is assumed to be 10 km. The differences in the supply chains for the multiple and independent retailer are shown in Figure 7.

Figure 7: Multiple and independent retailer supply chains for jeans



The results are shown in Figure 8. The analysis suggests that the transport energy used per kg of jeans from the supplier’s DC to the shop is approximately 70% greater for the independent shop than for the national multiple retailer (i.e. the base case). This is equivalent to approximately a 10% increase in total commercial freight transport energy use from cotton field to shop. This highlights the potential energy efficiency associated with distributing goods to stores in goods vehicles that are well loaded regardless of the supply chain organisation.

Figure 8: Supplying jeans to a multiple retailer compared with an independent clothes store (using US cotton)



6.5 Energy use in consumer transport

Figure 9 shows the importance of the transport stage carried out by the final consumer in the UK and French supply chains, which is assumed to take place by car. The journey distance is assumed to be a round trip of 11.3 km from the consumer's home to the shop and back again. It is assumed that this trip is for two purposes (i.e. shopping and one other – such as visiting a friend or relative, going to work or collecting a child from school). Therefore only half the total distance travelled is attributed to the shopping trip (i.e. 5.6 km). The consumer is assumed to purchase 5 kg of goods on the shopping trip. This consumer transport stage in the UK uses one third of the energy per kg of jeans transported that is used in the total commercial transport stages. It also uses approximately 50% more energy than that used in transporting the jeans from the UK port to the retail outlet. This is due to the very small quantity of goods carried by car compared with the goods carried by lorry. Increasing the quantity of goods transport during the consumer transport stage results in a significant reduction in the energy consumed per kg of jeans.

Figure 9: Transport energy consumed from cotton field to the consumer's home in the UK

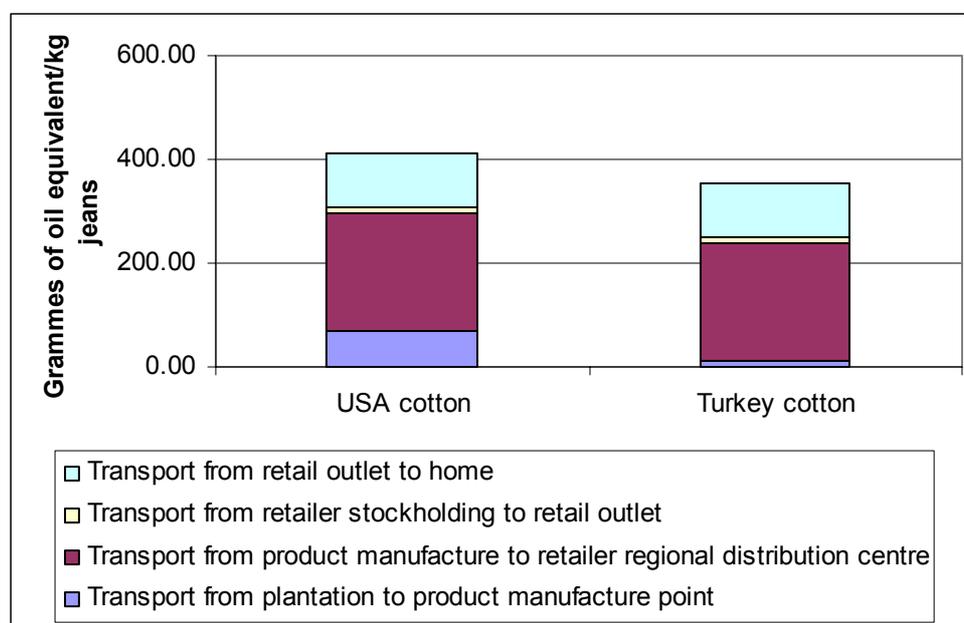


Figure 10 shows the effects on energy consumption per kg of jeans of the consumer purchasing goods with a combined weight of 1.4 kg, 5 kg (the base case), and 18 kg. The loads of 1.4 kg and 5 kg are intended to reflect a consumer purchasing a small and large number of clothing items during their shopping trip. The 18 kg load is intended to reflect a consumer visiting a large supermarket and purchasing both groceries and clothing. When 1.4 kg of goods are purchased, the consumer transport stage in the UK can be seen to consume more energy per kg of jeans transported than even the stages from the point of product manufacture to the UK port, even though the consumer transport distance is only 11 km compared to approximately 3000 km for the product manufacture to retailer RDC stage. This is due to the very small quantity of goods carried by car compared with the goods carried by lorry. Increasing the quantity of goods transport during the consumer transport stage results in a significant reduction in the energy consumed per kg of jeans, this is shown by results of the consumer purchasing 18 kg of goods.

Figure 10: Examining the effect of the quantity of goods are transported to the home by the consumer on transport energy use (using US cotton)

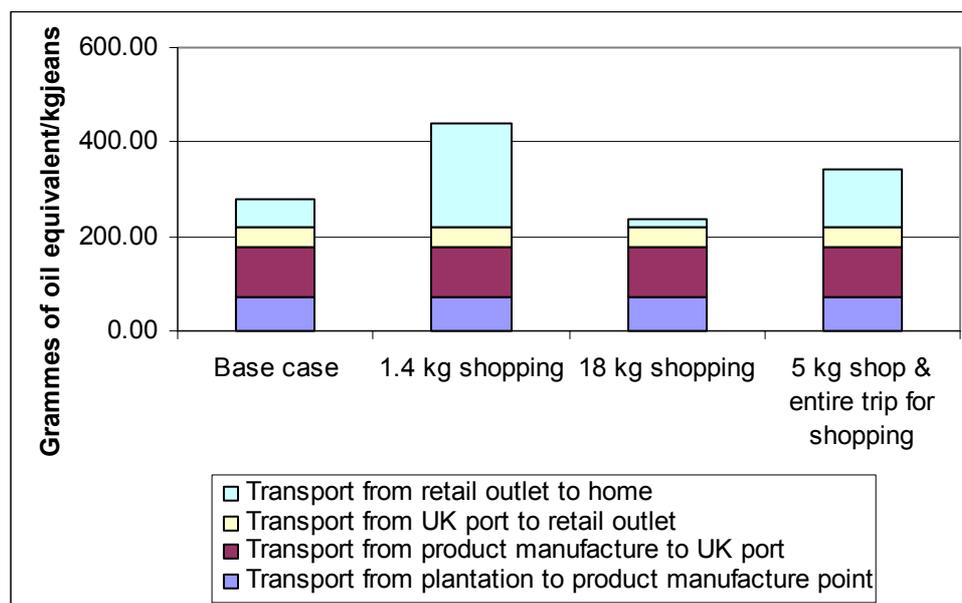
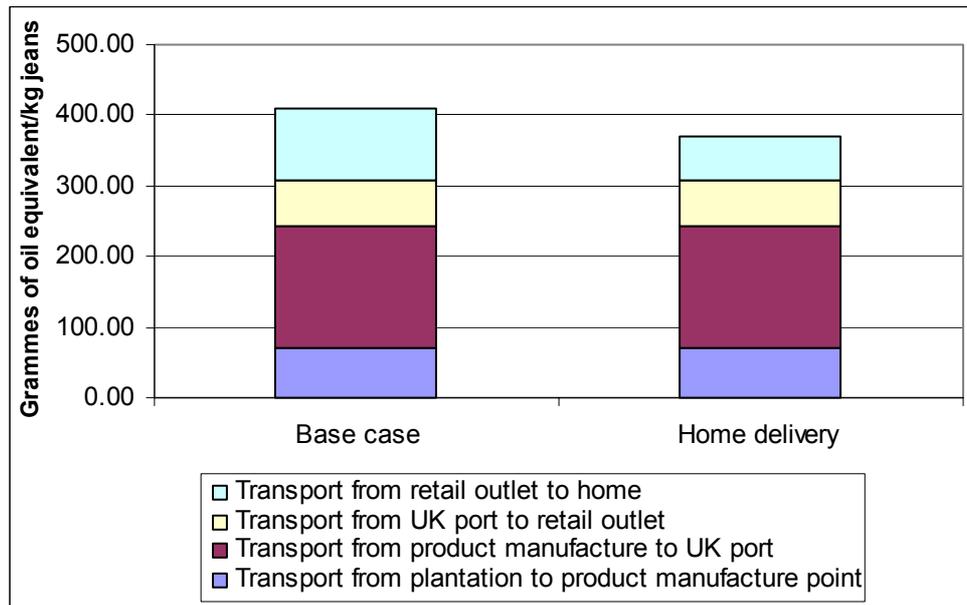


Figure 10 also shows the effects on energy consumption per kg of jeans if the consumer trip involves only one trip purpose (i.e. shopping) rather than two as assumed in the base case. This results in twice as much energy being used per kg of jeans on the trip from shop to home than in the base case. In this scenario, the energy used during the consumer shopping trip is approximately the same as the energy used in transporting the product from the jeans factory to the UK port per kg of jeans, despite the differences in distance involved in these two transport legs.

6.6 Impact on energy use of home delivery

In Section 6.5 it is assumed that the final consumer transports their jeans and other purchases to their home by car. An alternative to this method is for the retailer to arrange a home delivery by van. This possibility has been analysed and the results are shown in Figure 11. Research has suggested a 70-80% reduction in distance travelled if shopping trips by car are replaced with goods vehicles making home deliveries. It has therefore been assumed that the home delivery will result in 75% less distance travelled than if shoppers travel by car (Cairns, 1999).

Figure 11: Comparison of home delivery by company to consumer’s home with consumer car trip (using US cotton)



The results indicate that home delivery would result in approximately a 40% reduction in the energy used in the final transport leg to home compared with car transport by the consumer per kg of jeans. This results in approximately a 20% reduction in the total transport energy used from cotton field to consumer’s home.

As explained in section 6.5, the consumer trip in the base case shown in Figure 11 assumes that the consumer’s trip has two purposes (shopping and one other) and that this halves the transport distance attributed to the shopping. If the consumer trip in the base case was carried out solely for shopping, using home delivery would potentially result in approximately a 50% reduction in the total transport energy used from cotton field to consumer’s home.

7. Conclusions

This report has documented the results of the work carried out in order to study the supply chain structure, transport activities, energy consumption and carbon dioxide emissions in the manufacture and supply of jeans.

The case study carried out in this project with a national multiple retailer in the UK suggests that:

- Most commercial transport energy is used between the point at which the jeans are finished and supply to the UK market;
- The amount of energy used during the consumer transport stage can be greater than the total commercial transport energy used. This is dependent on the mode, distance, trip type and quantity of goods purchased during the shopping trip;
- The location from which cotton is sourced can have a important impact on the total energy used in commercial transport in the jeans supply chain, but this has little impact on the total energy used in producing and supplying jeans;
- This is due to transport activities not being a major contributor to total energy use in the jeans supply chains studied. The vast majority of total energy used in the supply chain is consumed during cotton cultivation, denim production and jeans manufacture.

The case study has illustrated that life cycle analysis (LCA) is useful in comparing the energy use implications of different supply chains and different strategies within any particular chain. It can readily be used to consider options such as sourcing and distribution centre locations, the number of stockholding points in the chain, transport modes, road freight vehicle types and weights, and transport to the consumer's home.

The case study results can be compared with some of the previous studies that have been reviewed. The proportion of energy accounted for by commercial freight transport in the case of jeans manufactured in another country and sold in the UK was found to be approximately 3% of the total energy used to manufacture the product. Previous research calculated that commercial freight transport represented 2% the total energy used in producing a pair of polyester trousers and 6% of the total energy for a pack of cotton briefs (Environmental Resources Management, 2002). Research into producing, supplying and cooking a hamburger in a fast-food restaurant calculated that freight transport accounted for between 5-9% of the total energy used (Carlsson-Kanyama and Faist, 2000). Another study of the transport energy used in the supply and cooking of a selection of foods found that freight transport ranged from approximately 7% of the total energy used in the case of mashed potato, to 32% in the case of rice (Carlsson-Kanyama, and Boström-Carlsson, 2001). These results reflect the energy-intensive manufacturing and processing activities that are required to produce denim and finished jeans compared with some foods.

Obviously, such energy comparisons between different studies need to be treated with caution due to potential differences in systems boundaries, assumptions made in the work and the data sources used. However, the LCA approach enables the calculation and comparison of energy used and environmental impacts for different products across the supply chain. It also provides the opportunity for companies and policy makers to consider the organisation and influences on an entire system rather than a single link within the supply chain. This may result in company decision-making and policy-making about environmental impacts that leads to system-wide benefits.

Previous studies that have used LCA to investigate energy consumption in product supply chains vary in the extent to which they attempt to study the entire chain. Some studies have concentrated only on the transport activities in the supply chain, while other studies have examined both production and transport activities. Studying only part of the supply chain or only specific activities can lead to greater difficulties in terms of the acceptance of the results and their interpretation.

References

- 50meg.com (2004), Jeans, <http://jeans.50megs.com/jeans.html>
- 50meg.com (2004), How jeans are Made, http://jeans.information.in.th/how_they_make_jeans.html
- Allen, J., Tanner, G., Browne, M., Anderson, S., Christodoulou, G. And Jones, P. (2003) Modelling policy measures and company initiatives for sustainable urban distribution – Final Technical Report, project carried out as part of the EPSRC/DfT Future Integrated Transport Programme, University of Westminster.
- Barrett, J., Cherrett, N., Hutchinson, N., Jones, A., Ravetz, J., Vallack, H. and Wiedmann, T. (2004) A Material Flow Analysis and Ecological Footprint of the South East: A Project Report, SEEDA, UK.
- Binkley, J. (not dated) Life cycle analysis - a Finland United Kingdom comparison, Published as part of COST 628, <http://www.tut.fi/units/ms/teva/projects/cost628wg1.html>
- Böge, S. (1995) The well-travelled yoghurt pot: lessons for new freight transport policies and regional production, *World Transport Policy & Practice*, Vol. 1 No. 1, pp. 7-11.
- Bradmill PTY Ltd, (2004), <http://www.bradmill.com.au/main.htm>
- BTTG (British Textile Technology Group) (1999a) Report 3: Textile Processing Techniques, Ref: S5471, British Textile Technology Group, September 1999.
- BTTG (British Textile Technology Group) (1999b) Report 4: Textile Mass Balance and Product Life Cycle, Ref: S5471, British Textile Technology Group, October 1999.
- BTTG (British Textile Technology Group) (1999c) Report 5: Waste Minimisation and Best Practice, Ref: S5471, British Textile Technology Group, November 1999.
- Cairns, S. (1999) Home Delivery Of Shopping: The Environmental Consequences. TSU Working Paper 1999/5, University College London.
- Carlsson-Kanyama, A. and Boström-Carlsson, K. (2001) Energy Use for Cooking and Other Stages in the Life Cycle of Food: A study of wheat, spaghetti, pasta, barley, rice, potatoes, couscous and mashed potatoes, FMS report 160, Forskningsgruppen för miljöstrategiska studier (FMS), Stockholm University. <http://www.infra.kth.se/fms/pdf/Report160.pdf>
- Carlsson-Kanyama, A. and Faist, M. (2000) Energy Use in the Food Sector: A data survey, Forskningsgruppen för miljöstrategiska studier (FMS), AFR report 291, Stockholm University. <http://www.infra.kth.se/fms/pdf/energyuse.pdf>
- Cotton Australia (2004) Facts and Figures, www.cottonaustralia.com.au - June 2004
- Cotton Counts (2004) Cotton: From Field to Fabric, <http://www.cotton.org/pubs/cottoncounts/fieldtofabric/index.cfm>
- Department of Agriculture, Fisheries and Forestry (2004), The Cotton Industry, Australian Government, <http://www.affa.gov.au/content/output.cfm?ObjectID=D85091E2-CF38-43B0-B46B2EF27E4C06F3>
- Department for Environment, Food and Rural Affairs (DEFRA) (not dated) Guidelines for Company Reporting on Greenhouse Gas Emissions: Annex 1 - Fuel Conversion Factors, DEFRA, UK. <http://www.defra.gov.uk/environment/envrpg/gas/05.htm>

Department for Transport (2003) Travel to the shops in Great Britain, Personal Travel Factsheet 6, Department for Transport, UK.

Eco-Logica Ltd (2003) WISEMOVES: The potential to reduce greenhouse gas emissions through localisation and co-operation, Final Report to Transport 2000.

Environmental Resources Management (2002) Streamlined Life Cycle Assessment of Two Apparel Products, Marks & Spencer plc, UK.

Garnett, T. (2003) Wise Moves: Exploring the Relationship Between Food, Transport and CO₂, Transport 2000 Trust, London.

Gillson, I., Poulton, C., Balcombe, K. and Page, S. (2004) Understanding the impact of Cotton Subsidies on developing countries, Working Paper, Overseas Development Institute.

Hodges, P. (2001) Just-In-Time Cotton Shipments Using the EFS System, 14th Annual EFS System Conference, 11-13 June 2001, Greenville, S.C.

Jones, A. (2001) Eating Oil – Food in a Changing Climate, A Sustain/Elm Farm Research Centre Report.

Laursen, S., Hansen, J., Bagh J., Jensen, O. and Werther, I. (1997) Environmental Assessment of Textiles: Life Cycle Screen of Textiles Containing Cotton, Wool, Viscose, Polyester or Acrylic Fibres, Danish Environmental Protection Agency, Project 369.

Levi Strauss (2004) About LS&Co. / Levi's® 501® Jeans Facts, <http://www.levistrauss.com/about/history/501s.htm>, June 2004

McKinnon, A. and Woodburn, A. (1993) The Consolidation of Retail Deliveries: Its Effect on CO₂ emissions, Transport Policy, 1994, Vol.1 No.2, pp.125-136.

Mason, R. and Simons, D. (FSP) with Peckham, C. and Wakeman, T. (EAFL) (2002) Wise Moves Modelling Report, Final Report to Transport 2000.

Mintel (2003a) Jeans – UK, Mintel, April 2003.

Mintel (2003b) Clothing Retail – UK, Mintel, August 2003.

Mutiga, A. (n.d.) Energy Data Conversions, available at: <http://www.afrepren.org/datahandbook/conver2.htm#powtab>

National Cotton Council of America (2004) U.S. Cotton Bale Dimensions, <http://www.cotton.org/tech/bale/bale-description.cfn>

National Imagery and Mapping Agency (2001) Distances between ports, 11th edition, Maryland, USA, <http://pollux.nss.nima.mil/pubs/>

National Renewable Energy Laboratory (NREL) (1998) Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus: Final Report, NREL/SR-580-24089 UC Category 1503, Joint Study Sponsored by U.S. Department of Agriculture and U.S. Department of Energy.

Nationmaster.com (2004) Map & Graph: Top 100 Agriculture: Cotton Production, http://www.nationmaster.com/graph-T/agr_cot_pro

Paxton, A. (1994) *The Food Miles Report: The Dangers of Long Distance Food Transport*, SAFE Alliance, London.

Ravula, P; Cundiff, J. and Grisso, R. (2003) *Cotton Logistics as a Model for Analysis of Biomass Transportation Issues*, paper presented at 2003 ASAE Annual International Meeting, 27- 30 July 2003, Las Vegas, Nevada, USA.

Sundin, M. (2002) *From the Cradle to the Gate: a life cycle inventory on cotton trousers - A minor field study in Southern India*, Linköping University, Sweden

Thomas, C., Tennant, T. and Rolls, J. (2000) *The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses and Non-Commercial Organisations*, UNEP Economics and Trade Unit, http://www.uneptie.org/energy/tools/ghgin/docs/GHG_Indicator.pdf

VTT (Technical Research Centre of Finland) (2001) *Unit Emission Project*, VTT Building and Transport, part of the MOBILE research program (M2T9903) funded by the Finnish Ministry of Transport and Communication, <http://www.lipasto.vtt.fi/yksikkopaastot/unitemissionproject.htm>

Whitelegg, J. (1994) *Driven to Destruction: Absurd Freight Movement and European Road Building*, Greenpeace, London.

van Winkle, T., Edeleanu, J., Prosser, E. and Walker, C. (1978) *Cotton versus Polyester*, in *American Scientist*, Vol.66, May-June, pp.280-290.

Zeander, J. (2002) *From Cotton to Clothes: life cycle inventory and corporate responsibility - A minor field study in Southern India*, Linköping University, Sweden

Appendix 1: Data sources and assumptions used in the calculations

Cotton and denim losses

Loss in turning cotton into denim = 15%

Loss in make up (i.e. cutting denim into jeans) = 10%

Based on information provided by retailer and information in Environmental Resources Management (2002).

Baled cotton

Bale weight = 227kg

No of bales in 40 foot container = 90

Source: Department of Agriculture, Fisheries and Forestry (2004)

Rolls of denim

Roll weight=100kg

Rolls in 40 foot container (65m³)=290

Rolls in 20 foot container (33m³)=150

Source: retailer

Manufactured jeans

Finished pair of 5 pocket Western jeans weight 600 grammes.

Distances between ports

Charleston (USA) to Iskenderun (Turkey) = 5667 nautical miles

Iskenderun (Turkey) to Tangiers (Morocco) = 2054 nautical miles

Tangiers (Morocco) to Algeciras = 12 nautical miles (22 km)

France to UK crossing is Cherbourg to Portsmouth or Poole

Cherbourg to Poole is 137 km

Cherbourg to Portsmouth is 120 km

Therefore average distance Cherbourg to UK port is 130 km

1 Nautical mile = 1.852 km

Source: National Imagery and Mapping Agency (2001)

Road transport from Morocco factory to manufacturer DC in south Wales

Drawbar vehicles of 40 tonnes gvw and articulated vehicles of 44 tonnes gvw

10-12,000 garments in vehicle

French port used in Cherbourg

UK port is Poole or Portsmouth (average distance on road from UK port to south Wales is 290 km)

Source for above information was the manufacturer

Manufacturer Distribution Centre to National Distribution Centre

Articulated vehicle plated at 28 tonnes gvw (vehicle alone weights 12 tonnes)

Full load = 9600 pairs of jeans

Average load factor is 70% of 9600

Distance from supplier DC to retailer NDC = 320 km one way

Source for above information was the retailer

Retailer National Distribution Centre to Regional Distribution Centre

Articulated vehicle plated at 28 tonnes gvw (vehicle alone weights 12 tonnes)

Full load = 9600 pairs of jeans (in reality vehicles carry mixed loads)

Jeans transported as hanging garments and boxed

Average load factor is 100% of 9600

Vehicle goes on to other work after making delivery (does not return empty)

Maximum distance NDC to RDC = 507 km one way

Minimum distance NDC to RDC = 95 km one way
Average distance NDC to RDC = 221 km one way
Source for above information was the retailer

Regional Distribution Centre to shop

Articulated vehicle plated at 23 tonnes gvw (vehicle alone weights 10 tonnes)
Full load = 7100 pairs of jeans (in reality vehicles carry mixed loads)
Jeans transported as hanging garments
Average load factor is 71% of 7100
Vehicle returns to RDC with empty equipment and packaging waste
Average distance RDC to shop = 101 km one way
Maximum distance RDC to shop = 263 km one way
Minimum distance RDC to shop = 2 km one way
Source for above information was the retailer

Jeans distributed to independent retailer via wholesaler and parcels carrier

Transport legs from supplier's DC to wholesaler's DC and onto parcel carrier's urban DC assumed to take place using articulated vehicle plated at 28 tonnes gvw (vehicle alone weights 12 tonnes).
Transport leg from parcel carrier's urban DC to shop assumed to take place using 3.5 t gvw van, which is carrying goods with a total weight of 200 kg destined for 40 delivery addresses, with a total round trip distance of 20 km (source: based on previous research on parcels operations in Allen et al, 2003).

Consumer transport from shop to home (base case assumptions)

Assumed to take place by car
Weight of goods purchased assumed to be 5 kg for a typical shopping trip on which several items are purchased.
Round trip distance assumed to be 11.3 km (source: Marks and Spencer estimate in Environmental Resources Management (2002)).
50% of total round trip distance assumed to be attributable to shopping.

Consumer transport from shop to home (other assumptions)

Other weights of consumer shopping modelled are 1.4 kg for a couple of clothes items (based on Marks and Spencer estimate in Environmental Resources Management (2002), and 18 kg for combined grocery and non-food shopping (McKinnon and Woodburn, 1994).

Company delivery to final customer's home (Home delivery)

Assume we can save 75% of the distance by home delivery = 1.7 km per trip rather than 5.6 km (Cairns, 1999).
Assume each trip and delivery takes 10 minutes, it would be possible to do approximately 50 deliveries per vehicle round in an eight hour working day. Assume average parcel weight is the same as for consumer car trip (i.e. 1.4 kg).

Transport vehicle energy data

Goods vehicle on motorway = $0.674 * (\text{Unladen weight of vehicle in tonnes} + \text{weight of load in tonnes}) + 16.196$
Goods vehicle on other road = $0.8921 * (\text{Unladen weight of vehicle in tonnes} + \text{weight of load in tonnes}) + 10.015$
All road goods vehicles assumed to be running empty for 15% of their return journey
Car = 10 litres/100km
Ship fuel consumption (kg marine diesel oil/day) = $81.585 * \text{POWER}(\text{Capacity in TEU}, -0.1258)$
Ship speed in knots = $4.1115 * \text{POWER}(\text{Capacity in TEU}, 0.2105)$
All ships assumed to be 75% loaded
Source: above formulae and data for calculating vehicle energy use provided by INRETS.

Manufacturer Distribution Centre energy use

Electricity = 1.68 million KWh per year (actual)

Assuming electricity actual to extracted = 4.28 (Source: Environmental Resources Management (2002))

Electricity (extracted)=7.2 million KWh per year

Total clothing production=6000 tonnes per year

Therefore 1.2 kWh electricity (extracted) per kg clothing

Gas (actual) =352,000 kWh per year

Assuming gas actual to extracted =1.11 (Source: Environmental Resources Management (2002))

Gas (extracted) =390,000 kWh per year

Total clothing production=6000 tonnes per year

Therefore 0.06 kWh gas (extracted) per kg clothing

Source for above information was the manufacturer

Retailer distribution centre energy use

Assumed 2.75 kWh (extracted) energy per kg clothing

Type and proportion of fuel used: 80% electricity and 20% gas

Source: based on data in Environmental Resources Management (2002).

Shop energy use

Assumed 14.29 kWh (extracted) energy per kg clothing

Type and proportion of fuel used: 87% electricity and 13% gas

Source: based on data in Environmental Resources Management (2002).

Non-transport activities

Assumptions used:

Cotton fibre production – 21.7 kWh/kg jeans

Fibre preparation – 7.6 kWh/kg jeans

Yarn – 23.5 kWh/kg jeans

Knitting/weaving fabric – 12.9 kWh/kg jeans

Dyeing and finishing – 7.0 kWh/kg jeans

Zip (polyester) – 0.4 kWh/kg jeans

Button (polyester) – 0.02 kWh/kg jeans

Thread (polyester) – 2.2 kWh/kg jeans

Fastner (brass) – 0.2 kWh/kg jeans

Garment makeup – 2.2 kWh/kg jeans

Swing ticket (card/polyester) – 0.27 kWh/kg jeans

Hanger (metal/plastic) – 5.0 kWh/kg jeans

Plastic cover (polyethylene) – 1.2 kWh/kg jeans

Carrier bag – 0.56 kWh/kg jeans – 0.56 kWh/kg jeans

Source: cotton fibre production data from van Winkle et al. (1978), all other information from retailer and adapted from data in Environmental Resources Management (2002).

CO₂ emissions for different fuels

UK Grid electricity = 0.43 kg CO₂/kWh

Natural gas = 0.19 kg CO₂/kWh

Gas/diesel oil = 0.25 kg CO₂/kWh

Gas/diesel oil = 2.68 kg CO₂/litre

Petrol = 3135 kg CO₂/tonne

Petrol = 0.24 kg CO₂/kWh

Petrol = 2.31 kg CO₂/litre

Heavy fuel oil = 3117 kg CO₂/tonne

Heavy fuel oil = 0.26 kg CO₂/kWh

Coal = 2419 kg CO₂/tonne

Coal = 0.3 kg CO₂/kWh

Source: DEFRA, not dated. (Sources used by DEFRA include: National Air Emissions Inventory, UK Greenhouse Gas Inventory, Digest of UK Energy Statistics DTI 1998, Greenhouse Gas Inventory Reference Manual IPCC 1996).

CO₂ emissions for electricity generation outside UK

Turkey = 0.42 kg CO₂/kWh

USA = 0.54 kg CO₂/kWh

Morocco = 0.57 kg CO₂/kWh

Source: Thomas, C., Tennant, T. and Rolls, J., 2000.

Note: 1996 data has been multiplied by 0.9 to convert to current year (based on improvement in UK between 1996 and 2003)

Electricity

Extracted energy - UK medium voltage electricity:

4.28 kWh_{ex}/Kwh delivered

(Source: Nichols and Sturges, ETSU/DTI, 1996 quoted in Environmental Resources Management (2002)

Transport fuel oil

Energy efficiency coefficient for diesel fuel = 0.8328.

Source: National Renewable Energy Laboratory, 1998.

Litres of oil to grammes of oil equivalent

1 litre of diesel = 880.50 goe

1 litre of petrol = 754.72 goe

Source: Mutiga (n.d.)