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Life cycle assessment for reuse/recycling of donated waste textiles compared to use of virgin material: An UK energy saving perspective

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Abstract

In the UK, between 4 and 5% of the municipal solid waste stream is composed of clothes/textiles. Approximately 25% of this is recycled by companies such as the Salvation Army Trading Company Limited (SATCOL) who provide a collection and distribution infrastructure for 'donated' clothing and shoes. Textiles can be reused or undergo a processing stage and enter a recycling stream. Research was conducted in order to quantify the energy used by a reuse/recycling operation and whether this resulted in a net energy benefit. The energy footprint was quantified using a streamlined life cycle assessment (LCA), an LCA restricted in scope in order to target specific aspects of the footprint, in this case energy consumption. Taking into account extraction of resources, manufacture of materials, electricity generation, clothing collection, processing and distribution and final disposal of wastes it was demonstrated that for every kilogram of virgin cotton displaced by second hand clothing approximately 65 kWh is saved, and for every kilogram of polyester around 90 kWh is saved. Therefore, the reuse and recycling of the donated clothing results in a reduction in the environmental burden compared to purchasing new clothing made from virgin materials.

Keywords: Reuse; Recycling; Clothing; Textiles; Extracted energy

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1. Introduction

In England, textiles, clothes, shoes and accessories can comprise 4–5% of all household waste (DTI, 2002), in 2003/2004 this would correspond to between 1 017 360 and 1 272 450 tonnes (DEFRA, 2005). There are a number of routes for unwanted textiles/clothes to be recovered. Some local authorities collect textiles through kerbside collection schemes, but at only 17% this lags well behind paper and card (51%) and glass (21%). By far the most successful route for local authorities to collect this waste stream is the civic amenity and bring banks. During 2002/2003, at some 5195 sites in England, 92% (46 000 tonnes) of discarded of textiles were collected by local authorities; this corresponds to 2.2 kg per household per year (DEFRA, 2005). Across England, there are clear regional differences in terms of quantity of textiles discarded and recovered from the waste stream. Overall, 2.6 kg per household per year were discarded (2002/2003), with the value in the North East being only 1.4 kg compared to 3.7 kg in the East Region (DEFRA, 2005); this reflects a wide a range of socio-demographic differences. It was estimated, that the waste arisings from the textile industry alone were between 550 000 and 900 000 tonnes per year for the UK up until 2000 (DETR, 2000).

Much of the textile waste stream is post consumer and it is estimated that approximately 25% of these discarded textiles are recovered. Between 400 000 and 700 000 tonnes of textiles are landfilled or incinerated each year, with the remaining 135 000–225 000 tonnes being either reused or recycled (SATCOL, 2004). Salvation Army Trading Company Ltd (SATCOL) has concluded that generally, when clothing is disposed of it still has at least 70% of its useful life left (SATCOL, 2004). The destination of discarded textiles varies with market conditions; in 1999 it was estimated that some 43% went for second hand clothing, 22% for filling materials, 12% for wiping cloths and 7% for fibre reclamation. The environmental benefits of textile recovery include a reduced demand for virgin resources and a reduction in pollution and energy burden as raw materials do not need to be imported (DTI, 2002).

SATCOL, SCOPE, Oxfam, BHF and others (DTI, 2002), all run charity bank systems. There are some 6000 banks in the UK, 85% being run by charities not local authorities. At present, each bank collects between 5–7 tonnes per annum across the UK. SATCOL (SATCOL, 2004), with its 2300 banks, door-to-door, multi material collections and donations manage some 500 tonnes per week.

SATCOL recycles clothing and textiles by providing a collection and distribution infrastructure for donated second hand clothing, textiles, shoes and accessories. The business has several aspects including:

- clothes banks,
- household collection schemes,
- charity shops,
- collection logistics,
- distribution of clothing to areas of the world where there is a need for low cost or second hand clothing.

SATCOL has formal links with over 250 local authorities and receives 10–15% of all the clothing, shoes, textiles and accessories donated in the UK. It facilitates the reuse of clothing by collecting, sorting, baling and transporting it to parts of the world where there is a demand for low cost clothing, in addition to running 38 retail outlets (charity shops) in the UK. There were around 7100 such outlets, mostly run by charities, in the UK in 2000 (DTI, 2002).

2. Methods

The aim of this research was to determine whether the recycling of clothes, shoes and textiles actually results in a net energy benefit. Life cycle assessment (LCA) has been proved to be a useful tool when assessing the environmental impact of municipal solid waste systems (Reich, 2005) and it can quantify the environmental performance of alternative solid waste management options (Arena et al., 2003). It is a powerful tool when allied to methodologies such as life cycle costing (LCC) for economic assessment of solid waste options (Reich, 2005). LCA has been used to investigate a range of solid wastes such as wood, tyres (Corti and Lombardi, 2004) and food waste (Lundie and Peters, 2005). It has also been used to determine the likely environmental and economic impacts due to substitution of materials (Petersen and Solberg, 2005) and can be used to quantify environmental performance of production and distribution of a wide range of products such as beer (Koroneos et al., 2005) and cotton (Proto et al., 2000).

LCA is a methodological framework that can be used to assess (or estimate) the environmental impact of the life of a product from production to disposal of the item. It does not normally involve the design and development phase of the product, as it is not thought that this has a significant environmental impact, although the design of the product itself (Fig. 1) can massively influence the other life cycle stages (Rebitzer et al., 2004). The emissions to air, water and land are assessed at each stage of manufacture, use and disposal of the product. These exchanges are then related to the potential environmental impacts such as resource depletion, ozone depletion and global warming. The significance of LCA as a decision making tool is recognised in the Waste and Resources R&D Strategy for England 2004–2007 (DEFRA, 2004). The strategy calls for a new range of tools, building on LCA, to enable decision makers to measure performance and design new policies based upon sound science.

Full LCA can be resource intensive and cumbersome and as a result it is common to reduce the scope of an LCA to target specific life cycle stages, such as end of life, or specific environmental issues, e.g. energy consumption, resource consumption or global warming. Where this occurs it is referred to as a streamlined LCA. The scope of an LCA defines the framework and application of the LCA. The scope of this study has been restricted in order to target energy consumption for the clothing recycling activity undertaken by SATCOL (Fig. 2). This study has lead to the quantification of SATCOL's clothing recycling energy footprint.

The system boundary is the interface between the environment, other product systems and the product of interest. In order for an investigation to be effective (Table 1), it is essential to define whether or not an element falls within the boundaries set for the study.

The energy consumption for the life cycle stages assessed should be traced back to the extraction of resources from the environment; this consumption has been applied to

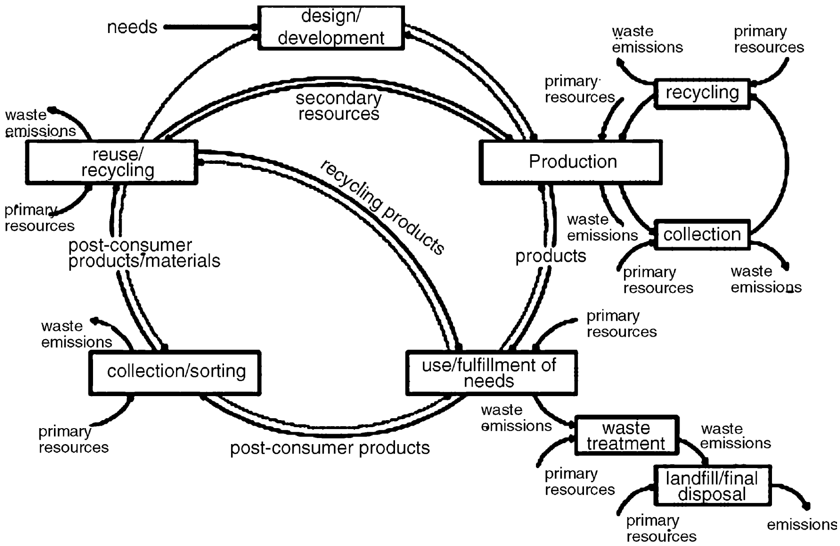

Fig. 1. Schematic representation of a generic life cycle of a product where the dotted lines represent information and the solid lines show material and energy flows (Rebitzer et al., 2004).

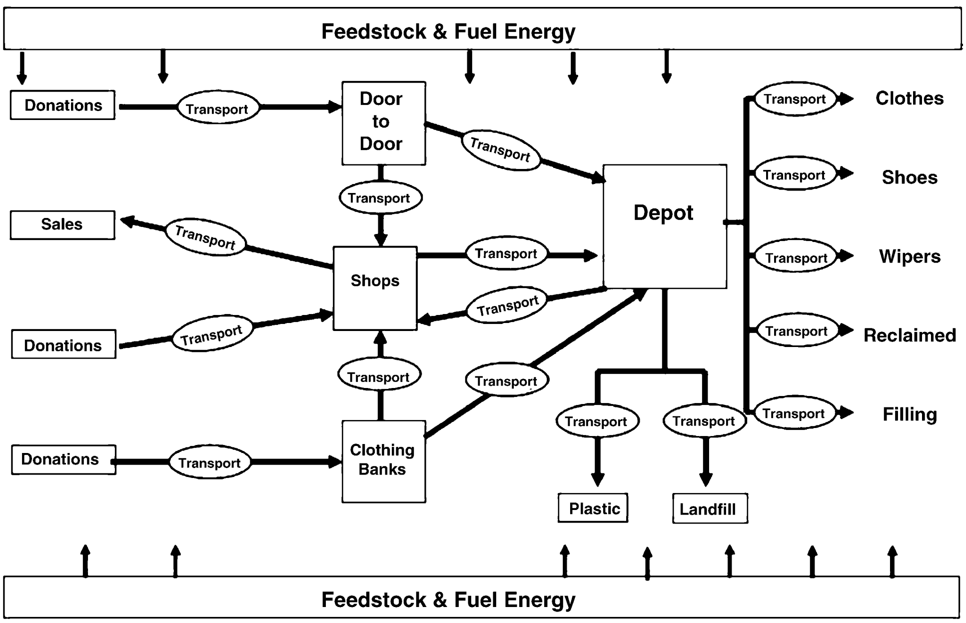

Fig. 2. Key process activities in SATCOL.

Table 1
System boundaries

Within system boundary	
	Extraction of resources
	Manufacture of materials, including fuels and chemicals consumed
	Electricity generation
	Clothing collection
	Clothing processing
	Clothing distribution
	Disposal of wastes
Outside system boundary	
	Capital equipment
	All post re-sale life cycle stages
	Maintenance of buildings or equipment

functional units. Two functional units have been defined: annual recycled tonnes and 1 tonne of recycled clothing. Energy consumption was calculated by quantifying the consumption of energy, fuels and materials by the system for the year 2000/2001. Life cycle data for materials and energy sources was then used to convert these factors into extracted energy. The data was sourced from either direct communication by SATCOL or published generic life cycle data for relevant materials fuels and energy generation.

Assumptions were made in order to keep the investigation within the set boundaries e.g. it is generally assumed that only 5% of donations to charity shops or clothing banks are made in a trip dedicated to the deposition; only the energy used for these dedicated trips have been included. It has also been assumed that once the clothing has been bulk transported to users it is delivered directly to the point of use. Any further dedicated transport falls outside the boundaries of this investigation. The collection of clothing from clothing banks had an associated energy cost for transportation. This was calculated by using the miles per litre data supplied by SATCOL and converted into extracted energy using the standard data of 14.82 kWh/kg (Nichols and Sturges, 1996).

3. Results

For the year 2000–2001, 16 871 tonnes of material were collected, of which 15 576 tonnes were sold for reuse and the remaining 1295 tonnes discarded as waste. The material that was reused or recycled was distributed as in Table 2. A comparison against the national average is made and it can be seen that SATCOL reuse a higher percentage of clothing than the average. Second hand clothing shops in the UK (charity shops), accounted for 684 tonnes of the 8094 tonnes of second hand clothing, the remainder being distributed through other routes.

The two main collection routes for the clothing are door-to-door collection and bring banks. However, since this study commenced an additional route has been added. With the introduction of government legislation on kerbside collections, multi material collections have been instituted to around one million homes in the UK comprising paper, glass, cans

Table 2
Categories of use for donated textiles, SATCOL compared to National Average 2000/2001

Destination	Tonnes	Percentage	National average percentage (DTI, 2002)
Second hand clothes (reuse)	8094	50	43
Wipers	2428	15	12
Filling materials	2104	13	22
Reclaimed fibres	1295	8	7
Wastes	1295		7
Second hand shoes	971	6	9
Total	16187	100	100

and textiles with encouraging levels of participation. In addition, clothing may be deposited either at the charity shops directly or taken to the SATCOL main centre, but the vast majority of clothing is collected from the organised collection routes.

Door-to-door collection accounted for 4349 tonnes of donated clothing. SATCOL provided 98.2 tonnes of polythene bags for the clothing to be collected in. The breakdown of extracted energy is

- polythene bags: 2 792 248 kWh of extracted energy,
- 23.85 kWh/kg: production of the polymer,
- 5.56 kW/kg: fabrication (Boustead, 1993).

There is also an associated 1120 miles transportation cost for the polythene bags from the supplier, this adds 6970 kWh to the polythene bags.

The bring banks accounted for 12 328 tonnes of clothing, it is assumed that 95% of deposits to bring banks are combined with trips for other purposes e.g. shopping. For the purpose of this study an average dedicated deposit has been calculated as involving a trip of 7.5 miles and a donation of 20 kg of clothing. This equates to a transport burden of 231 000 miles with an extracted energy of 490 000 kWh (calculated using 6.6 miles/l). Bring bank collection used 14.3 tonnes of polythene bags; using the same figures as for door-to-door the total extracted energy for these bags is 420 563 kWh.

The shops received 3542 tonnes of clothing, of which 195 tonnes was donated directly. Sales accounted for 684 tonnes and the rest were retuned to the depot. The shops consumed a combined total of extracted energy for gas and electricity totalling 7 455 000 kW/h of which 95% can be directly attributed to the sale of the clothing. The shops used a total of 19.5 tonnes of polythene bags with an extracted energy cost of 573 000 kWh. As with the bring banks it has been assumed that 95% of trips were not dedicated to visiting the shop, and no transport burden has been applied to these trips. The same calculation has been used as for the bring banks for the remaining 5%, thus amounting to a consumer transport burden of 3700 miles or 7743 kWh of extracted energy. Operation of the depot has associated extracted energy costs (Table 3).

The average extracted energy consumed transporting 1 tonne material to the customer is 77.5 kWh. For the 14 892 tonnes dispatched to the customer this is equivalent to 1 154 000 kWh. It is assumed that any materials not used or resold will be disposed of to landfill as they have already been rejected from the recycling stream. The dis-

Table 3
Extracted energy for the SATCOL depot 2000–2001

Item	Total extracted energy (kWh)	Percentage
Electricity	1730000	35.4
Strapping	1140386	23.4
Gas	986000	20.2
Wrapping plastic	545975	11.2
Baling wire	265969	5.4
Fork Lift Calor Gas	215000	4.4
Total	4883330	100

posal of 1300 tonnes of material can be estimated as having an extracted energy cost of 50 000 kWh.

SATCOL internal transport system is a major consumer of energy within the operation. The energy is used for transporting clothing banks to trailer sites (37%); trailers to depots (31%) door-to-door collection to trailer sites (21%); banks and door-to-door collections to shops (7%) and car journeys and maintenance (5%). The total extracted energy for the internal transport system is 8 873 000 kWh.

The annual extracted energy burden for SATCOL recycled clothing system is summarised to be 26 500 000 kWh for the year 2000–2001. Using this figure and the total quantity of clothing recycled the total extracted energy required to recycle a tonne is calculated as being 1697 kWh.

4. Discussion

The clothing collected by SATCOL has already been used, but generally could still have a significant amount of remaining use. When materials are recycled there is an environmental benefit as a result of avoiding the environmental burden associated with the manufacture of new products and the disposal of wastes. Environmental credits can be awarded when it can be shown that environmental burden can be prevented, the size of the credit is determined by the quantity of virgin materials and wastes that are avoided, offset by the environmental burden incurred during reprocessing. The most controversial area regarding environmental credits is determining the actual quantity of virgin material that has not been used as a result of the recycling. Clothing poses an even more difficult problem in that it cannot be stated that each item has actually displaced the purchase of a garment made from virgin material. Where waste clothing is used for furniture filling or wipers there is a known displacement of paper or foam products. Table 4 details the extracted energy required in the manufacturing processes for cotton and polyester garments.

These (Table 4) data refer to the manufacture of clothing, however, in addition to this there is an environmental burden for packaging, transport and sale of these garments which add an extra 30–40% to the environmental burden of the manufacturing process.

It is possible to calculate the reuse of 1 tonne of garments by deducting the energy used to reuse or recycle 1 tonne of clothing from the energy used to manufacture it from

Table 4
Summary of extracted energy consumption for the manufacture 1 tonne of cotton and polyester garments

	Cotton garment	Polyester garment
Baled cotton lint	15424	
Polyester fibre		35043
Preparation and blending	7975	8057
Spinning	24616	24870
Knitting	8768	13673
Dying and finishing	7484	7474
Making up	2380	2380
Total (kWh)	66648	91508

virgin materials. This gives a net energy saving of 64 951 kWh for cotton garments and the reuse of polyester garments has an even greater net energy saving of 89 811 kWh. The total energy extraction associated with collection, sorting, baling, selling and distribution of these garments is 2.6% (cotton) and 1.8% (polyester) respectively of the energy required to manufacture them from virgin materials.

Wipers are difficult to assess, as a tonne of cotton wipers may not be equivalent to 1 tonne of paper wipers. The extracted energy associated with the manufacture of 1 tonne of paper products is approximately 20 000 kWh. If it is assumed that 1 tonne of cloth wipers is equivalent to 1 tonne of paper wipers there is an energy credit of around 18 303 kWh/tonne.

The quantity of clothing donated in the UK has increased each year from 1990 to 2000 (DTI, 2002), whether this is due to an increase in public awareness of recycling facilities or whether more textiles are discarded each year is an open question. The quantity received by SATCOL in 2003/2004 was 23 000 tonnes, 27% higher than it was in 2000/2001. This amounted to approximately 75 000 000 individual items of clothing being diverted from the final disposal waste stream (SATCOL, 2004).

The Waste and Resources R&D Strategy for England (DEFRA, 2004), places emphasis upon the social dimension of waste management (Theme 5). It recognises the requirement for significant new research to lead to an in-depth understanding of pro-environmental behaviour and the tools required to facilitate behaviour change in the population. Textile recycling is one such area that is relatively well understood by the general public who can more easily value the economic and social benefits of this recycling, and so more readily accept waste facilities that contain bring banks for textiles and clothes. Well-designed waste reduction campaigns will therefore build upon this by designing effective communications campaigns based upon cognitive understanding of public attitudes (Tonglet et al., 2004).

The UK government has described sustainable development as ‘a better quality of life for everyone, now and for generations to come’ and states that achieving it requires four objectives to be targeted in the UK (SDU, 2004).

Textile recycling at SATCOL meets these criteria, firstly through social progress which recognises the needs of everyone by providing low cost clothing for those who need it. It leads to effective protection of the environment (SDU, 2004), by reducing the energy burden and emissions from manufacture as well as reduction of landfill. There is prudent use of natural resources (SDU, 2004); by removing the need to manufacture garments from virgin materials. There is maintenance of high and stable levels of economic growth and employment by offering work to 300+ individuals in the UK alone and increasing their skills through training. National and regional government need to imbed policies that increasingly support textile recycling as this engages the population in improved practice and reduces energy demand from the sector.

5. Conclusion

In excess of 1 million tonnes of clothing are disposed of in the domestic waste stream each year, however an increasing quantity is being collected for potential reuse or reprocessing. This investigation quantified the energy burden associated with the processing and transportation of these items by Salvation Army Trading Company Ltd (SATCOL). All the processes, including the energy burden associated with retailing and distribution and the donations have been shown to be insignificant compared with the energy consumed during the manufacture of these items from virgin materials. The reuse of 1 tonne of polyester garments only uses 1.8% of the energy required for manufacture of these goods from virgin materials and the reuse of 1 tonne of cotton clothing only uses 2.6% of the energy required to manufacture those from virgin materials.

The operations of SATCOL fall within the remit of sustainable development and go a long way to meet the four objectives set by UK government. This study is the most recent detailed economic evaluation of energy savings and such detail will be used by national and regional planners in devising future waste management programmes to embed policies to support textile recycling practice and reduce energy demand from the sector.

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