FINAL REPORT

Marks & Spencer plc

Streamlined Life Cycle Assessment of Two Marks & Spencer plc Apparel Products

February 2002

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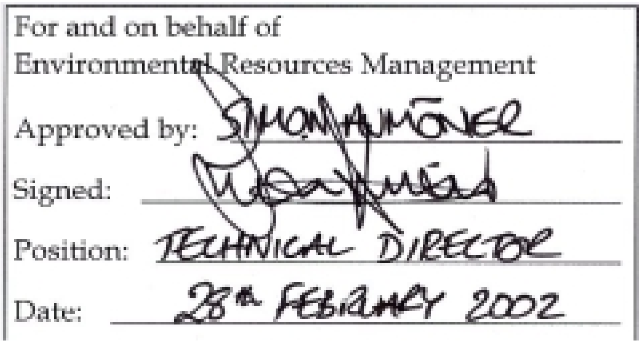


For and on behalf of
Environmental Resources Management
Approved by: SIMON AUMÔNIER
Signed:
Position: TECHNICAL DIRECTOR
Date: 28th FEBRUARY 2002

EXECUTIVE SUMMARY

Introduction

There is increasing pressure to encourage business to minimise the impacts their activities have on the environment. Reduction in the consumption of raw materials and energy and in the production of pollutants and wastes is high on the agenda of governments and the public.

The purpose of the Streamlined LCA study, conducted by Environmental Resources Management (ERM) for Marks and Spencer plc (M&S, was to determine the energy footprints for two M&S garments. This was achieved by identifying and quantifying the 'cradle-to-grave' energy consumption associated with the two products.

The two products assessed were a pair of pleated polyester trousers (34" waist, 31" leg) and a three pack of men's cotton briefs (medium).

Energy consumption has been traced back to resources extracted from the environment. It is reported as extracted energy (which relates to the calorific value of the resources extracted).

A software tool has been developed, from the energy footprints, which allows M&S personnel to assess the life cycle energy consumption of polyester and cotton garments.

An assessment of the benefits of clothes recycling and a comparison of e-commerce and high street retail were also undertaken as part of this study.

Men's cotton briefs

The briefs that have been assessed are M&S 100% cotton men's briefs (stroke number 6653), size medium, which are manufactured and packaged in Egypt from Indian cotton yarn.

The total extracted energy consumption associated with the lifetime of a three pack of men's briefs has been calculated to be 105 kWh. *Figure 1* presents a percentage breakdown by life cycle stage. Consumer use is identified as the most significant life cycle stage, transport and packaging are notably insignificant contributors to the total burden.

Polyester trousers

The polyester trousers studied are M&S pleated navy blue 100% polyester trousers (Stroke number 3226), size 34" (waist), 31" (leg).

The total extracted energy consumption associated with the lifetime of a pair of trousers has been calculated to be 200 kWh. *Figure 2* presents a percentage breakdown by life cycle stage. Consumer use is identified as the most significant life cycle stage, transport and packaging are notably insignificant contributors to the total burden.

Figure 1 Analysis of life cycle energy consumption for a pack of men's cotton briefs (104.9 kWh)

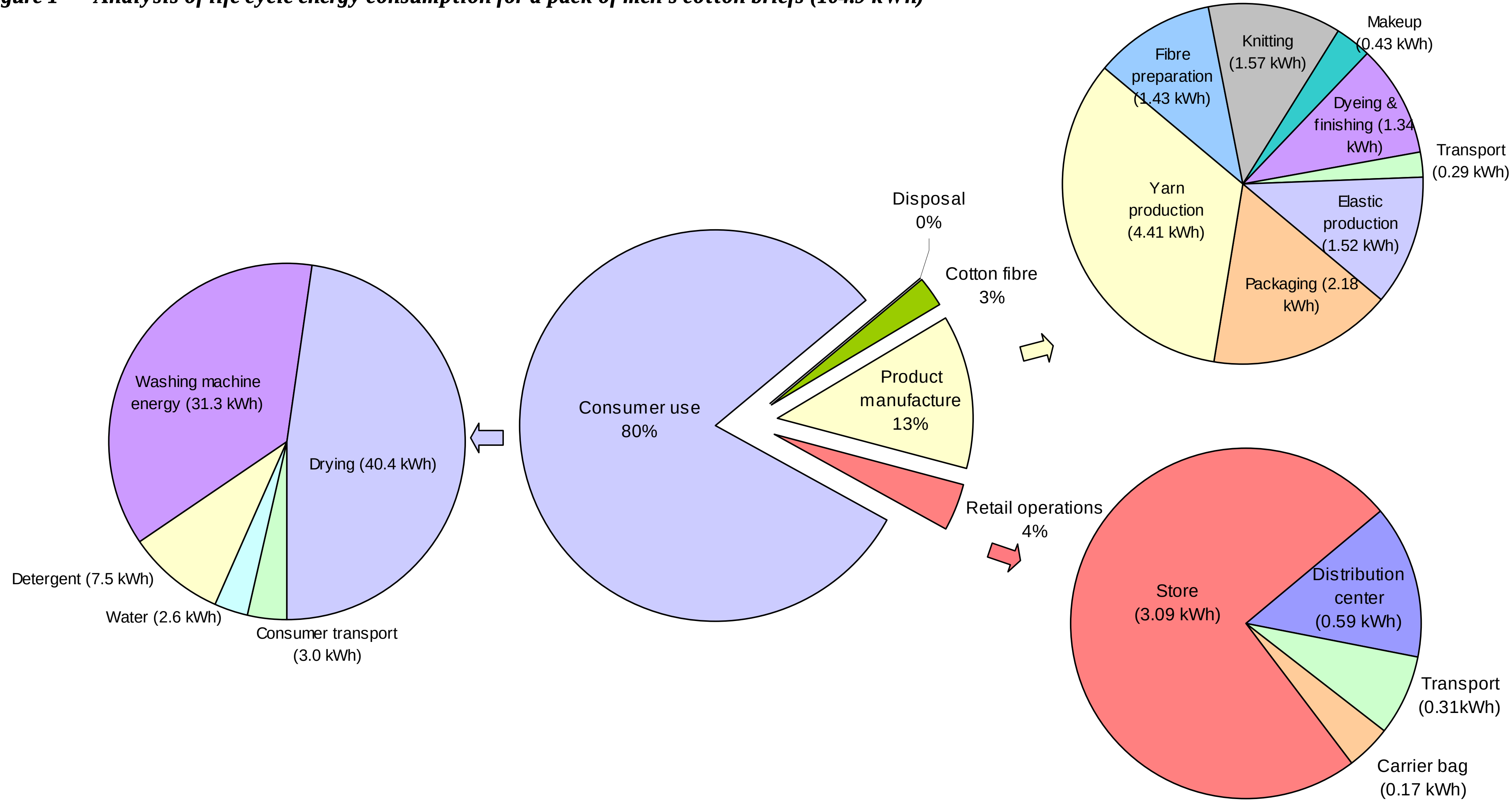
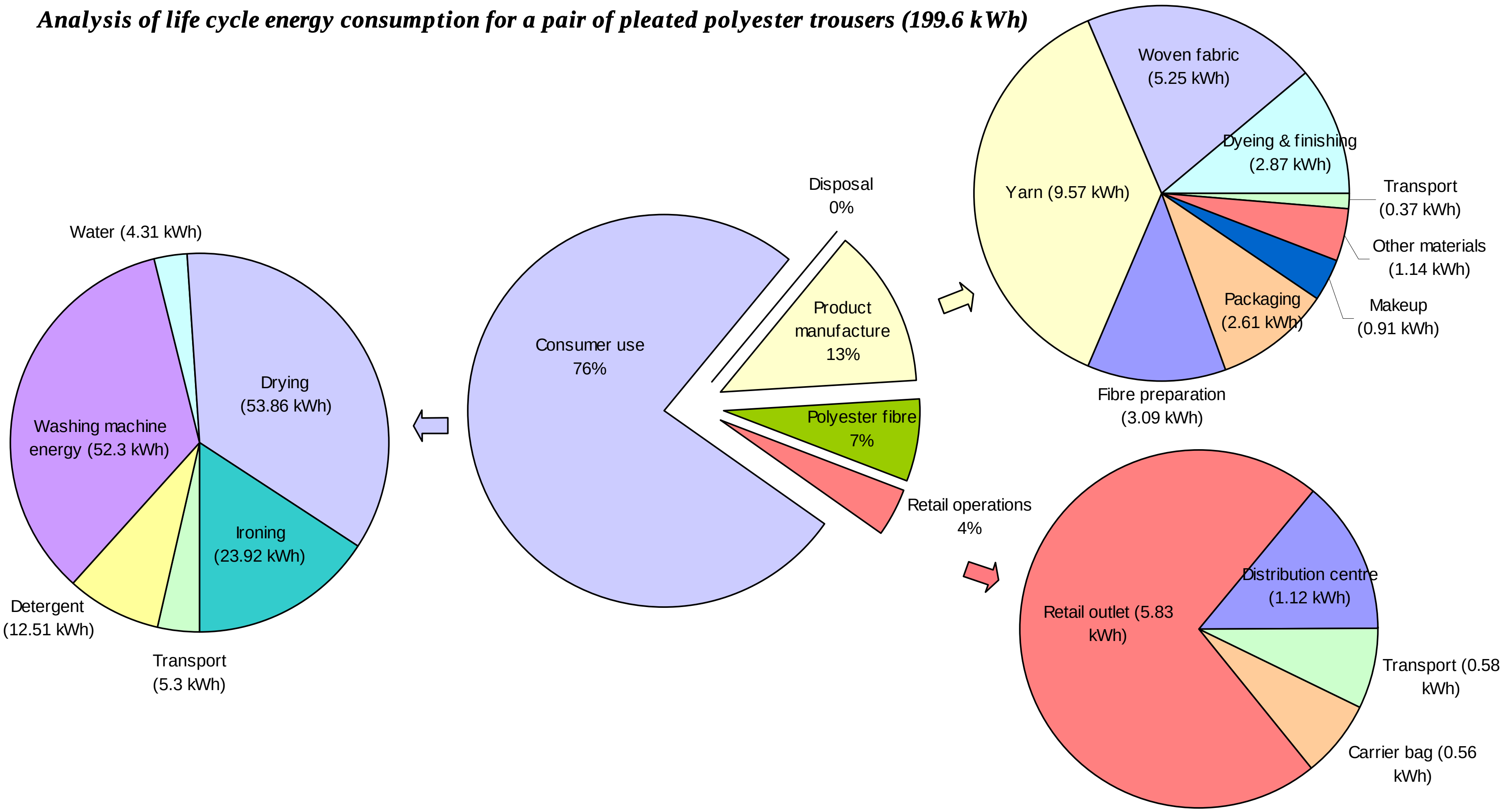


Figure 2 Analysis of life cycle energy consumption for a pair of pleated polyester trousers (199.6 kWh)



Clothes recycling

A complementary M&S sponsored study of Salvation Army textile recycling operations found that processing and distribution of post consumer clothing consumes 1.7 kWh of extracted energy per kg of second hand clothing recycled. The manufacture of a pair of polyester trousers (0.4 kg) consumed 39.26 kWh of extracted energy. There is, therefore, significant benefit to be achieved through recycling as the energy burden of recycling is insignificant in comparison with the savings made through off-setting new production.

The clothes recycling study concluded:

- for every kg of new cotton clothing displaced by second hand clothing approximately 65 kWh is saved; and
- for every kg of new polyester clothing displaced by second hand clothing approximately 90 kWh is saved.

E-commerce versus high street shop

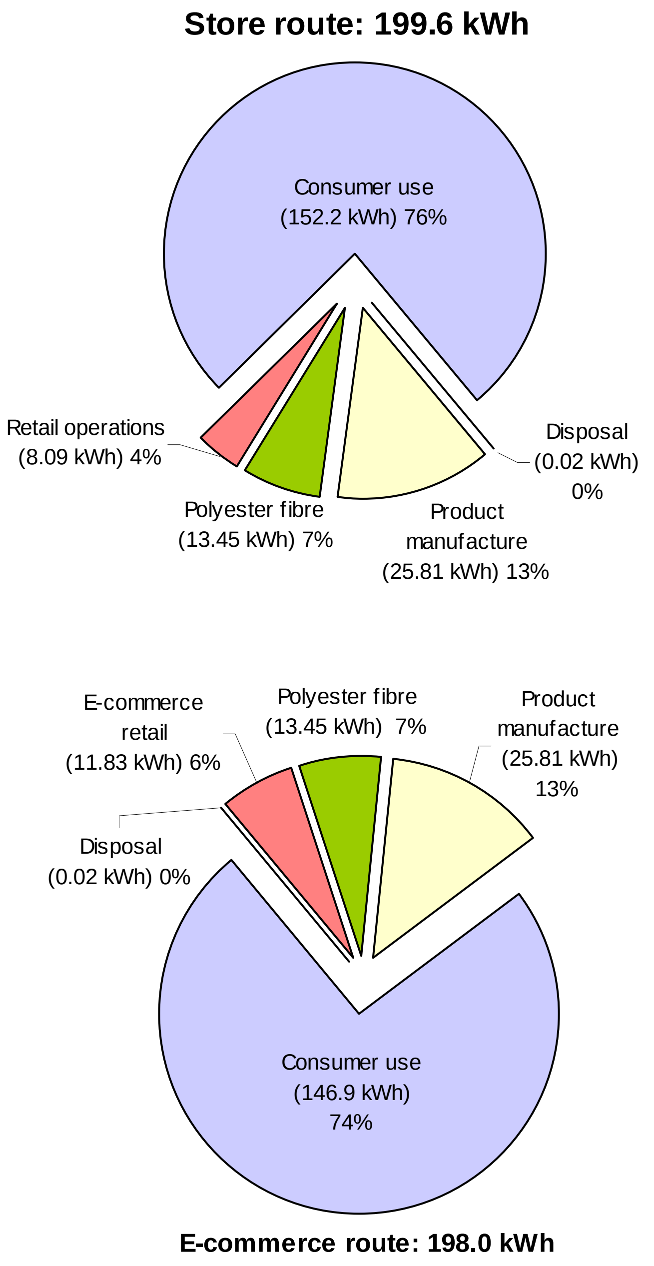
An assessment of the energy consumption associated with the sale of a pair of trousers was undertaken for the two sales routes.

E-commerce provides an energy saving of 1.56 kWh per pair of trousers. This is mainly due to the savings in energy associated with high street stores and consumer transport. This is off-set to a certain degree by the increased transport and packaging associated with home deliveries from a centralised depot. The effect of moving towards more e-commerce and home deliveries would be an increased energy burden associated with retail activities, but a lower life cycle burden for clothing products.

In terms of the life cycle of a pair of trousers, a move to e-commerce would result in a reduction of less than a 1% in the energy burden for a pair of trousers.

Figure 3 shows how the energy profile for a pair of polyester trousers would change if the trousers were sold over the internet.

Figure 3 ***Store versus e-commerce***



Conclusions

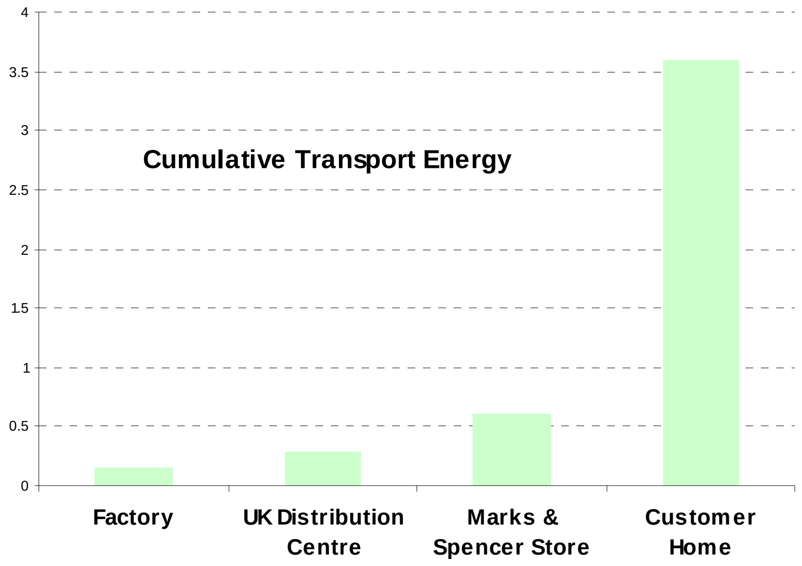
The life cycle extracted energy consumption for a three pack of men's briefs is approximately 105 kWh, 81 % of which is associated with consumer care.

The life cycle extracted energy consumption for a pair of trousers is approximately 200 kWh, 76% of which is associated with consumer care.

E-commerce has been shown to provide a marginal energy benefit with regards to the life cycle burden of clothing.

Transport of clothing by suppliers and manufacturers is an insignificant part of the clothing life cycle with regards to energy consumption. Though bulk transport is insignificant, it is interesting to note that transport by the customer is more energy intensive than all the other transport steps combined. *Figure 4* illustrates how transport becomes less efficient as material moves through the life cycle.

Figure 4 ***Transport: cumulative energy consumption kWh (pack of briefs)***



In environmental terms, most benefit can be gained from addressing energy consumption associated with consumer care. A move from washing at 50°C to 40°C, recommending measured dosing of detergents and promoting energy efficient washing machines and tumble driers have the potential to reduce significantly the life cycle energy consumption of clothing and UK domestic electricity consumption. The study suggests that a move from washing at 50°C to 40°C will reduce the life cycle energy burden of clothing by 10%.

From the assessment of clothes recycling, there is significant benefit to be achieved, although the benefit is dependent on determining the quantity of products made from virgin material that are avoided.

The study suggests that efforts to improve the environmental profile of clothing, with regards to energy, should be directed at consumer use. In environmental terms, achieving a 10% decrease in the use stage burden is as effective as achieving a 30% reduction in the manufacturing and retail burden.

It is our recommendation that, when assessing energy efficiency expenditure, a life cycle approach to cost benefit analysis should be used to ensure maximum benefit is achieved.

This streamlined LCA has demonstrated the benefit of taking a life cycle approach to environmental management.

CONTENTS

1 INTRODUCTION

This report summarises the results of the Streamlined Life Cycle Assessment (LCA) study conducted by ERM for Marks & Spencer plc (M&S).

There is increasing pressure to encourage business to minimise the impacts their activities have on the environment. Reduction in the consumption of raw materials and energy and in the production of pollutants and wastes is high on the agenda of governments and the public.

The purpose of the study was to determine the energy footprints for two M&S garments. This was achieved by identifying and quantifying the 'cradle-to-grave' energy consumption associated with the two products.

The two products assessed were a pair of pleated polyester trousers (34”waist, 31”leg) and a 3 pack of men’s cotton briefs (medium).

Energy consumption has been traced back to resources extracted from the environment. Energy consumption has therefore been reported as extracted energy and relates to the calorific value of the resources extracted.

A software tool has been developed, from the energy footprints, which allows users to assess the life cycle energy consumption of polyester and cotton garments. The software program can be installed from the CD provided with this report.

An assessment of the benefits of clothes recycling and a comparison of e-commerce and high street retail were also undertaken as part of this study.

1.1 INTRODUCING LIFE CYCLE ASSESSMENT

Business interacts with the environment through a number of routes: the production and supply of materials and energies they use; their business operations; the disposal of wastes and the use and disposal of their products. At each of these stages in the life cycle, natural resources are consumed and emissions (to air, water and land) released to the environment. This view of a business is referred to as the environmental footprint.

Life Cycle Assessment is a standardised methodology, ISO14040 [1], allowing practitioners to trace back to the environment all of the resources consumed and all of the emissions to air, water and land at each stage in the manufacture, use and disposal of products. These exchanges with the environment are then related to potential environmental impacts such as global warming, resource depletion and ozone depletion.

1.1.1 Streamlined LCAs

In general, most life cycle studies fall somewhere between a full LCA on one side and the application of life cycle concepts on the other. An assessment that includes all the aspects detailed in ISO14040: goal and scope; an inventory of all inputs and outputs; all life-cycle stages; an impact assessment; interpretation analysis; detailed sensitivity analysis; and peer review is called a full Life Cycle Assessment (LCA). The complexity of a full LCA, requires that it is extremely resource intensive. At the opposite extreme is the application of Life Cycle Concepts such as the qualitative assessment of environmental issues across the life cycle.

Studies that fall between the two extremes are called streamlined LCAs. In streamlined LCA, the study scope is restricted in order to target specific issues or aspects of a footprint. Restricting the extent of the system studied, the resolution of the data collected or the range of environmental impacts/issues to be addressed facilitates the use of LCA as a management tool.

Streamlined LCAs provide valuable information about key stages of the life cycle or specific issues, such as the energy footprint of a product, without requiring the resources of a full LCA.

1.2 THE JUSTIFICATION FOR ADDRESSING ENERGY AND USING A LIFE CYCLE APPROACH

There were two main reasons for addressing energy consumption. Firstly, it is a significant aspect of the life cycle of clothing. Secondly, energy consumption is a good indicator of other environmental impacts such as global warming and resource depletion.

LCA is a tool for ensuring that resources expended on environmental initiatives result in an overall reduction of the burden on the environment. Clothes recycling is one such initiative.

LCA is the only tool that can be used to establish the net environmental burden of products.

2 GOAL AND SCOPE OF THE LIFE CYCLE ASSESSMENT

The objective of the study was to quantify the lifetime energy consumption for two M&S apparel products. The study determined the significance of each life cycle stage and informs M&S of the implications of customer care choices for the life cycle energy burden of each product.

The two products specified by M&S to be assessed were:

- a pair of pleated polyester trousers (34” 31”);
- a pack of men’s cotton briefs (M).

The study will be used to raise awareness of the energy burden of clothing and the significance of customer care.

The study has been used to develop a software tool that will allow M&S to determine the energy consumption of other polyester and cotton products.

This study has not been subjected to external peer review.

The scope defines the boundaries of the systems to be studied, the data required, the functional unit and any assumptions and limitations.

2.1 THE SYSTEM BOUNDARIES

The systems for the two products are provided graphically in *Figure 2.1* and *Figure 2.2*.

The system boundary separates the system of interest from the technosphere (economic system outside the system of interest) and the natural environment.

Defining the system boundary determines what is included and excluded from the system under study.

For the briefs and trousers, the following life cycle stages have been included:

- extraction of resources and production of materials;
- manufacture of materials and chemicals;
- transport;
- distribution and retail;
- consumer transport;
- use; and
- disposal.

Figure 2.1 *System diagram: cotton briefs*

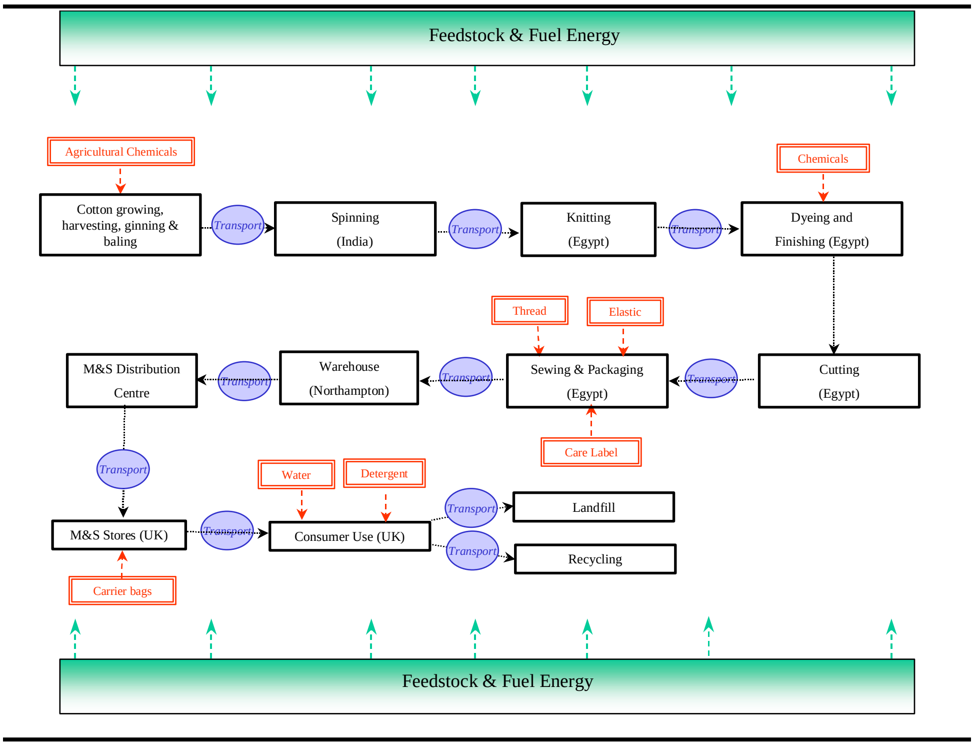
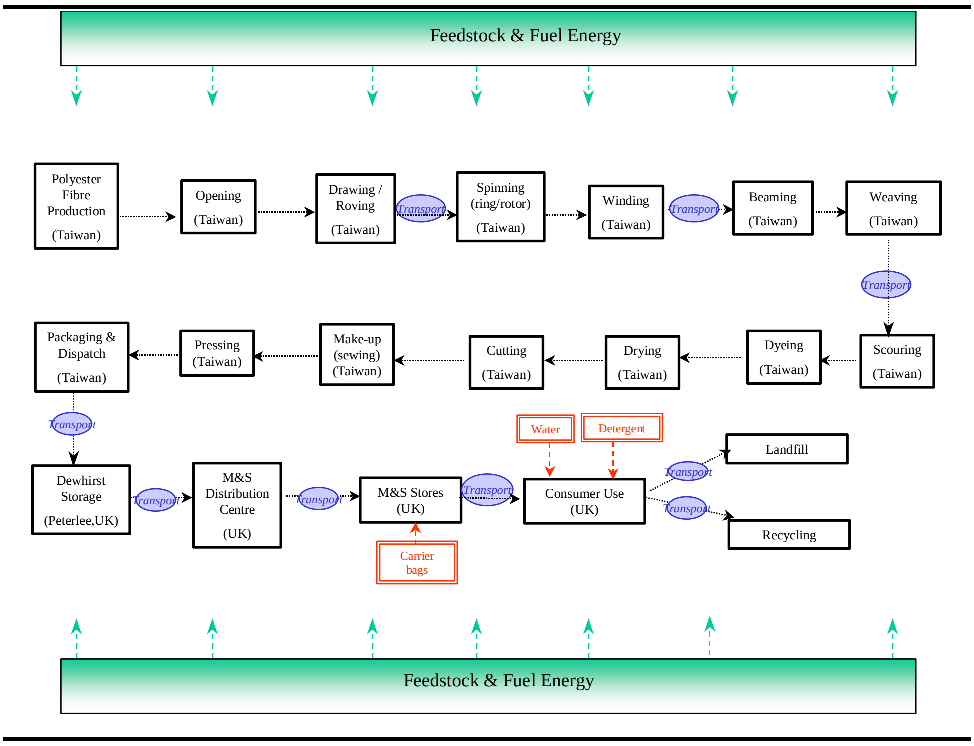


Figure 2.2 *System diagram: polyester trousers*



2.2 FUNCTIONAL UNIT

The functional unit is the reference point for the study, to which environmental burdens are related. The functional units that have been used are as follows:

- 1 pair of polyester trousers;
- 3 pairs of men's briefs.

As the goal of the study was to quantify the energy consumption of each product over its lifetime, the functional unit is defined further by lifetime. M&S advised a useful life of 2 years for the two garments.

2.3 DATA REQUIREMENTS

To produce an extracted energy profile for each garment, electricity, fuel and material use, at each of the life cycle stages, were traced back to resources extracted from the ground and converted to energy resources extracted from the environment.

Numerous sources of data have been used in generating an extracted energy profile for each product system. The sources fall into three main categories:

- published life cycle data for materials, fuels and energy generation;
- published data relating to material and energy consumption of the life cycle stages; and
- data communicated directly to ERM from M&S and third parties.

Regarding data quality, efforts have been made to ensure data provided by contributors is reasonable and accurate and that the life cycle data that is used is representative, up to date and valid.

2.4 ASSUMPTIONS AND LIMITATIONS

The following limitations and assumptions were made:

- use of generic LCA databases for extracted energy of material and energy inputs;
- use of published energy and material use data for textile processing and fibre production;
- 50% of washes are tumble dried;
- the average useful life of the two products is 2 years;
- the trousers are washed 46 times annually;
- the briefs are washed 52 times annually;
- UK Electricity generation is representative of generating efficiencies in foreign countries; and

- the maintenance and manufacture of capital equipment has been omitted from the study.

3 ENERGY CONSUMPTION

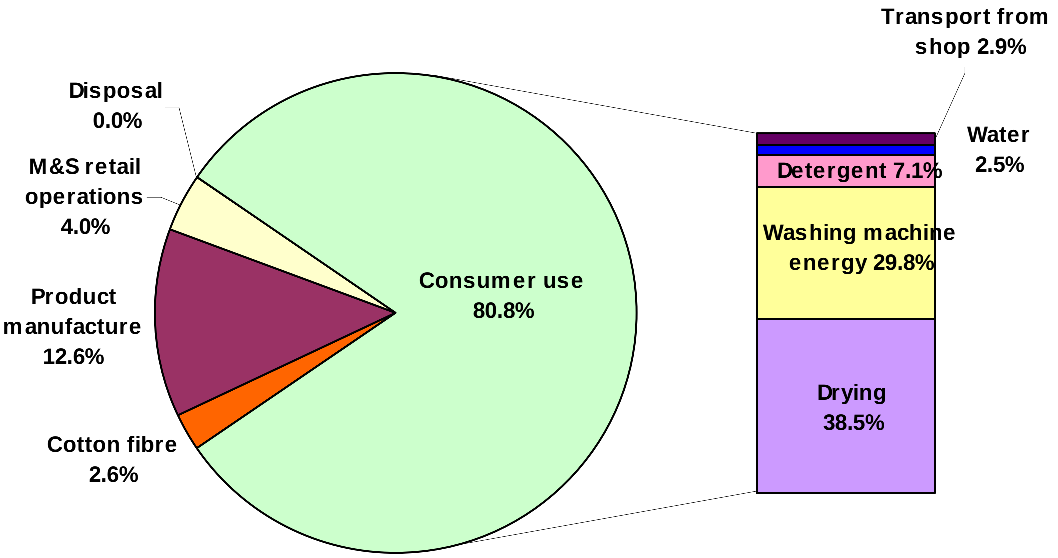
3.1 MEN'S COTTON BRIEFS

The briefs that have been assessed are M&S 100% cotton men's briefs (stroke number 6653), size medium, which are manufactured and packaged in Egypt from Indian cotton yarn. The average weight of a pair of briefs is 72g (measured from sample).

The data used and the models developed to calculate the lifetime energy consumption are presented in Annex A.

The total extracted energy consumption associated with the lifetime of a 3 pack of men's briefs has been calculated to be 105 kWh. *Figure 3.1* presents percentage breakdown detailing the contribution of the life cycle stages. Consumer use accounts for 81%, with 39% associated with washing (at 50°C and an average load of 3kg) and 39% associated with tumble drying (assuming 50% of washes are tumble dried).

Figure 3.1 Percentage break down of extracted energy burden by life cycle stage



3.2 POLYESTER TROUSERS

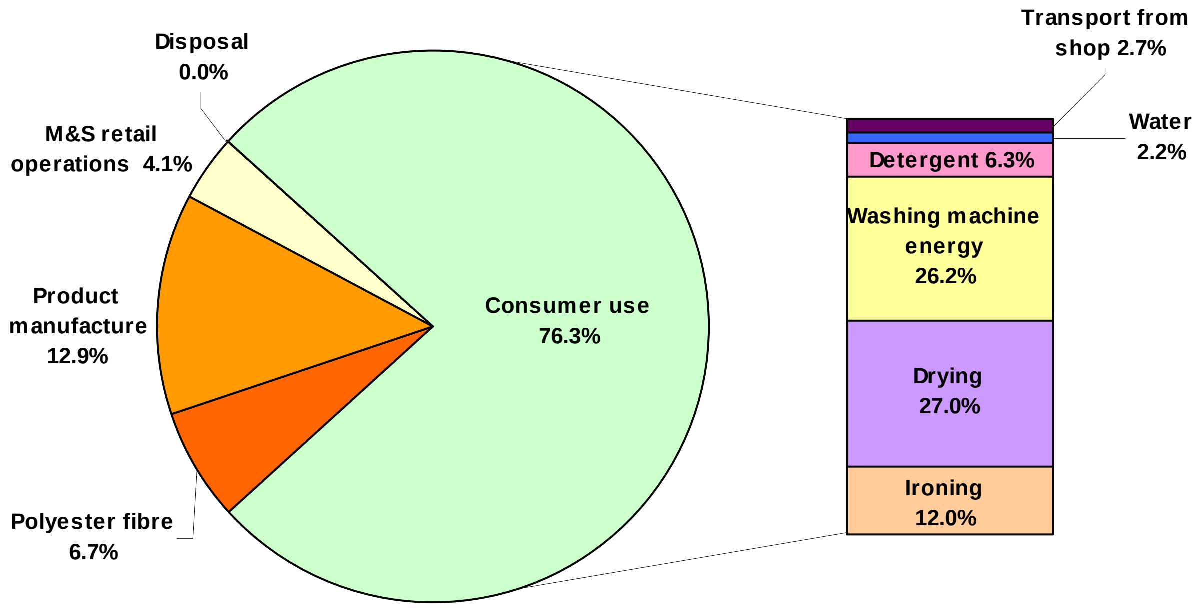
The polyester trousers studied are M&S pleated navy blue 100% polyester trousers (stroke number 3226), size 34" (waist), 31" (leg). The polyester fabric is manufactured in Taiwan and the trousers are made up in Indonesia.

The data used and the models developed to calculate the lifetime energy consumption are presented in *Annex B*.

An average lifetime of a pair of trousers is considered to be in the region of 2 years and 92 washes. The trousers have been assessed on this basis.

The total extracted energy consumption associated with the lifetime of a pair of trousers has been calculated to be 199.57 kWh. *Figure 3.2* presents percentage breakdown detailing the contribution of the life cycle stages. Consumer use accounts for 76%, with 37% associated with washing (at 50°C and an average load of 3kg), 27percent associated with tumble drying (assuming 50% of washes is tumble dried) and 12% associated with ironing (assuming that it takes 2 minutes to iron a pair of trousers).

Figure 3.2 Analysis of life cycle energy consumption for a pair of pleated polyester trousers (lifetime of two years)



3.3 CLOTHES RECYCLING

In the UK, between 135 000 and 225 000 tonnes of post-consumer textiles are reused or recycled per year out of an annual textile waste arising of 650 000 tonnes. This is consistent with the 25% recycling figure reported by the UK Textile Recycling Association [2].

Based on the study of SATC textile recycling operations [3], the collection, processing and distribution of post consumer clothing consumes 1.7 kWh of extracted energy per kg of second hand clothing recycled. The manufacture of a pair of polyester trousers (0.4 kg) consumed 39.26 kWh of extracted energy (see *Annex B*).

It can be concluded that the collection, processing and transport of second hand clothing consumes an insignificant quantity of energy in comparison to the saving in energy that can be achieved by reducing the quantity of virgin clothing that is required. However, an energy credit can only be awarded to recycled clothing if it can be demonstrated that it is off-setting the production of products made from virgin materials.

To illustrate the benefit of recycling:

If we assume that 25% (UK textile recycling figure) of polyester trousers are recycled and reused as trousers, avoiding the need for the manufacture of new trousers, an energy credit of –9.6 kWh could be awarded to the energy profile of a pair of trousers. This credit would reduce the life cycle energy burden for trousers by 5%, a significant saving. For one pair of M&S polyester trousers, the life cycle burden would be reduced from 199.6 to 190 kWh.

However, in reality it is likely that second hand clothing displaces some virgin production, but not on the weight for weight basis as assumed above.

In the context of the life cycle of clothing, clothes recycling offers a significant opportunity to reduce the extracted energy burden associated with clothing, as the manufacture of a garment from virgin materials accounts for between 10% and 20% of the total life cycle burden.

However, most benefit could be achieved by addressing consumer use, as this accounts for more than 70% of the total life cycle burden of day wear clothing.

3.4 E-COMMERCE VERSUS HIGH STREET SHOPS

With the establishment of e-commerce as a retail route for clothing by M&S, the consequences for energy consumption were assessed for the sale of a pair of polyester trousers (this being a representative delivery according to M&S) to determine if e-commerce would result in a reduced energy footprint.

All life cycle stages, pre dispatch from the distribution centres and post delivery have been excluded from the comparison. They have been excluded on the basis that they are common to both the e-commerce route and shop route and that there is little or no difference in energy consumption for these stages.

3.4.1 E-commerce retail

Customers place an order, using the online order form and catalogue, on the M&S website (http://www.marksandspencer.com). Garments are then dispatched from distribution centres direct to customers. Additional packaging is applied for home delivery. For a pair of trousers this equates to 41g of polythene (2 bags).

Based on 'average' delivery distance data (provided by M&S), the number of parcels per delivery and 'returns', fuel (diesel) use per parcel delivered was calculated to be 0.75 litres. This equates to an extracted energy of 9.34 kWh / parcel. A pair of trousers is considered representative of a typical parcel.

We have assumed that the customer spends ten minutes on a PC per product ordered, and we have assumed 1 minute of PC time for M&S processing per garment ordered. A standard PC and monitor uses 250 Watts.

It has been assumed that the packaging is made of HDPE. APME data for HDPE [4] has been used, which results in a total gross energy for the production of the polymer of 22.49 kWh / kg. Together with an allocation of 5.56 kWh / kg for fabrication, this equates to an extracted energy consumption of 1.15 kWh for packaging. The fabrication figure is in line with APME [5] conversion energies for polymer processing.

Table 3.1 Extracted energy consumption associated with the internet sale of a pair of trousers

Step	**Extracted Energy kWh**
Computer use (customer)	0.20
Computer use (M&S)	0.02
Transport from distribution center	9.34
Packaging	1.15
Total	**10.71**

3.4.2 High street shop route

Clothing is dispatched to stores from which customers purchase the garment and then transport it home.

Table 3.2 *Extracted energy consumption associated with the high street sale of a pair of trousers*

Step	Extracted Energy kWh
Transport to retail outlet	0.58
Carrier bag	0.56
Retail outlet	5.83
Consumer transport	5.3
Total	**12.27**

3.4.3 Comparison

On the basis of the assumptions made, e-commerce provides an energy saving of 1.56 kWh per pair of trousers. This is mainly due to the savings in energy associated with high street stores and consumer transport. However, this is off-set by the transport and extra packaging associated with home deliveries from a centralised depot. In terms of M&S retail activities, a move to e-commerce and home deliveries would result in an increased energy burden for the company but a lower life cycle burden for the trousers.

In terms of the life cycle of a pair of trousers, a move to e-commerce would result in less than a 1% reduction in the energy burden for a pair of trousers.

4 SENSITIVITY

The purpose of this section is to determine if the conclusions of the study with regards to goals of the project are sensitive to the assumptions and data used.

It is accepted that the values calculated for extracted energy are subject to error due to inconsistencies in the data used and because the data used may not be an accurate representation of the real situation. However, the scale of any errors are considered insignificant in the face of the conclusions. ERM believe that the study is a reasonable estimate of life cycle extracted energy consumption for the two garments.

Most concerns with regards to accuracy are directed at consumer use and manufacturing. With regards to the conclusions, they are not believed to be sensitive to any reasonable changes that could be made to the assumptions and data used.

4.1 CONSUMER USE

By far the most significant life cycle stage is consumer use.

Assumptions regarding average wash load, garment life, electricity use per wash, detergent dosing, percentage of wash loads tumble dried and the time to iron the trousers will affect the extracted energy consumption associated with this life cycle stage.

Assumptions regarding life time and number of washes play a significant role in determining the split between manufacturing and consumer use. However, no reasonable changes to the extracted energy associated with the life cycle stages would result in consumer use being downgraded to a lower level of significance.

Section 5 shows the effect that assumptions regarding wash load and wash temperature would have.

4.2 EXTRACTED ENERGY CALCULATIONS

The extracted energy values calculated for the life cycle stages are most dependent on the relationship between energy used and energy extracted from the environment, the most significant relationship being that for electricity. In the UK, it has been calculated that for every kWh used in the home, 4.86 kWh is extracted from the environment, giving an overall efficiency of 21%. This inefficiency is a result of thermal inefficiencies of power stations, and energy losses associated with generation and transmission, in addition to the fuels consumed to extract fuels from the ground.

In the UK, power generation and transmission is reported to have an efficiency of 31% (3.2 kWh consumed for every kWh delivered) based on the quantity of fuel consumed by power stations and the amount of electricity supplied. This figure does not include fuel consumption associated with the extraction, production and delivery of fuels. Any inaccuracies in the 4.86 kWh figure will influence the values calculated in the assessment. However, it would not change the conclusion that electricity use associated with consumer care is by far the most significant aspect of the life cycle of clothing.

4.3 MANUFACTURING LIFE CYCLE STAGES

Most uncertainty with regards to extracted energy consumption is associated with fibre production and garment manufacture. Efforts have been made to combine supplier data and performance with typical industry data to ensure that a representative manufacturing model is produced for these life cycle stages. Though the model could be refined it was considered that the effort necessary was not justified by the improved precision gained.

Due to the dated nature of the cotton data used, improvements could be made in this area. However, the benefit would be small as it is unlikely that developments in the industry would result in this stage of the life cycle influencing the conclusions of the study or the significance of cotton production.

5 INTERPRETATION

The significance of consumer use, at over 75% of the life cycle burden, means that this stage offers the greatest opportunity to reduce the energy consumption of clothing and to make a significant contribution to increasing sustainability of these product systems.

The fibre material breakdown for the 70 000 tonnes of clothing sold (supplied by M&S) has been used to assess the significance of consumer use:

- 30% cotton;
- 30% polyester;
- 20% wool; and
- 20% viscose.

On a weight for weight basis, both polyester trousers and cotton briefs, per kg of garment, consume approximately 490 kWh through out their life cycles.

Assuming that trousers and briefs were representative of all clothing made and sold from these materials, the total energy burden would be 20 billion kWh. This is equivalent to the annual electricity consumption of 1.3 million households.

5.1 BENEFIT OF LOWER WASH TEMPERATURES

A move from washing at 50°C to 40°C would result in an 11% reduction in life cycle energy consumption for briefs and a 10% reduction for polyester trousers.

The annual extracted energy consumption associated with washing of 21 000 tonnes of cotton clothing at 50°C is 2 billion kWh. This is equivalent to the annual electricity consumption (extracted energy) of 125 000 households. The saving associated with washing at 40°C would be enough to supply 35 000 households per year.

5.2 THE BENEFIT OF CLOTHES RECYCLING SCHEMES

Clothes recycling consumes 1.7 kWh of extracted energy per kg of clothing recycled. For every kg of cotton clothing sold for re-use as clothing, if briefs are considered representative and assuming a 100% offset for the production of new clothing, the extracted energy saving is 72 kWh.

Using the above assumptions, the saving associated with re-using polyester clothing is 92.6 kWh per kg.

There is therefore a significant benefit to be achieved through recycling, as the energy burden of recycling is insignificant in comparison with the savings through off setting new production.

5.3 INCREASING AVERAGE WASH LOAD

Table 5.1 shows the influence that increasing the average wash load from 3kg to 3.5 kg would have on the extracted energy consumption for washing a pair of trousers. The table demonstrates the importance of ensuring that full loads are washed. A move from an average of 3kg to an average of 3.5 kg would give a 14 % reduction in the energy consumption associated with washing, or a 5% reduction in the total life cycle burden.

Table 5.1 Extracted energy (kWh) for 92 washes

Load Assumption	Water	Electricity	Detergent	Total
3kg average load				
50°C per pair of trousers	4.31	52.30	12.51	69.12
3.5 kg average Load				
50°C per pair of trousers	3.70	44.83	10.72	59.25
Saving	**0.61**	**7.47**	**1.79**	**9.87**

5.4 TUMBLE DRYING SAVINGS

Tumble drying accounted for more than 25% of the total life cycle burden for the two garments, on the basis that 50% of wash loads are tumble dried.

Significant reductions could therefore be achieved through promotion of natural air drying. However, consumer convenience and the UK climate would suggest that improvements in the efficiency of tumble driers is where the greatest opportunity lies.

6 CONCLUSIONS

The life cycle extracted energy consumption for a 3 pack of men's briefs is approximately 105 kWh, 81% of which is associated with consumer care.

The life cycle extracted energy consumption for a pair of trousers is approximately 200 kWh, 76% of which is associated with consumer care.

E-commerce has been shown to provide a marginal energy benefit with regards to the life cycle burden of clothing.

Transport of clothing by suppliers and manufacturers is an insignificant part of the clothing life cycle with regards to energy consumption.

In environmental terms, most benefit can be gained from addressing energy consumption associated with consumer care. A move from washing at 50°C to 40°C, recommending measured dosing of detergents and promoting energy efficient washing machines and tumble driers have the potential to significantly reduce the life cycle energy consumption of clothing and UK domestic electricity consumption. The study suggests that a move from washing at 50°C to 40°C will reduce the life cycle energy burden of clothing by 10%.

From the assessment of clothes recycling, there is significant benefit to be achieved. However, the benefit is dependent on determining the quantity of products made from virgin material that are avoided.

The study suggests that efforts to improve the environmental profile of clothing, with regards to energy, should be directed at consumer use. In environmental terms, achieving a 10% decrease in the use stage burden is as effective as achieving a 30% reduction in the manufacturing and retail burden.

It is our recommendation that when assessing energy efficiency expenditure a life cycle approach to cost benefit analysis should be used to ensure maximum benefit is achieved.

This streamlined LCA has demonstrated the benefit of taking a life cycle approach to environmental management.

7 REFERENCES

1) ISO; 1997. Environmental management – Life cycle assessment – principles and framework. International Organization for Standardization.

2) *Environmental Resources Management; 2001.* Textile Recycling. Department of Trade and Industry.

3) *Environmental Resources Management; 2001.* Clothing Recycling Life Cycle Assessment Study . Salvation Army Trading Company Limited.

4) *I. Boustead, 1993.* Eco-profiles of the European polymer industry. Report 3: Polyethylene and polypropylene. Association of Plastics Manufacturers in Europe.

5) *I. Boustead, 1997.* Eco-profiles of the European plastics industry. Report 10: polymer conversion. Association of Plastics Manufacturers in Europe (APME).

6) *The Office For The Regulation Of Electricity And Gas; December 1999.* Energy Efficiency, Fuel Poverty And The Supply Price Control. A Consultation Paper Issued By The Office For The Regulation Of Electricity And Gas.

Annex A

Streamlined LCA of Men’s Cotton Briefs

1 MEN'S THREE PACK OF COTTON BRIEFS

1.1 PRODUCT DESCRIPTION

The briefs that have been assessed are Marks & Spencer plc (M&S) 100% cotton men's briefs (stroke number 6653), size medium, which are manufactured and packaged in Egypt from Indian cotton yarn. The average weight of a pair of briefs is 72g (measured from sample).

Table 1.1 and *Table 1.2* detail supplier data relating to the components of the finished garment.

Table 1.1 Product information

Component	Weight (g)	Material	Place of manufacture
Knitted fabric	-		Egypt
Elastic	12.30	Synthetic rubber	France
Thread	-	Polyester and Cotton	Israel
Care labels	0.05	Polyester	Egypt
Insert	4.00	Card	

By using the average weight of a pair of briefs and subtracting the weight of elastic and care label, we have assumed the remainder to be cotton fabric, this equates to 59.7g of cotton fabric per pair of briefs.

Table 1.2 Packaging information

Component	Weight (g)	Material
Hook	2.00	Polypropylene
Windowed box	35.00	Cardboard
Size label	0.04	Paper
Bar code label	0.10	Paper

1.2 LIFE CYCLE ENERGY USE

For the purposes of this study, energy consumption will be calculated for each life cycle stage and reported in terms of extracted energy.

Extracted energy requirements refer to the total energy consumption when traced back through all operations to the extraction of raw materials from the earth.

The following sections detail the extracted energy associated with each life cycle stage and the data sources for extracted energy.

1.2.1 *Extracted energy for common inputs and processes*

The tables in *Annex C* detail the extracted energy associated with fuels, materials, fuels and transport modes identified in the product life cycle.

For the fabrication of polymer products such as hooks and buttons, an allocation of 5.56 kWh / kg has been made. This figure is in line with APME [1] conversion energy for injection moulding of PP product (7.9 kWh / kg), HDPE pipe extrusion (1.98 kWh / kg) and blow moulding of HDPE bottles (6.11 kWh / kg).

2 MANUFACTURING: EXTRACTED ENERGY CONSUMPTION

2.1 FIBRE PRODUCTION

We have used a figure of 13.514 kWh per kg of baled cotton fibre (lint) *[2]*. Though dated, pre 1980, the energy figure is considered comprehensive in that it includes electricity and fuel for growing and ginning and the energy required to produce the fertilisers and pesticides. The figure does not include energy of human labour or solar energy consumed by the cotton plants.

Throughout the production processes for textiles, material is lost.
Table 2.1 details fibre losses for each stage of the production process as published by BTTG [3]. Using the minimum loss values, every kilogram of finished product requires 1.14 kg of fibre input.

68.08g of baled cotton lint is required to produce one pair of briefs, assuming the minimum material loss at each stage. This equates to energy consumption of 0.92 kWh for cotton lint per pair of men's briefs or 2.76 kWh for 3 pairs of men's briefs .

Table 2.1 BTTG typical material losses

Production stage	% losses	Cotton Output g
Cotton Lint		68.08
Preparation and blending	2 – 10	66.72
Spinning natural fibres	1 – 20	66.05
Knitting	2 – 6	64.73
Dyeing and finishing	3 –10	62.79
Making up	5 – 20	59.65

2.2 SPINNING, KNITTING, DYEING, FINISHING AND MAKING UP

2.2.1 Fabric and garment production

Energy consumption for the production process defined by the supplier have been calculated, see *Table 2.2*, using the lower range of energy requirements of operations detailed in the BTTG figures [4].

Where energy has been reported as energy used at machine (process energy), electricity and fuel energy has been allocated based on the nature of the operations. From the process energy, extracted energy has been calculated based on a medium voltage electricity supply and the use of oil as a fuel.

Table 2.2 ***BTTG figure for energy demand of textile processing operations per kg of product***

Operation	Process Energy MJ/kg	Extracted Energy kWh/kg	Assumption
Opening and Cleaning	2.1	2.50	100% Electricity
Drawing	3.1	3.69	100% Electricity
Roving	0.8	0.95	100% Electricity
Preparation		***7.13***	
Spinning	18.7	***22.23***	100% Electricity
Winding	5.8	6.90	100% Electricity
Knitting	1.0	1.19	100% Electricity
		8.08	
Scouring	6.2	2.58	90% Fuel, 10% Electricity
Dyeing	3.4	1.42	90% Fuel, 10% Electricity
Dyeing Chemicals (350 kg tonne)		2.36	
Drying	1.8	0.75	90% Fuel, 10% Electricity
Dyeing and Finishing		***7.11***	
Cutting and Makeup	2.0	***2.38***	100% Electricity

For dyeing, the BTTG figure of 350 kg [5] of chemical per tonne of fabric has been used. An average extracted energy of 6.75 kWh per kg has been allocated to chemicals based on an equal split between organic and inorganic chemicals *(see Annex C*). No energy consumption for water use has been allocated.

Table 2.3 shows the extracted energy consumption associated with the production of the briefs using the loss figures detailed in *Table 2.1* and the energy consumption data for the production processes presented in *Table 2.2.*

Table 2.3 ***Cotton flow and extracted energy consumption for each production stage***

Production	Cotton fibre output g	Extracted Energy per pair kWh	Extracted Energy 3 pair kWh
Garment make up	59.65	0.14	0.43
Dyed and finished fabric	62.79	0.45	1.34
Knitted fabric	64.73	0.52	1.57
Yarn	66.05	1.47	4.41
Prepared fibre	66.72	0.48	1.43
Total		**3.06**	**9.17**

2.2.2 *Transport of yarn to Egypt from India*

For the purposes of bulk transport, we have used energy use per tonne-km. *Table 2.4* details the energy consumed in transporting the yarn required for a single pair and for three pairs of briefs. Shipping distances between Egypt and India were calculated and a road haulage distance of 500 km allocated.

Table 2.4 Yarn transport: extracted energy use

Transport	kWh/tonne-km	Distance km	Energy per pair kWh	Energy for 3 pairs kWh
40 te long haul lorry	0.35	500	0.033	0.099
Ship	0.036	8200	0.019	0.058
Total			**0.052**	**0.157**

2.2.3 Elastic production

Life cycle inventory data for synthetic rubber, 41.15 kWh extracted energy per kg of synthetic rubber, has been used to calculate the extracted energy consumption associated with the elastic in the briefs. This equates to energy consumption of 0.506 kWh per pair of briefs for the elastic.

No allocation for fabrication or transport has been made.

2.2.4 Thread production

No specific energy consumption has been allocated to the thread, as no data were supplied regarding the weight of thread. However, the weight of thread is included in the total mass of fabric and the calculations above.

2.2.5 Care label production

Due to the negligible weight of the care labels, it has been excluded from the study.

2.2.6 Packaging production

Polypropylene hook

For the purposes of the study, it has been assumed that the hook is 100% polypropylene. No transport allocation has been made. APME data for polypropylene has been used, the total extracted energy for the production of the polymer is 22.11 kWh/kg. Using a fabrication energy of 5.56 kWh/kg and assuming no losses, this equates to energy consumption of 0.055 kWh for the hook.

Window box

The box is a printed white cardboard box (approx 33g) with a clear plastic window (approx. 2g).

The extracted energy for ‘cartonboard’ (26.24 kWh/kg) has been used to estimate the energy associated with the card. This equates to energy consumption of 0.839 kWh per box.

No transport or fabrication allocation has been made for the box.

The clear plastic is assumed to be polypropylene. APME data for polypropylene has been used, total gross energy for the production of the polymer is 22.11 kWh/kg. Using a fabrication energy of 5.56 kWh/kg, and assuming no losses, this equates to energy consumption of 0.055kWh per window .

Paper labels

No allocation for paper labels have been made as their weight and contribution is considered insignificant.

Card inserts

Each pair of briefs includes a 4g card insert.

The extracted energy for 'paper- coated bleached' (25.42 kWh/kg) has been used to estimate the energy associated with the card. This equates to 0.102 kWh per insert and 0.305 for the 3 pairs of men's briefs.

2.2.7 Transport packaging

The supplier of the briefs to M&S specified 500g of LDPE packaging for 16 packs of briefs. This equates to 31g of packaging per pack.

APME data for polypropylene has been used, total gross energy for the production of the polymer is 24.60 kWh/kg. Using a fabrication energy of 5.56 kWh/kg, and assuming no losses, this equates to an extracted energy consumption of 0.93 kWh per pack.

2.2.8 Transport to the UK from Egypt

For the purposes of bulk transport, we have used energy use per tonne-km. The energy consumed transporting a packaged three pack of briefs, 298g, is presented in *Table 2.5*.

Table 2.5 ***Extracted energy for transport from Egypt to England per pack***

Transport	KWh/tonne-km	Distance km	Energy kWh
40 te long haul lorry	0.35	500	0.052
Ship	0.036	6800	0.073
Total			**0.125**

2.2.9 Manufacturing Sub total

Table 2.6 shows the energy consumed at each stage in the manufacture of a three pack of men's briefs and the percentage breakdown. The spinning of yarn is the most energy intensive stage of manufacturing, accounting for 33% of energy consumption.

Table 2.6 ***Extracted energy consumption associated with the manufacture of a three pack of men's brief***

Manufacturing Stage	KWh	Percentage
Fibre preparation	1.43	10.86
Yarn	4.41	33.49
Transport of yarn to Egypt from India	0.16	1.21
Knitting of fabric	1.57	11.92
Dyeing and finishing	1.34	10.17
Elastic production	1.52	11.54
Packaging production	1.25	9.49
Transport packaging	0.93	7.06
Garment makeup (cutting and sewing)	0.43	3.26
Transport to the UK from Egypt	0.13	0.99
Total	**13.17**	**100.00**

2.3 POST MANUFACTURING M&S RETAIL OPERATIONS

2.3.1 Distribution centre

From gas and electricity consumption data supplied by M&S (*see Table 2.7*), 0.59 kWh extracted energy has been attributed to a pack of briefs for this stage.

Table 2.7 ***Distribution energy consumption***

Energy Source	MkWh for Clothing	Extracted Energy kWh/kg
Electricity	35.7	2.18
Gas	33.15	0.56
Total	**68.85**	**2.74**

2.3.2 Disposal of transit packaging

Landfill

It has been assumed that the packaging is disposed to landfill. The ***WISARD*** [6] waste management software was used to calculate energy consumption of waste disposal, assuming transport of waste 20 km to a large wet composite lined landfill. Total extracted energy for waste disposal is 0.0386 kWh/kg. The disposal of the transit packaging associated with a box of briefs to landfill would consume 0.001 kWh.

2.3.3 Transport from distribution centre to retail outlet

Annual fuel consumption for distribution of clothing was supplied by M&S. From annual consumption, it was calculated that 0.096 kg of diesel is required to deliver each kg of clothing delivered, this equates to an extracted energy consumption of 1.42 kWh/kg and 0.306 kWh per pack of briefs.

2.3.4 Carrier bag

The carrier bag which is normally used for a pack of briefs, weighs approximately 6g. The bag is made of HDPE.

APME data for HDPE has been used. Total extracted energy for the production of the polymer is 22.5 kWh / kg, and together with an allocation of 5.56 kWh / kg for fabrication, this equates to 0.168 kWh per carrier bag.

2.3.5 Retail outlet

A proportion of the energy use in an M&S store has been allocated to a pack of briefs.

Assumptions have had to be made to calculate the energy use attributable to a pack of briefs. The annual energy use by clothing square footage of M&S retail outlets has been allocated on a mass basis to the 70 000 tonnes of clothing sold by M&S annually. This equates to 0.037 kWh of oil, 1.6 kWh of gas and 2.914 kWh of electricity per kg of clothing. *Table 2.8* details the energy consumption of M&S retail outlets.

Table 2.8 Retail outlet annual energy consumption

Fuel	Clothing MkWh	Clothing kWh / kg clothing	Extracted energy KWh / kg
Oil	2.6	0.037	0.04
Gas	112	1.600	1.79
Electricity	204	2.914	12.47
Total	**319**	**4.551**	**14.30**

Total energy consumption for the retail outlet per pack of briefs is 3.09 kWh.

2.3.6 Sub-total for retail

Table 2.9 shows the extracted energy consumption associated with the distribution and sale of a three pack of men's briefs.

Table 2.9 Extracted energy consumption for the retail of a three pack of men's briefs

	Extracted Energy kWh	Percentage
Distribution center	0.59	14.18
Transport to retail outlet	0.31	7.45
Carrier bag	0.17	4.09
Retail outlet	3.09	74.28
Total	**4.16**	**100.00**

2.4 PRODUCT USE AND CUSTOMER CARE

The energy use associated with customer care has been calculated on the basis of an average lifetime of two years for the briefs. It has been assumed that each pair of briefs was worn once every week.

Energy, water and detergent consumption during washing have been allocated on a mass basis.

The recommended washing temperature for the briefs is 50°C. Washing at 50°C has been assessed and the implications of changing the recommended wash temperature to 40°C have also been assessed.

2.4.1 *Transport from retail outlet*

It has been assumed that the majority of shoppers use the car to go shopping. An average travel distance of 7 miles and an average shop of 1.4 kg has been assumed (M&S estimate). This equates to 8km / kg of shopping.
Using extracted energy data for car travel, 1.37 kWh / km, results in an extracted energy consumption of 3 kWh per pack of briefs.

2.4.2 *Disposal of packaging*

The box, carrier bag, hook and inserts weigh 55 g in total.

It has been assumed that the packaging is disposed to landfill. The ***WISARD*** [6] waste management software was used to calculate energy consumption of waste disposal, assuming transport of waste 20 km to a large wet composite lined landfill. Total extracted energy for waste disposal is 0.0386 kWh / kg. The disposal of 55g of packaging to landfill would consume 0.002 kWh.

This is negligible when compared to other life cycle stages.

2.4.3 *Washing*

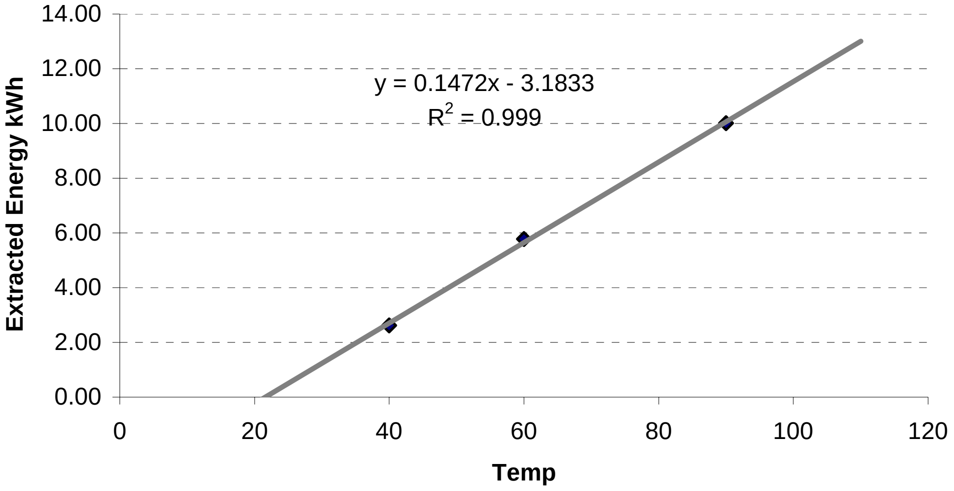
Table 2.10 details the results of a survey of European manufacturers of washing machines conducted by GEA and published in 1995 [7]. GEA in their report address average consumer behaviour (1994) reporting an average load of 3kg per wash and an average detergent use of 135g per wash. The average load capacity for the machines surveyed was 4.85kg. Using the EU labelling criteria, the average machine in *Table 2.10* would fall in the 'C' efficiency class for washing machines as it has a Specific Energy Consumption of 0.25 kWh / kg (60 wash and load capacity of 4.85kg). In Great Britain in 1998, approximately 45% of washing machines sales were 'C' and an equal number were 'B' efficiency machines [8].

Table 2.10 ***Average values for washing machines (only values without pre-wash included for energy and water consumption) [7]***

Wash Temp	Energy kWh/load	Extracted Energy kWh/load	Water Use
30°C	-	-	
40°C	0.54	2.62	82
60°C	1.19	5.78	79
90°C	2.06	10.01	68

From *Table 2.10*, a relationship between temperature and energy has been determined (*see Figure 2.1*). Using the linear equation, extracted energy for a 50°C wash has been calculated to be 4.18 kWh/load.

Figure 2.1 ***Energy to temperature relationship***



For the purpose of this study, the average machine outlined above has been assumed to be representative of the UK and has been used to determine extracted energy consumption associated with electricity use of washing. An average load of 3kg has been assumed.

Detergents

Typical detergent dose and extracted energy consumption for the manufacture of standard powder, compact powder and tablet detergents was supplied by Unilever (see *Table 2.11)*. For the purpose of this study, it has been assumed that the standard powder has been used and that the recommended dose is used.

Table 2.11 Extracted energy and dosing for common detergents

Detergent	Recommended Dose g	Extracted Energy KWh
Tablet	80	1.08
Compact powder	75	0.97
Standard powder	108	1.00

Water

From data reported by 'Water UK' for the year up to April 2000, energy consumption associated with the supply of clean water (553 kWh/Ml) and the treatment of sewerage (454 kWh/Ml) has been used to calculate the energy consumption associated with water use in washing machines. No allowance for evaporation has been made. It has been assumed that energy use relates to electricity consumption. On the basis of these assumptions supply and treatment of the water used accounts for 0.001 kWh of electricity per litre. On the basis of a medium voltage supply, this equates to 0.0043kWh of extracted energy per litre of water. Average water use of 80 litres per wash has been assumed. This equates to 0.345 kWh per wash or 0.115 kWh/kg (assuming average load of 3kg)

Compared to electricity use, water use can be seen to be relatively insignificant.

Extracted energy consumption of washing

Table 2.12 details the extracted energy consumption associated with washing.

Table 2.12 Washing extracted energy consumption

	Extracted Energy kWh			
	Water	Electricity	Detergent	Total
40°C per load	0.34	2.62	1.00	3.96
50°C per load	0.34	4.18	1.00	5.52
40°C per kg load	0.11	0.87	0.33	1.32
50°C per kg load	0.11	1.39	0.33	1.84
40°C per three pack of briefs	0.02	0.19	0.07	0.29
50°C per three pack of briefs	0.02	0.30	0.07	0.40

Table 2.13 shows the lifetime extracted energy consumption, associated with washing briefs.

Table 2.13 Extracted energy for 104 washes

	Extracted Energy kWh			
Wash Temp	Water	Electricity	Detergent	Total

	Extracted Energy kWh			
Wash Temp	**Water**	**Electricity**	**Detergent**	**Total**
40°C per three pack of briefs	2.58	19.62	7.49	29.69
Percentage Analysis	8.70	66.08	25.22	100.00
50°C per three pack of briefs	2.58	31.30	7.49	41.37
Percentage Analysis	6.24	75.66	18.10	100.00

2.4.4 Drying

It has been assumed that for 50%, of washes, the briefs are dried mechanically. The basis for this assumption is that 35% of UK households own tumble dryers and 15% own washer dryers [10]. Although these households may use natural drying for part of the time, households without tumble/washer dryers may use other mechanical heat sources in the home to dry clothes at certain times.

According to a survey of UK drier sales [7], the average air vented drier has a specific energy consumption (dry cotton cycle) of 0.80 kWh/kg and condenser driers an average of 0.79 kWh/kg.

A survey of the Hotpoint range of tumble driers in the UK by ERM resulted in an average energy consumption per dry cotton load of 3.5 kWh and for synthetics per load 1.6 kWh. Using the load capacities for the Hotpoint machines energy consumptions for cotton, 0.74 kWh per kg, and synthetics, 0.59 kWh/kg, were calculated. Data supplied by Crosslee plc for their standard tumble drier was in line with the Hotpoint data, 0.75 kW/kg for cotton loads and 0.52 kWh/kg for synthetics. The Hotpoint data falls within Efficiency class ‘D’. In 1998, approximately 60% of drier sales in the UK fell into the ‘D’ energy efficiency category [9].

In the absence of specific data on consumer use characteristics energy consumption has been calculated using the Hotpoint data.

For cotton drying, this equates to 3.6 kWh/kg extracted energy. On the basis that 50% of washes are tumble dried, this equates to 40.39 kWh extracted energy per pack of briefs over their lifetime.

2.4.5 Extracted energy for consumer care

Table 2.14 shows the lifetime extracted energy consumption, associated with washing and drying briefs.

Table 2.14 Extracted energy (kWh) for 104 washes

Wash Temp	Water	Electricity	Detergent	Drying	Total
40°C per three pack of briefs	2.58	19.62	7.49	40.39	70.08
Percentage Analysis	*3.68*	*28.00*	*10.69*	*57.64*	*100.00*
50°C per three pack of briefs	2.58	31.30	7.49	40.39	81.76
Percentage Analysis	*3.16*	*38.28*	*9.16*	*49.40*	*100.00*

2.5 DISPOSAL

2.5.1 Recycling

Between 135 000 and 225 000 tonnes of post-consumer textiles are reused or recycled per year in the UK out of an annual textile waste arising of 650 000 tonnes [11]. This is reported to be consistent with the Textile Recycling Associations 25% recycling figure [11].

Based on the study of Salavation Army textile recycling operations, an energy credit can be awarded where displacement of new products occurs.

We have no evidence that the briefs are recycled to any extent, though experience would suggest that some may be re-used as rags in the home.

2.5.2 Landfill

Landfill is by far the dominant disposal route in the UK, 83% of municipal waste arisings in 1998/1999 were sent to landfill, 9% recycled and 8% incinerated [12]. It is therefore reasonable to assume that, if landfill is the main disposal route and 25% of textile waste is recycled, the majority of textiles end up in a landfill.

It has been assumed that the briefs are disposed to landfill. The ***WISARD*** [6] waste management software was used to calculate energy consumption of waste disposal, assuming transport of waste 20 km to a large wet composite lined landfill. Total extracted energy for waste disposal is 0.0386 kWh/kg. The disposal of a pair of briefs to landfill would consume 0.003 kWh.

3 TOTAL ENERGY USE FOR A THREE PACK OF MEN'S BRIEFS

Table 3.1 details the energy consumed by each stage of the life cycle for a three pack of men's briefs.

Consumer care can be seen to be the most significant life cycle stage. The electricity consumption associated with washing and tumble drying being the most significant contributor to this life cycle stage.

The results of the study are not precise but can be considered an accurate measure of significance.

Table 3.1 Energy consumption by life cycle stage for a three pack of men's briefs (based on useful garment life of 104 washes)

Life Cycle Stage		kWh	%
Cotton Fibre		2.76	2.63
Product manufacture		13.17	12.56
Fibre preparation		1.43	1.36
Yarn		4.41	4.21
Transport of yarn to Egypt from India		0.16	0.15
Knitting of fabric		1.57	1.50
Dyeing and finishing		1.34	1.28
Elastic production		1.52	1.45
Packaging production		1.25	1.19
Transport packaging		0.93	0.89
Garment makeup (cutting and sewing)		0.43	0.41
Transport to the UK from Egypt		0.13	0.12
M&S retail operations		4.16	3.97
Distribution center		0.59	0.56
Transport to retail outlet		0.31	0.30
Carrier bag		0.17	0.16
Retail outlet		3.09	2.95
Consumer use		84.76	80.83
Transport from retail outlet		3	2.86
Laundry		81.76	77.97
	Water	2.58	2.46
	Detergent	7.49	7.14
	Washing machine electricity	31.30	29.85
	Drying	40.39	38.52
Disposal		0.01	0.01
		104.86	100.00

4 REFERENCES

1) *Boustead, 1997.* Eco-profiles of the European plastics industry. Report 10: polymer conversion. Association of Plastics Manufacturers in Europe (APME)

2) *T. Leo van Winkle et al; 1978.* Cotton versus polyester. American Scientist

3) *BTTG; 1999.* Report 3: Textile Processing Techniques. BTTG.

4) *BTTG; 1999.* Report 5: Waste minimisation and best practice. BTTG.

5) *BTTG; 1999.* Report 4: Textile mass balance and product life cycles. BTTG.

6) Ecobalance; 1999. WISARD: The Environment Agency's life cycle software for waste management. Environment Agency.

7) *Group for efficient Appliances; 1995.* Washing machines, driers and dishwashers. Danish Energy Agency.

8) *DETR; 2000.* Washing Machines in the United Kingdom: A Sector Review Paper on Projected Energy Consumption for the Department of the Environment, Transport and the Regions, 2000

9) DETR; 1999. Tumble Dryers in the United Kingdom: A Sector Review Paper on Projected Energy Consumption for the Department of the Environment, Transport and the Regions

10) *AEA Technology; 1999.* Wet appliances in the United Kingdom. DETR.

11) *Environmental Resources Management; 2001.* Textile Recycling. Department of Trade and Industry.

12) *DETR, 2000.* Waste Strategy 2000 for England and Wales. Department of the Environment, Transport and the Regions.

Annex B

Streamlined LCA of Men’s Polyester Trousers

1 POLYESTER TROUSERS

1.1 PRODUCT DESCRIPTION

The polyester trousers to be studied are Marks & Spencer pleated navy blue 100% polyester trousers (stroke number 3226), size 34” (waist), 31” (leg). The polyester fabric is manufactured in Taiwan and the trousers are made up in Indonesia.

Table 1.1 details supplier data relating to the components of the finished garment.

Table 1.1 Product construction (supplier data)

Component	Weight (g)	Material	Place of manufacture
Fabric		Polyester	Taiwan (UK & Germany)
Zip	5.8	Polyester	UK
Thread	15.3	Polyester	Hong Kong
Buttons	0.4	Polyester	Spain
Care labels	0.8	Polyester	
Hook fastener	2.7	Brass	UK
Swing tickets	5.0	Card	

Once the trousers are made up, they are dispatched to Peterlee, England from Indonesia. In England, they are unpacked, pressed and then hung singly on a 53g clothes hanger (polystyrene and metal) with a 16g clear polyethylene cover and two cardboard labels weighing 5g. The trousers weigh 408g without packaging and swing tickets, of which 8.9g is fastenings (buttons, hook and zip), 15.3g thread and the remainder, 383.8g, is woven polyester fabric.

1.2 LIFE CYCLE ENERGY USE

For the purposes of this study, energy consumption will be calculated for each life cycle stage and reported in terms of extracted energy.

Extracted energy requirements refer to the total energy consumption when traced back through all operations to the extraction of raw materials from the earth.

The following sections detail the extracted energy associated with each life cycle stage and the data sources for extracted energy.

1.2.1 Extracted energy for common inputs and processes

The Tables in *Annex C* detail the extracted energy associated with fuels, materials and transport modes identified in the product life cycle.

For the fabrication of polymer products such as hooks and buttons, an allocation of 5.56 kWh/kg has been made. This figure is in line with APME (1) [1] conversion energy for polymers.

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(1) Association of Plastics Manufacturers in Europe

2 MANUFACTURING: EXTRACTED ENERGY CONSUMPTION

2.1 FIBRE PRODUCTION

A number of literature sources which detail the energy requirements for the production of polyester were reviewed as part of this study. For this study extracted energy for the production of polyester fibre was based on the data contained in *Table 2.1*.

Table 2.1 Energy Consumption (MJ/kg) in polyester resin and polyester filament fibre production [2]

Energy	Polyester resin Manufacture	Polyester filament fibre manufacture	Total Energy
Process Energy	50	13.45	63.45
Energy of material Resources	45.77	0.19	45.96
Total Energy	**95.77**	**13.64**	**109.41**

2.2 SPINNING, WEAVING, DYEING, FINISHING AND MAKING UP

Throughout the production processes for textiles material is lost. *Table 2.2* details fibre losses for each stage of the production process as published by BTTG [3]. Using the minimum loss values, every kilogram of finished product requires 1.153 kg of fibre input.

Table 2.2 BTTG typical material losses

Production stage	% losses	Polyester Fibre Output
Polyester Fibre		442.6
Preparation and blending	2 – 10	433.7
Spinning synthetics	1 – 7	429.3
Weaving	3 – 8	416.5
Dyeing and finishing	3 –10	404
Making up	5 – 20	383.8

Energy consumption for the production process defined by the supplier have been calculated, see *Table 2.3,* using the lower range of energy requirements of operations detailed in the BTTG figures [4].

Where energy has been reported as energy used at machine (process energy), electricity and fuel energy has been allocated based on the nature of the operations. From the process energy extracted energy has been calculated based on a medium voltage electricity supply and the use of oil as a fuel.

Table 2.3 *BTTG figure for energy demand of textile processing operations per kg of product*

Operation	Process Energy MJ/kg	Extracted Energy kWh/kg	Assumption
Opening and Cleaning	2.1	2.50	100% Electricity
Drawing	3.1	3.69	100% Electricity
Roving	0.8	0.95	100% Electricity
Preparation		***7.13***	
Spinning	18.7	***22.23***	100% Electricity
Winding	1.0	1.19	100% Electricity
Beaming	3.2	3.80	100% Electricity
Weaving	6.4	7.61	100% Electricity
Weaving		***12.60***	
Scouring	6.2	2.58	90% Fuel, 10% Electricity
Dyeing	3.4	1.42	90% Fuel, 10% Electricity
Dyeing Chemicals (350 kg tonne)		2.36	
Drying	1.8	0.75	90% Fuel, 10% Electricity
Dyeing and Finishing		***7.11***	
Cutting and Makeup	2.0	***2.38***	100% Electricity

For dyeing, the BTTG figure [5] of 350 kg of chemical per tonne of fabric has been used. An average extracted energy of 6.75 kWh per kg has been allocated to chemicals based on an equal split between organic and inorganic chemicals (see *Annex C*). No energy consumption for water use has been allocated.

Table 2.4 shows the extracted energy consumption associated with the production of the trousers using the loss figures detailed in *Table 2.2* and the energy consumption data for the production processes presented in *Table 2.3*.

Table 2.4 *Polyester flow and extracted energy consumption for each production stage*

Production	Polyester fibre g	Extracted Energy kWh
Garment	383.8	0.91
Dyed and finished fabric	404	2.87
Woven fabric	416.5	5.25
Yarn	429.3	9.57
Prepared fibre	433.7	3.09
Polyester fibre	442.6	13.45
Total		**35.14**

2.2.1 *Transport of fabric to Indonesia from Taiwan*

For the purposes of bulk transport, we have used energy use per tonne-km. Shipping distances from Indonesia to Taiwan have been calculated and a 250 km road haulage distance has been allocated for this stage (*see Table 2.5*).

Table 2.5 Transport extracted energy

Transport	kWh/tonne-km	Distance km	Tonne –km	Energy kWh
40 Tonne Truck	0.35	250	0.1	0.04
Freighter	0.036	4000	1.62	0.06
Total				**0.1**

2.2.2 Zip production

The zip is manufactured from polyester. Using the data for amorphous PET, 22.69 kWh / kg, and assuming a fabrication energy of 5.56 kWh per kg of zip this equates to 0.16 kWh extracted energy for the zip.

2.2.3 Fastener production

The fastener is made from brass. For the purpose of this study, and in the absence of specific data for the production of the brass fastener, extracted energy for the production of copper (copper being the major component of brass) has been used (29 kWh / kg). No transport or fabrication allocation has been made. Extracted energy consumption for the fastener equates to 0.08 kWh.

2.2.4 Button production

The button is made from polyester. For the purpose of this study, extracted energy consumption per kg has been assumed to be the same as for the zip, this equates to 0.01kWh for the buttons.

2.2.5 Thread Production

For the purposes of the study, polyester thread is assumed to be similar to the polyester yarn used to manufacture the trousers. Using the data in *Section 2.1* and *Section 2.2*, an allocation of 58.5 kWh per kg of thread has been used, this equates to 0.89 kWh.

No transport allocation has been made.

2.2.6 Transport to Peterlee from Indonesia

For the purposes of bulk transport, we have used energy use per tonne-km. Shipping distances from Indonesia to the UK have been calculated and 500 km of road haulage has been allocated, see *Table 2.6*.

Table 2.6 Transport energy use

Transport	kWh/tonne-km	Distance km	Tonne -km	Energy kWh
40 Tonne Truck	0.35	500	0.204	0.07
Freighter	0.036	17000	6.936	0.25
Total				**0.32**

2.2.7 Swing tickets

The swing tickets are made up of printed card, a plastic button and thread. The swing tickets weigh approximately 5g: 4.5g of cardboard, and 0.5g for the button and thread.

The extracted energy data for 'paper- coated bleached' has been used to estimate the energy associated with the card (25.42 kWh/kg). Using this figure gives an energy consumption of 0.114 kWh for the cardboard.

No transport allocation has been made.

2.2.8 Hanger production

The clothes hanger weighs 53g, 9g steel and 44g PS (polystyrene). Using the high alloy steel life cycle inventory, 33 kWh per kg of steel has been allocated. This equates to energy consumption of 0.495 kWh for the hanger metal.

APME inventory data for polystyrene (29.25 kWh/kg) has been used, and in a 5.56 kWh fabrication energy has been allocated, this equates to an extracted energy consumption of 1.53 kWh.

The total energy consumption associated with the hanger is therefore 2.03kWh. M&S have a policy of re-using hangers. However, for the purpose of this study it has been assumed they are one trip only.

2.2.9 Plastic cover production

The plastic cover weighs approximately 16g. It has been assumed that the cover is made of polyethylene.

APME data for polyethylene has been used, which results in a total gross energy for the production of the polymer of 23.84 kWh/kg. Allocating 5.56 kWh/kg for fabrication equates to a total energy consumption of 0.47 kWh per cover.

2.2.10 Garment pressing and packaging

No allocation of energy use has been made as it is considered to be insignificant.

2.2.11 Transport to distribution centre

The packaged garment weighs 482g. 250 km of road transport have been allocated to this stage, (see *Table 2.7).*

Table 2.7 Extracted energy consumption for transport

Transport	kWh/tonne-km	Distance km	Tonne -km	Energy kWh
40 Tonne Truck	0.35	250	0.121	0.042

2.2.12 Extracted energy sub total for manufacturing and fibre production

Table 2.8 shows the energy consumed at each stage in the manufacture of a pair of polyester trousers and the percentage breakdown. The spinning of yarn and the production of polyester fibre are the most energy intensive stages of manufacturing.

Table 2.8 Extracted energy consumption for each production stage

Production	Extracted Energy kWh	Percentage
Transport to distribution center	0.04	0.10
Cover	0.47	1.20
Hanger	2.03	5.17
Swing Ticket	0.11	0.28
Transport to Peterlee	0.32	0.82
Garment Makeup	0.91	2.32
Fastener	0.08	0.20
Thread	0.89	2.27
Button	0.01	0.03
Zip	0.16	0.41
Transport to Indonesia	0.01	0.03
Dyed and finished fabric	2.87	7.31
Woven fabric	5.25	13.37
Yarn	9.57	24.38
Prepared fibre	3.09	7.87
Polyester fibre	13.45	34.26
Total	**39.26**	**100.00**

2.3 POST MANUFACTURING (RETAIL)

2.3.1 Distribution centre

From gas and electricity consumption data supplied by Marks & Spencer, see *Table 2.9*, 1.12 kWh extracted energy has been attributed to a pair of trousers for this stage.

Table 2.9 ***Distribution energy consumption***

Energy Source	**MkWh for Clothing**	**Extracted Energy kWh/kg**
Electricity	35.7	2.18
Gas	33.15	0.56
Total	**68.85**	**2.74**

2.3.2 Transport from distribution centre to retail outlet

Annual fuel consumption for distribution of clothing was supplied by M&S. From annual consumption it was calculated that 0.096 kg of diesel is required to deliver each kg of clothing delivered, this equates to an extracted energy consumption of 1.42 kWh/kg and 0.58 kWh per pair of trousers.

2.3.3 Carrier bag

The M&S carrier bag which is likely to be used for trousers, weighs approximately 20g. The bag is made of HDPE.

APME data for HDPE has been used, which results in a total gross energy for the production of the polymer of 22.49 kWh/kg. Together with an allocation of 5.56 kWh/kg for fabrication, this equates to a total energy consumption of 0.56 kWh per carrier bag.

2.3.4 Retail outlet

A proportion of the energy use in an M&S store has been allocated to a pair of trousers.

Assumptions have had to be made to calculate the energy use attributable to a pair of trousers. The annual energy use by clothing square footage of M&S retail outlets has been allocated on a mass basis to the 70 000 tonnes of clothing sold by M&S annually. This equates to 0.037 kWh of oil, 1.6 kWh of gas and 2.914 kWh of electricity per kg of clothing. *Table 2.10* details the energy consumption of M&S retail outlets.

Table 2.10 Retail outlet annual energy consumption

Fuel	**Clothing MkWh**	**Clothing kWh/kg clothing**	**Extracted energy KWh/kg**
Oil	2.6	0.037	0.04
Gas	112	1.600	1.79
Electricity	204	2.914	12.47
Total	**319**	**4.551**	**14.3**

Total energy consumption for the retail outlet per pair of trousers is 5.83 kWh.

2.3.5 Disposal of cover

The box, carrier bag, hook and inserts weigh 55 g in total.

It has been assumed that the packaging is disposed to landfill. The ***WISARD*** [6] waste management software was used to calculate energy consumption of waste disposal, assuming transport of waste 20 km to a large wet composite lined landfill. Total extracted energy for waste disposal is 0.0386 kWh / kg. The disposal of the 16g cover to landfill would consume 0.0006 kWh.

This is negligible when compared to other life cycle stages.

2.3.6 Sub-total for retail

Table 2.11 shows the extracted energy consumption associated with the distribution and sale of a pair of trousers.

Table 2.11 Extracted energy consumption for the retail of a pair of trousers

Retail steps	**Extracted Energy kWh**	**Percentage**
Distribution center	1.12	13.84
Transport to retail outlet	0.58	7.17
Carrier bag	0.56	6.92
Retail outlet	5.83	72.06
Total	**8.09**	**100.00**

2.4 PRODUCT USE AND CUSTOMER CARE

The energy use associated with customer care has been calculated on the basis of an average lifetime of two years for the trousers. It has been assumed the trousers are worn as office wear for 46 working weeks each year and that the trousers are worn and washed each week.

Energy, water and detergent consumption during washing have been allocated on a mass basis per pair of trousers.

2.4.1 Transport from retail outlet

It has been assumed that the majority of shoppers use the car to go shopping. An average travel distance of 7 miles and an average shop of approximately 1.4 kg have been assumed (an M&S estimate). This equates to 8km / kg of shopping.

Using extracted energy data for car travel, 1.37 kWh / km, results in an extracted energy consumption of 5.3 kWh per pair of trousers.

2.4.2 Washing

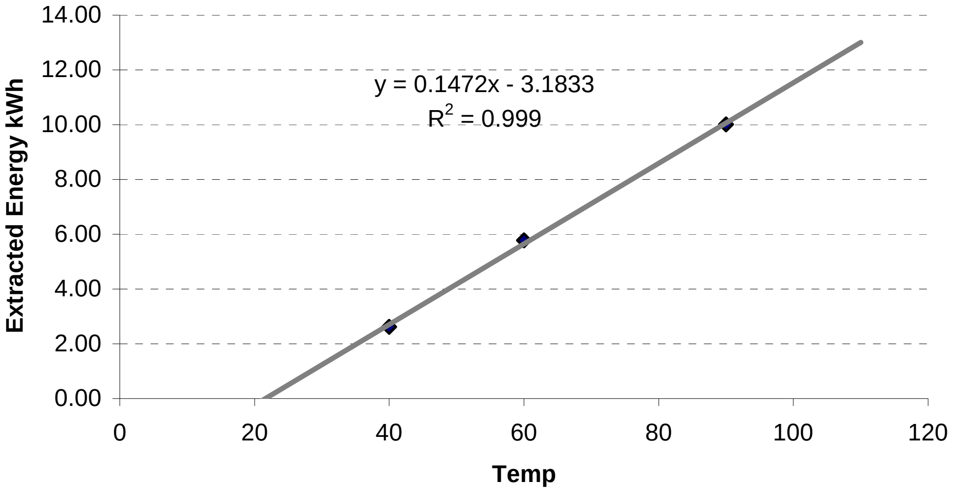
Table 2.12 details the results of a survey of European manufacturers of washing machines conducted by GEA and published in 1995 [7]. GEA, in their report address average consumer behaviour (1994), reporting an average load of 3kg per wash and an average detergent use of 135g per wash. The average load capacity for the machines surveyed was 4.85kg. Using the EU labelling criteria, the average machine in *Table 2.10* would fall in the 'C' efficiency class for washing machines as it has a Specific Energy Consumption of 0.25 kWh / kg (60 wash and load capacity of 4.85kg). In Great Britain in 1998, approximately 45% of washing machines sales were 'C' and an equal number were 'B' efficiency machines [8]

Table 2.12 Average values for washing machines (only values without pre-wash included for energy and water consumption)

Wash Temp	**Energy kWh/load**	**Extracted Energy kWh/load**	**Water Use**
30°C	-	-	
40°C	0.54	2.62	82
60°C	1.19	5.78	79
90°C	2.06	10.01	68

From *Table 2.12*, a relationship between temperature and energy has been determined (see *Figure 2.1)*. Using the linear equation, extracted energy for a 50°C wash has been calculated to be 4.18 kWh / load.

Figure 2.1 Energy to temp relationship



For the purpose of this study, the average machine outlined above has been assumed to be representative of the UK and has been used to determine extracted energy consumption associated with electricity use of washing. An average load of 3kg has been assumed.

Detergents

Typical detergent dose and extracted energy consumption for the manufacture of standard powder; compact powder; and tablet detergents, was supplied by Unilever, see *Table 2.13.* For the purpose of this study, it has been assumed that the standard powder has been used and the recommended dose is used.

Table 2.13 Extracted energy and dosing for common detergents

Detergent	**Recommended Dose G**	**Extracted Energy kWh**
Tablet	80	1.08
Compact powder	75	0.97
Standard powder	108	1.0

Water

From data reported by 'Water UK' for the year up to April 2000, energy consumption associated with the supply of clean water (553 kWh / Ml) and the treatment of sewerage (454 kWh / Ml) has been used to calculate the energy consumption associated with water use in washing machines. No allowance for evaporation has been made. It has been assumed that energy use relates to electricity consumption. On the basis of these assumptions, supply and treatment of the water used accounts for 0.001 kWh of electricity per litre. On the basis of a medium voltage supply, this equates to 0.0043kWh of extracted energy per litre of water. Average water use of 80 litres per wash has been assumed, this equates to 0.344 kWh per wash or 0.115 kWh / kg (assuming average load of 3kg)

Compared to electricity use, water use can be seen to be relatively insignificant.

Extracted energy consumption of washing

Table 2.14 details the extracted energy consumption associated with washing.

Table 2.14 ***Washing extracted energy consumption***

	Extracted Energy kWh/wash			
	Water	**Electricity**	**Detergent**	**Total**
40°C per load	0.34	2.62	1.00	3.96
50°C per load	0.34	4.18	1.00	5.52
40°C per kg load	0.11	0.87	0.33	1.32
50°C per kg load	0.11	1.39	0.33	1.84
40°C per pair of trousers	0.05	0.36	0.14	0.54
50°C per pair of trousers	0.05	0.57	0.14	0.75

Table 2.15 shows the life time extracted energy consumption associated with washing a pair of trousers.

Table 2.15 ***Extracted energy for 92 washes***

	Extracted Energy kWh			
Wash Temp	**Water**	**Electricity**	**Detergent**	**Total**
40°C per pair of trousers	4.31	32.78	12.51	49.61
Percentage Analysis	*8.70*	*66.08*	*25.22*	*100.00*
50°C per pair of trousers	4.31	52.30	12.51	69.13
Percentage Analysis	*6.24*	*75.66*	*18.10*	*100.00*

2.4.3 Drying

It has been assumed that, for 50% of washes, trousers are dried mechanically. The basis for this assumption is that 35% of UK households own tumble dryers and 15% own washer dryers [10]. Although these households may use natural drying for part of the time, households without tumble / washer dryers may use other mechanical heat sources in the home to dry clothes at certain times.

According to a survey of UK drier sales [7], the average air vented drier has a specific energy consumption (dry cotton cycle) of 0.80 kWh/kg and condenser driers an average of 0.79 kWh/kg.

A survey of the Hotpoint range of tumble driers in the UK by ERM resulted in an average energy consumption per dry cotton load of 3.5 kWh and for synthetics per load 1.6 kWh. Using the load capacities for the Hotpoint machines, energy consumptions for cotton, 0.74 kWh per kg, and synthetics, 0.59 kWh/kg, were calculated. Data supplied by Crosslee plc. for their standard tumble drier was in line with the Hotpoint data, 0.75 kW/kg for cotton loads and 0.52 kWh/kg for synthetics. The Hotpoint data falls within Efficiency class 'D'. In 1998, approximately 60% of drier sales in the UK fell into the 'D' energy efficiency category [9].

In the absence of specific data on consumer use characteristics energy consumption has been calculated using the Hotpoint data.

For synthetic drying, this equates to 2.87 kWh/kg extracted energy. On the basis that 50% of washes are tumble dried, this equates to 53.86 kWh extracted energy per pair of trousers over its lifetime.

2.4.4 Ironing

It has been assumed that a pair of trousers is ironed after each wash. The time taken to iron a pair of trousers has been estimated at 2 minutes. A survey of 13 models of iron generated an average power rating of 1.6 kW. Irons do not consume electricity throughout their operation, but intermittently in order to maintain the required temperature. This results in lower energy use than if an iron consumes electricity according to its rating. For the purposes of this study, no allowance for this intermittent demand has been made.

Using the above assumptions, electricity use for two minutes of ironing equates to 0.053 kWh or 0.26 kWh extracted energy.

2.4.5 Customer care sub total

Table 2.16 details the energy consumed in the customer care stage for a pair of trousers over it life.

Table 2.16 Extracted energy (kWh) for 92 washes

Wash Temperature	Water	Electricity	Detergent	Drying	Ironing	Total
40°C per pair of trousers	4.31	32.78	12.51	53.86	23.92	127.39
Percentage Analysis	*3.39*	*25.73*	*9.82*	*42.28*	*18.78*	*100.00*
50°C per pair of trousers	4.31	52.30	12.51	53.86	23.92	146.91
Percentage Analysis	*2.94*	*35.60*	*8.52*	*36.66*	*16.28*	*100.00*

2.5 END OF LIFE

2.5.1 Recycling

Between 135 000 and 225 000 tonnes of post-consumer textiles are reused or recycled per year in the UK out of an annual textile waste arising of 650 000 tonnes. This is reported to be consistent with the Textile Recycling Associations 25% recycling figure. [11]

We have no specific evidence that the polyester trousers after 2 years of use would be recycled, though logic would suggest that a proportion would be recycled.

Based on a study of SATC (Salvation Army Trading Company) textile recycling operations, the collection, processing and distribution of post consumer clothing consumes 1.7 kWh of extracted energy per kg of second hand clothing recycled. The manufacture of a pair of polyester trousers consumed 39.26 kWh of extracted energy.

It can be concluded that the collection, processing and transport of second hand clothing consumes an insignificant quantity of energy in comparison to the saving in energy that can be achieved by reducing the quantity of virgin clothing that is required. However, an energy credit can only be awarded to recycled clothing if it can be demonstrated that it is off-setting the production of products made from virgin materials.

To illustrate the benefit of recycling:

If we assume that 25% (UK textile recycling figure) of polyester trousers are recycled and reused as trousers, avoiding the need for the manufacture of new trousers, an energy credit of –9.6 kWh could be awarded to the energy profile of a pair of trousers. This credit would reduce the life cycle energy burden for trousers by 5%, a significant saving. For one pair of Marks and Spencer plc polyester trousers the life cycle burden would be reduced from 199.6 to 190 kWh.

2.5.2 Landfill

Landfill is by far the dominant disposal route in the UK, 83% of municipal waste arisings in 1998/1999 were sent to landfill, 9% recycled and 8% incinerated [12]. It is therefore reasonable to assume that, if landfill is the main disposal route and 25% of textile waste is recycled, the majority of textiles end up in a landfill.

It has been assumed that the trousers are disposed to a landfill. The WISARD waste management software [6] was used to calculate energy consumption of waste disposal, assuming transport of waste 20 km to a large wet composite lined landfill. Total energy for waste is 0.0386 kWh/kg. The disposal of a pair of trousers to landfill would consume 0.016 kWh.

3 LIFE CYCLE ENERGY CONSUMPTION

Table 3.1 details the energy consumed by each stage of the life cycle for a pair of men's polyester trousers.

Consumer care can be seen to be the most significant life cycle stage. The electricity consumption associated with washing and tumble drying being the most significant contributor to this life cycle stage.

The results of the study are not precise but can be considered an accurate measure of significance.

Table 3.1 ***Extracted energy consumption by life cycle stage***

Life Cycle Stage	kWh	Percentage %
Polyester fibre	13.45	6.74
Product manufacture	25.81	12.93
Prepared fibre	3.09	1.55
Yarn	9.57	4.80
Woven fabric	5.25	2.63
Dyed and finished fabric	2.87	1.44
Transport to Indonesia	0.01	0.01
Zip	0.16	0.08
Button	0.01	0.01
Thread	0.89	0.45
Fastener	0.08	0.04
Garment makeup	0.91	0.46
Transport to Peterlee	0.32	0.16
Swing Ticket	0.11	0.06
Hanger	2.03	1.02
Cover	0.47	0.24
Transport to distribution center	0.04	0.02
M&S Retail Operations	8.09	4.05
Distribution center	1.12	0.56
Transport to retail outlet	0.58	0.29
Carrier bag	0.56	0.28
Retail outlet	5.83	2.92
Consumer use	152.20	76.26
Transport from retail outlet	5.3	2.66
Laundry	146.90	73.61
water	4.31	2.16
detergent	12.51	6.27
Washing machine energy	52.30	26.21
drying	53.86	26.99
ironing	23.92	11.99
Disposal	0.02	0.01
Total	**199.57**	**100.00**

4 REFERENCES

1) *Boustead, 1997.* Eco-profiles of the European plastics industry. Report 10: polymer conversion. Association of Plastics Manufacturers in Europe (APME)

2) Franklin Associates; 1993. Resource and Environmental Profile Analysis of a Manufactured Apparel Product - Life Cycle Analysis (LCA): Woman's Knit Polyester Blouse. Franklin Associates.

3) BTTG; 1999. Report 3: Textile Processing Techniques. BTTG.

4) BTTG; 1999. Report 5: Waste minimisation and best practice. BTTG.

5) *BTTG; 1999.* Report 4: Textile mass balance and product life cycles. BTTG.

6) Ecobalance; 1999. WISARD: The Environment Agency's life cycle software for waste management. Environment Agency.

7) *Group for efficient Appliances; 1995.* Washing machines, driers and dishwashers. Danish Energy Agency.

8) *DETR; 2000.* Washing Machines in the United Kingdom: A Sector Review Paper on Projected Energy Consumption for the Department of the Environment, Transport and the Regions.

9) DETR; 1999. Tumble Dryers in the United Kingdom: A Sector Review Paper on Projected Energy Consumption for the Department of the Environment, Transport and the Regions.

10) *AEA Technology; 1999.* Wet appliances in the United Kingdom. DETR.

11) Environmental Resources Management; 2001. Textile Recycling. Department of Trade and Industry.

12) *DETR, 2000.* Waste Strategy 2000 for England and Wales. Department of the Environment, Transport and the Regions.

Annex C

Life Cycle Extracted Energy Data for Materials and Energy Inputs

Table 1 *Extracted energy: car*

Energy Sources	**kWh/km**
Hard coal	0.11
Nuclear	0.06
Hydro power	0.01
Natural gas	0.08
Lignite	0.03
Oil	1.09
Biofuel	0.00
TOTAL	**1.37**

Source: ETH - ENET 30179 Okoinventare fur Energiesysteme (Updated - April 95, Europe)

Table 2 *Extracted energy: freighter*

Energy Sources	**KWh/tonne.km**
Oil	0.032
Hydro power	0.000
Nuclear	0.000
Biofuel	0.000
Lignite	0.000
Natural gas	0.002
Hard coal	0.002
TOTAL	**0.036**

Source: ETH - ENET 30179 Okoinventare fur Energiesysteme (Updated - April 95, Europe)

Table 3 *Extracted energy: 40T truck*

Energy Sources	**KWh/tonne.km**
Biofuel	0.00
Hydro power	0.00
Oil	0.26
Lignite	0.01
Natural gas	0.02
Hard coal	0.03
Nuclear	0.02
TOTAL	**0.35**

Source: ETH - ENET 30179 Okoinventare fur Energiesysteme (Updated - April 95, Europe)

Table 4 *Extracted energy: UK low voltage electricity*

Energy Sources	kWhex/kWh delivered
Natural gas	0.48
Nuclear	0.80
Biofuel	0.05
Hard coal	3.04
Hydro power	0.06
Oil	0.42
Lignite	0.00
TOTAL	**4.86**

Source: "Environmental benefits of offset energy", Nichols and Sturges, ETSU/DTI, 1996 (Updated - April 95)

Table 5 *Extracted energy: UK medium voltage electricity*

Energy Sources	KWhex/kWh delivered
Hard coal	2.70
Oil	0.37
Hydro power	0.05
Natural gas	0.42
Lignite	0.00
Nuclear	0.71
Biofuel	0.02
TOTAL	**4.28**

Source: "Environmental benefits of offset energy", Nichols and Sturges, ETSU/DTI, 1996 (Updated - April 95)

Table 6 *Extracted energy: natural gas delivered UK*

Energy Sources	KWh/kg
Hydro power	0.001
Biofuel	0.001
Oil	0.479
Lignite	0.000
Natural gas	16.188
Nuclear	0.014
Hard coal	0.114
TOTAL	**16.80**

Source: "Environmental benefits of offset energy", Nichols and Sturges, ETSU/DTI, 1996 (Updated - April 95)

Table 7 *Extracted energy: diesel UK*

Energy Sources	KWh/kg
Hydro power	0.01
Biofuel	0.01
Oil	13.75
Lignite	0.00
Natural gas	0.63
Nuclear	0.08
Hard coal	0.35
TOTAL	**14.82**

Source: "Environmental benefits of offset energy", Nichols and Sturges, ETSU/DTI, 1996 (Updated - April 95)

Table 8 *Extracted energy: Kg low sulphur oil UK*

Energy Sources	KWh/kg
Hydro power	0.01
Biofuel	0.01
Oil	13.75
Lignite	0.00
Natural gas	0.63
Nuclear	0.08
Hard coal	0.35
TOTAL	**14.82**

Source: "Environmental benefits of offset energy", Nichols and Sturges, ETSU/DTI, 1996 (Updated - April 95)

Table 9 *Extracted energy: Kg LDPE*

Energy Sources	KWh/kg
Unspecified	0.06
Biofuel	0.00
Nuclear	0.46
Hard coal	0.91
Oil	10.40
Natural gas	12.61
Hydro power	0.15
TOTAL	**24.60**

Source: "Ecoprofiles of the European plastics industry Report 3: Polyethylene and polypropolene" 1993 (Pre 1995, Europe)

Table 10 *Extracted energy: HDPE*

Energy Sources	KWh/kg
Hydro power	0.11
Natural gas	11.39
Unspecified	0.00
Hard coal	0.61
Oil	10.03
Nuclear	0.36
TOTAL	**22.50**

Source: "Ecoprofiles of the European plastics industry Report 3: Polyethylene and polypropolene" 1993 (Pre 1995, Europe) HCV

Table 11 *Extracted energy: high alloy steel*

Energy Sources	KWh/kg
Hydro power	1.17
Biofuel	0.11
Oil	5.45
Lignite	3.00
Natural gas	3.73
Nuclear	6.49
Hard coal	12.98
TOTAL	32.96

Source: ETH - ENET 30179 Okoinventare fur Energiesysteme (Updated - April 95, Europe), HCV

Table 12 *Extracted energy: carton board*

Energy Sources	KWh/kg
Unspecified extracted energy	26.24
TOTAL	**26.24**

Source: Pira Environmental Manangement System (PEMS) version 3 (Pre 1995, Europe)

Table 13 *Extracted energy: bleached coated paper*

Energy Sources	KWh/kg
Unspecified extracted energy	25.42
TOTAL	**25.42**

Source: Pira Environmental Manangement System (PEMS) version 3 (Pre 1995, Europe)

Table 14 *Extracted energy: organic chemicals*

Energy Sources	KWh/kg
Nuclear	2.63
Hydro power	0.47
Biofuel	0.02
Oil	3.12
Lignite	1.22
Natural gas	0.80
Hard coal	2.46
TOTAL	**10.72**

Source: ETH - ENET 30179 Okoinventare fur Energiesysteme (updated - April 95, Europe)

Table 15 *Extracted energy: inorganic chemicals*

Energy Sources	KWh/kg
Nuclear	0.24
Biofuel	0.00
Hydro power	0.04
Oil	2.02
Lignite	0.11
Natural gas	0.15
Hard coal	0.23
TOTAL	**2.79**

Source: ETH - ENET 30179 Okoinventare fur Energiesysteme (updated - April 95, Europ

Table 16 *Extracted energy: polypropylene (average)*

Energy Sources	KWh/kg
Hydro power	0.23
Natural gas	5.91
Unspecified	0.02
Hard coal	0.46
Oil	15.22
Nuclear	0.28
TOTAL	**22.11**

Source: "Ecoprofiles of the European plastics industry Report 3: Polyethylene and polypropolene" 1993 (Pre 1995, Europe)