

Part 9 – Estimation of greenhouse gas emissions

Climate change is now widely accepted as posing a serious challenge to the survival of humans. GHG emissions need to be reduced drastically and soon while we still have the potential to regain control. Estimation of GHG emissions is not part of a standard LCA. However, given the urgency to act in the face of climate change, it is considered necessary to present an estimation of the GHG emissions for the life cycles of cotton and polyester t-shirts.

9.1 Greenhouse gas emission results

Figures 40 to 43 and Tables 5 to 8 show the same results as Part 8 (the environmental impacts of cotton and polyester t-shirts) but translated into GHG emissions. In the interpretation and use of these results it is essential to note that:

- the GHG emission figures are affected by the intrinsic limitations of LCA
- this is a screening LCA not a detailed one
- standard LCA practice does not incorporate estimation of GHG emissions, so this exercise is unique and therefore it is not possible to compare the consistency of the estimates with other similar reports.

In the future, GHG emissions accounting will be required to calculate the carbon tax payable by the cotton industry as part of the Australian Emissions Trading Scheme. By then, a common methodology for GHG accounting in LCA will be needed.

The estimated GHG emissions for each product are:

- cotton: 26 kg CO₂e/kg textile
- polyester: 31 kg CO₂e/kg textile.

This means that producing 1000 polyester t-shirts would emit approximately 1.25 tonnes of CO₂e more than the production of 1000 cotton t-shirts. Table 5 provides a summary of the GHG emissions in different life-cycle stages for cotton and polyester. Please refer to Part 8 for an analysis of the results.

Table 4. GHG emission summary

Stage	Cotton (kg CO ₂ e/ kg textile)	Polyester (kg CO ₂ e/kg textile)
Fibre production	3.2	8.9
Textile manufacturing	22.6	22.6
Use and disposal	370.1	370.1

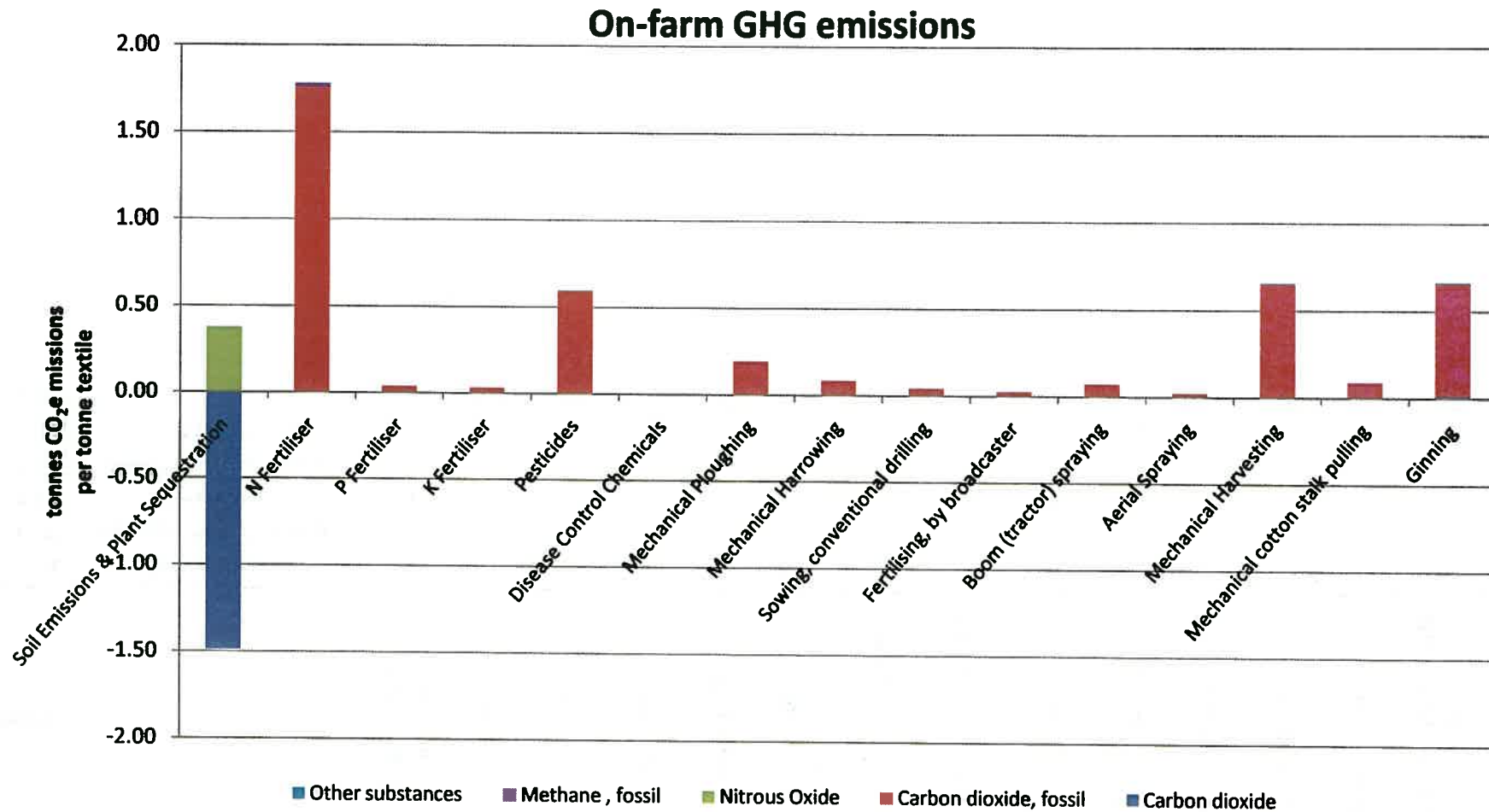


Figure 40. GHG emissions from farm-related operations

Table 5. GHG emissions from farm-related operations (tonnes CO₂e per tonne of textile)

Total	Substance	Soil emissions and plant sequestration	N fertiliser	P fertiliser	K fertiliser	Pesticides	Disease control chemicals	Mechanical ploughing	Mechanical harrowing	Sowing, conventional drilling	Fertilising, by broadcaster	Boom (tractor) spraying	Aerial spraying	Mechanical harvesting	Mechanical cotton stalk pulling	Ginning
-1.48	Carbon dioxide	-1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
4.25	Carbon dioxide, fossil origin	0.00	1.76	0.04	0.03	0.59	0.00	0.19	0.09	0.04	0.03	0.07	0.02	0.65	0.09	0.64
0.39	Nitrous oxide	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.04	Methane, fossil origin	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
0.01	Other substances	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.21		-1.11	1.78	0.04	0.03	0.60	0.00	0.20	0.09	0.05	0.03	0.07	0.02	0.66	0.09	0.66

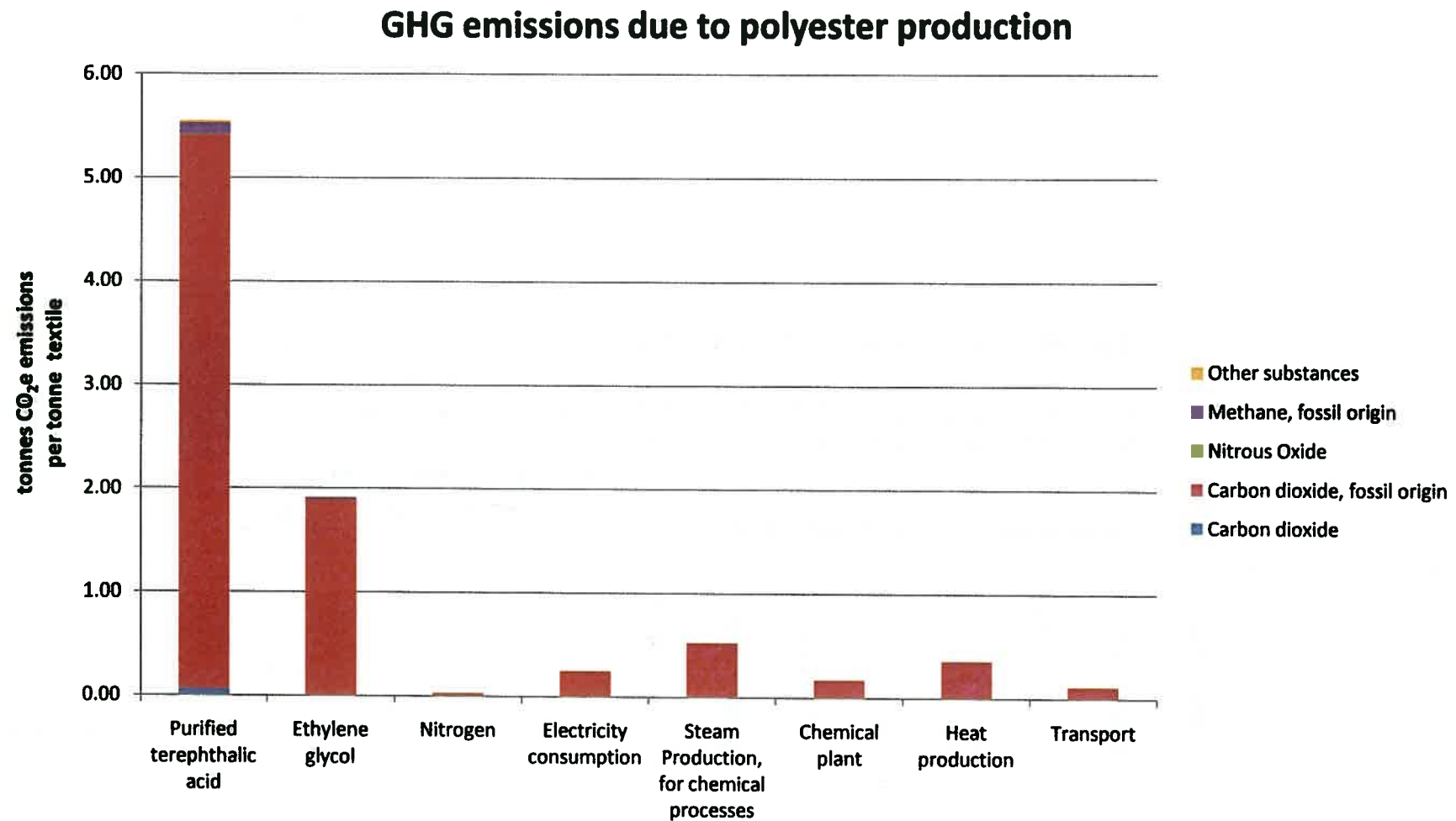


Figure 41. GHG emissions from polyester production operations

Table 6. GHG emissions from polyester production operations (tonnes CO₂e per tonne of textile)

Total	Substance	Purified terephthalic acid	Ethylene glycol	Nitrogen	Electricity consumption	Steam production, for chemical processes	Chemical plant	Heat production	Transport
0.06	Carbon dioxide	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.67	Carbon dioxide, fossil origin	5.35	1.88	0.03	0.25	0.52	0.17	0.36	0.11
0.01	Nitrous oxide	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.15	Methane, fossil origin	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00
0.03	Other substances	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8.92		5.55	1.91	0.04	0.25	0.52	0.18	0.36	0.11

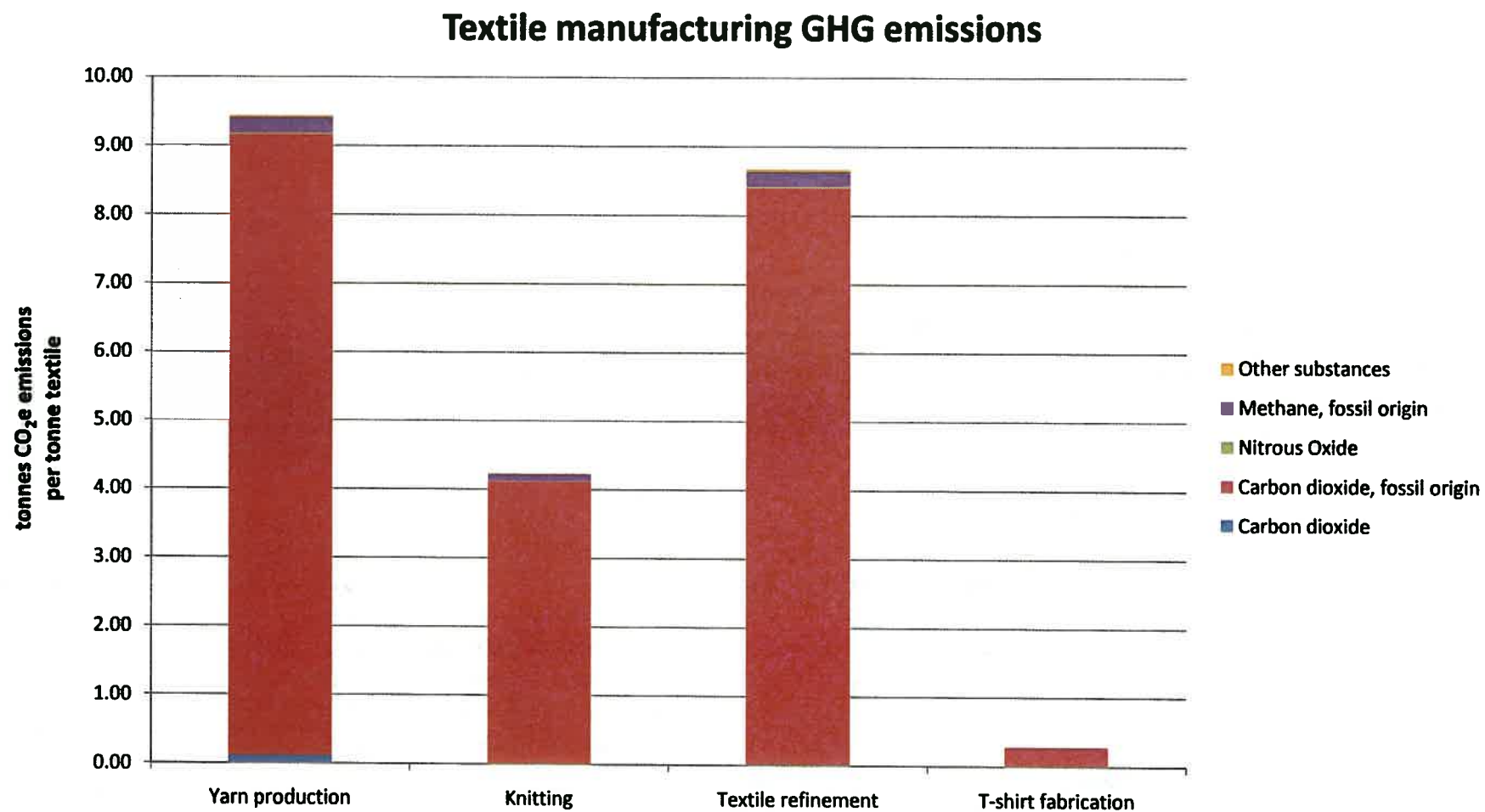


Figure 42. GHG emissions from textile manufacturing operations

Table 7. GHG emissions from textile manufacturing operations (tonnes CO₂e per tonne of textile)

Total	Substance	Yarn production	Knitting	Textile refinement	T-shirt fabrication
0.14	Carbon dioxide	0.11	0.01	0.02	0.00
21.81	Carbon dioxide, fossil origin	9.05	4.10	8.39	0.27
0.05	Nitrous oxide	0.02	0.01	0.02	0.00
0.55	Methane, fossil origin	0.23	0.10	0.21	0.01
0.07	Other substances	0.03	0.01	0.03	0.00
22.62		9.44	4.23	8.67	0.28

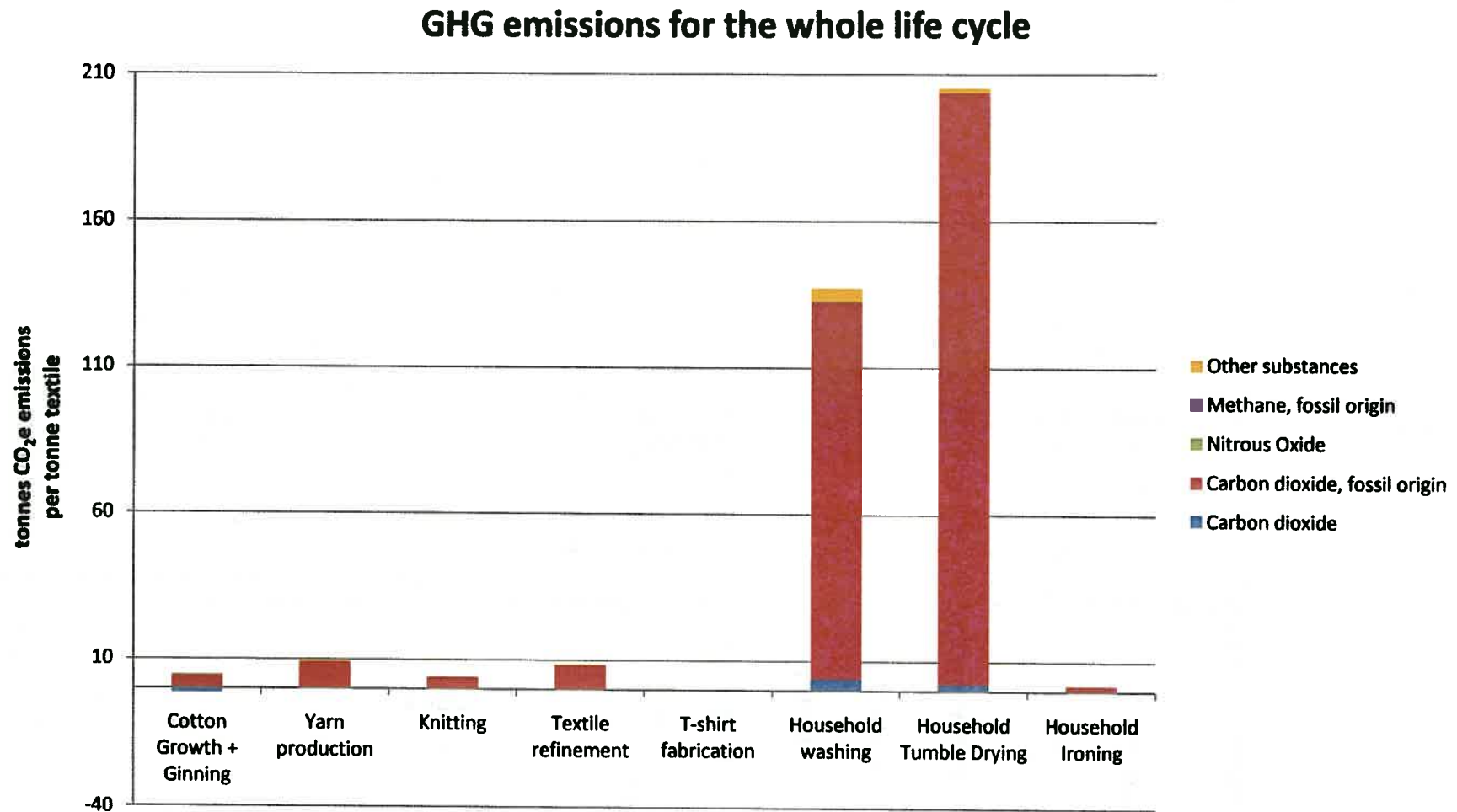


Figure 43. GHG Emissions from cradle to grave

Table 8. GHG emissions from cradle to grave (tonnes CO₂e per tonne of textile)

Total	Substance	Cotton growth and ginning	Yarn production	Knitting	Textile refinement	T-shirt fabrication	Household washing	Household tumble drying	Household ironing
5.06	Carbon dioxide	-1.48	0.11	0.01	0.02	0.00	4.08	2.30	0.02
357.73	Carbon dioxide, fossil origin	4.25	9.05	4.10	8.39	0.27	128.22	201.45	2.00
0.59	Nitrous oxide	0.39	0.02	0.01	0.02	0.00	0.15	0.00	0.00
0.66	Methane, fossil origin	0.04	0.23	0.10	0.21	0.01	0.07	0.00	0.00
6.09	Other substances	0.01	0.03	0.01	0.03	0.00	4.36	1.63	0.02
370.13		3.21	9.44	4.23	8.67	0.28	136.88	205.38	2.04

Part 10 - Conclusions

This report assessed the energy and environmental life cycles of a 100% Australian cotton t-shirt and a 100% polyester cotton t-shirt and has provided information on how to achieve a more efficient and sustainable production of cotton t-shirts. The analysis has focused on three stages: production, consumption and disposal.

Production stage

A cotton t-shirt's footprint is lower than a polyester t-shirt's footprint in all the categories analysed: climate change (23% less), ozone layer depletion (48% less), mineral resources depletion (32% less) and fossil fuels depletion (22% less) (Figure 44). Future research should aim at expanding the comparison to other important environmental categories such as soil and water acidification, eutrophication, water resources depletion, salination, soil life support functions or human and ecological toxicity.

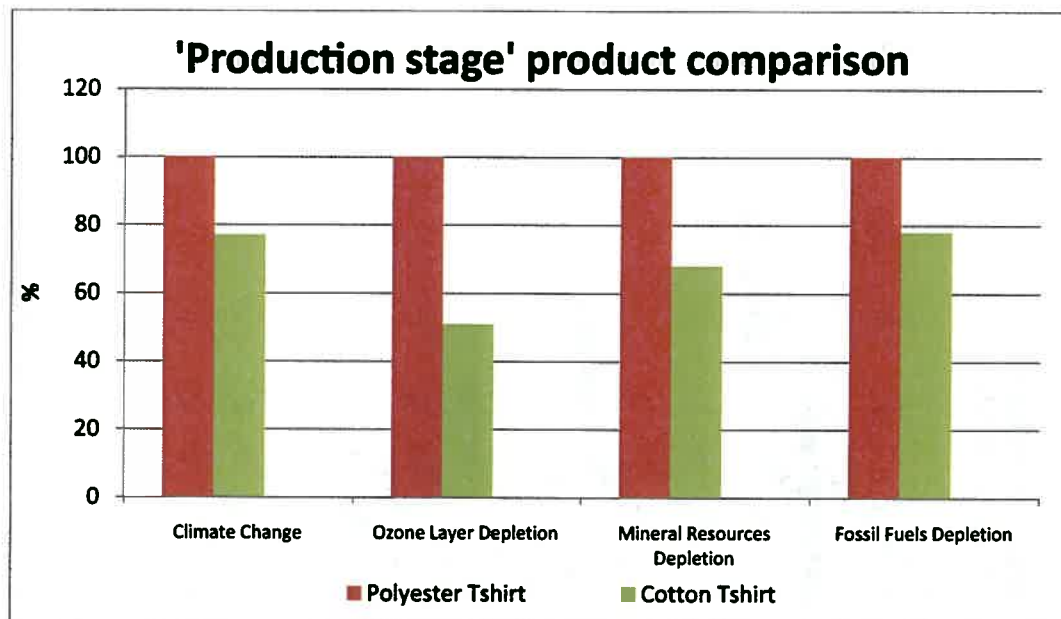


Figure 44. Cradle-to-gate comparison

The estimated GHG emissions for each product are:

- cotton: 26 kg CO₂e/kg textile
- polyester: 31 kg CO₂e/kg textile.

This means that the production of 1000 polyester t-shirts would emit approximately 1.25 tonnes of CO₂e more than the production of 1000 cotton t-shirts.

Polyester is a xylene-based material. As with any petrochemical, xylene is obtained directly from crude oil. This is its main disadvantage, because the extraction and transport of crude oil are processes that consume very high amounts of energy, and they also contribute very significantly to the depletion of the world's mineral and fossil fuel resources and the depletion of the ozone layer. The dependence of polyester production on the use of crude oil as a raw material is the single highest contributor to its environmental footprint.

The cotton industry can further reduce its carbon footprint in a number of ways. The most effective measures to reduce the carbon footprint on a cotton farm are (Figure 25):

1. Use fertilisers and pesticides that use less fossil fuel during their production or use natural fertilisers such as manure. The advantage of natural fertilisers is that they do not lead to an increase in the total carbon pool, whereas the use of fossil fuels does increase that pool.
2. Use more fuel-efficient machinery or promote the use of alternative fuels when possible.
3. Reduce soil emissions by implementing reduced-tillage strategies.
4. Recover energy from agricultural and textile by-products through pyrolysis at the disposal stage (Figure 45).

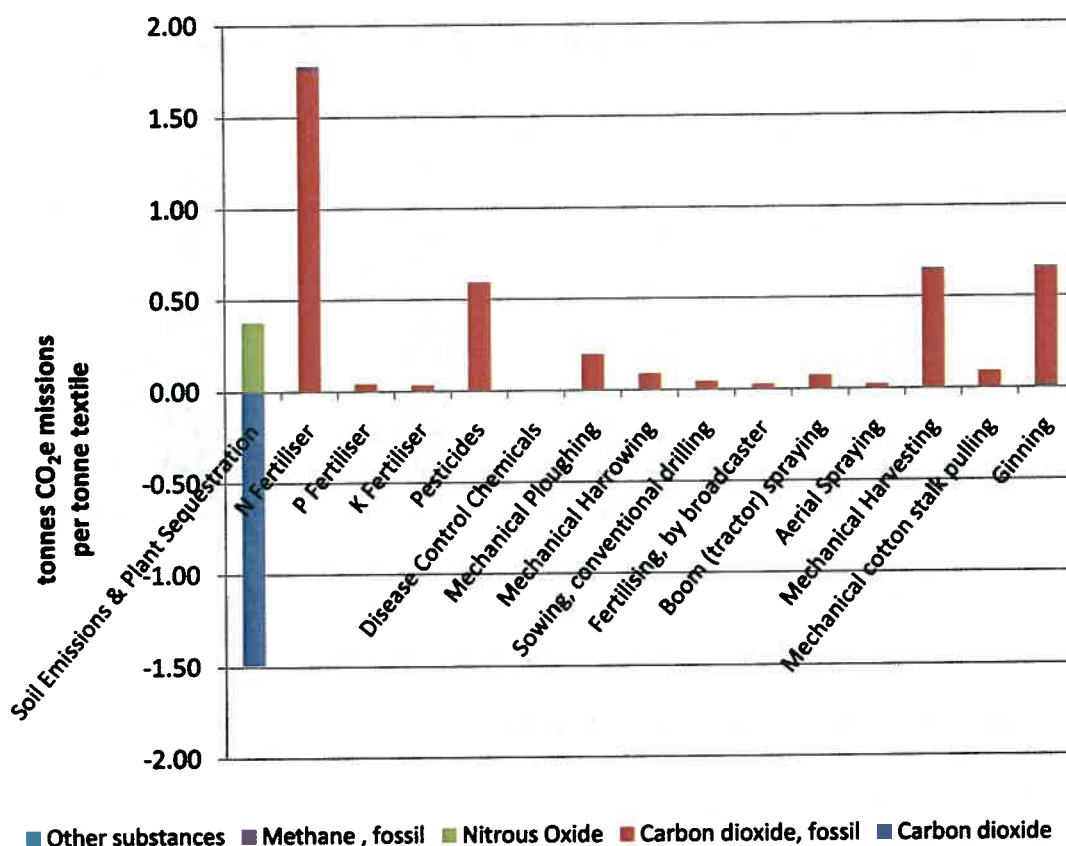


Figure 45. Footprint of raw materials used in cotton growth

Disposal stage

Several ways to recover energy from textile and agricultural by-products through pyrolysis have been analysed. Pyrolysis is a process of controlled burning of material that aims at maximising the production of useful bio-oil, synthesis gas and char while minimising the production of useless ash (unlike incineration). The by-products considered for energy recycling have been cotton plant stalks, cotton gin waste, cottonseeds and used t-shirts (Figure 46).

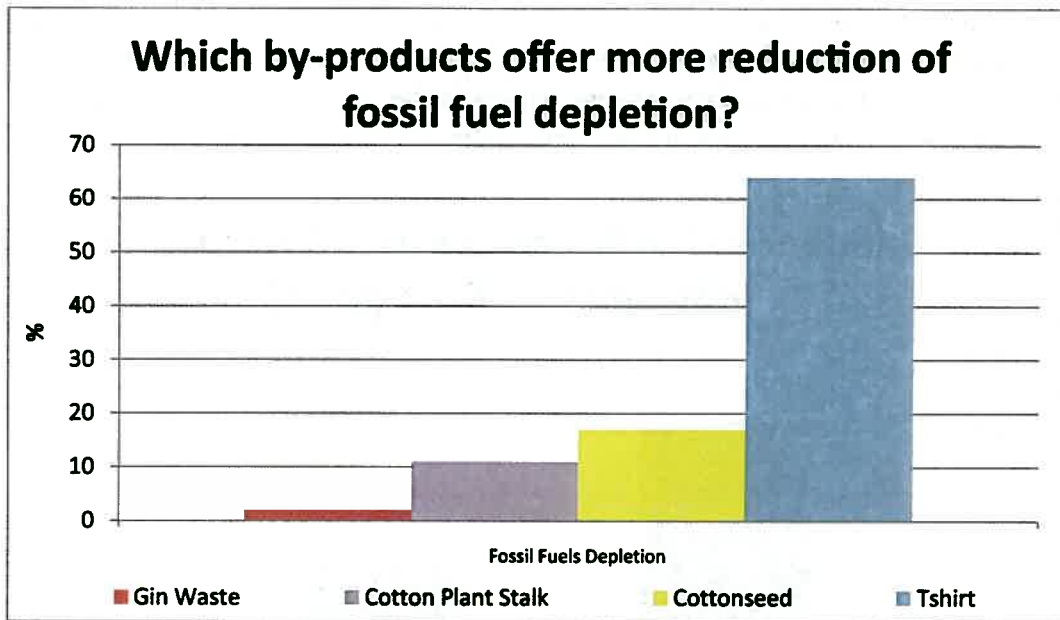


Figure 46. Comparison of the potential effect of different pyrolysis options, not considering use phase

However, these are just estimations of the potential of energy recovery options; no in-depth analysis of cotton by-product pyrolysis has been performed.

One of the single most effective options is the pyrolysis of disposed t-shirts. Textile waste pyrolysis could reduce fossil fuel depletion in cotton by about 64%. Both the cotton and polyester footprints could be reduced with this option, however there is a difference. The energy contained in a cotton t-shirt (which is liberated during pyrolysis) comes from carbon captured from the air. When CO₂ is emitted as a result of pyrolysis, the net CO₂ emissions will be zero in the case of cotton. In contrast, the energy contained in a polyester t-shirt comes from fossil fuels. Therefore, when CO₂ is liberated in pyrolysis, the amount of CO₂ circulating in the biosphere increases. This additional CO₂ would obviously contribute to global warming.

The bottom line is that the cotton industry, although found to have less impact than the polyester industry, can still significantly reduce its footprint.

Consumption stage

Previous textile LCAs have shown that the consumption (or use) phase is by far the most significant. Past assumptions on user habits and use patterns have been general, not site specific. A site-specific model of the typical Australian household laundry has therefore been built using statistics from the Australian Bureau of Statistics. Similarly, local data on electricity, fuel and chemical consumption on Australian cotton farms and OECD textile processing mills has been obtained.

An analysis of the impact of changing user habits was also included. Two different changes were analysed — reduction in washing frequency and the use of more energy-efficient laundry appliances. Energy-saving options in the use phase were more effective than disposal strategies aimed at energy recovery (described above) (Figure 47).

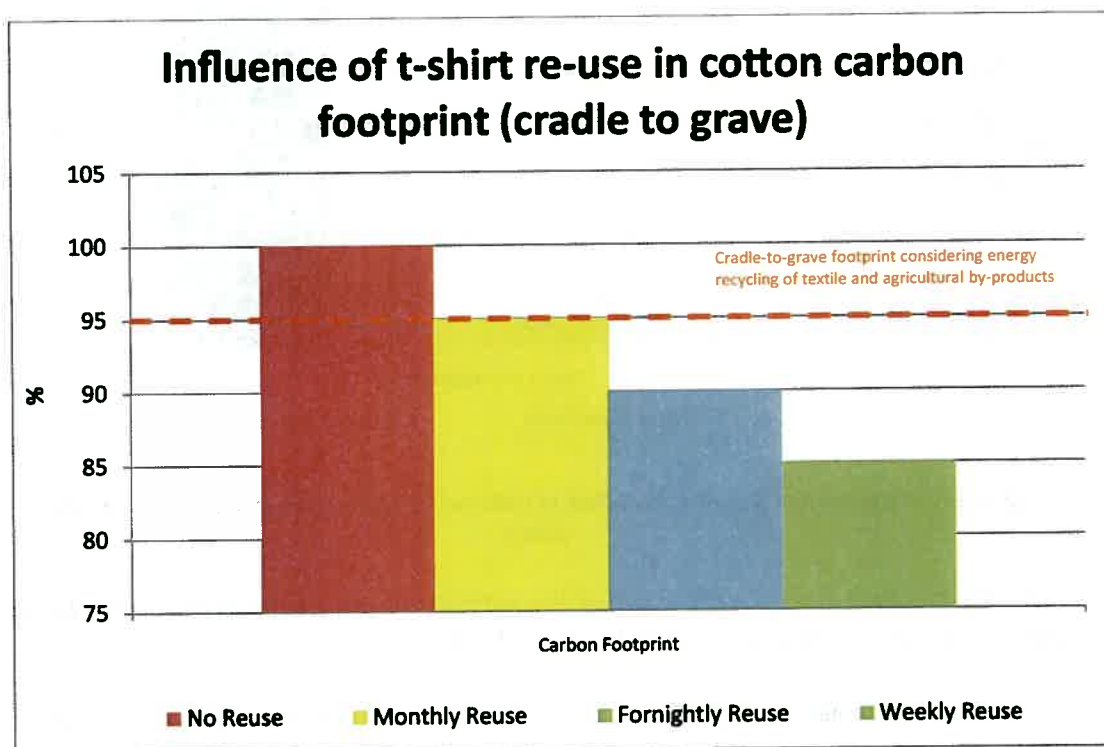


Figure 47. Reduction of cotton carbon footprint through t-shirt re-use

Comparison Summary

Table 10 summarises the environmental performance of a cotton t-shirt vs. a polyester t-shirt.⁹

Table 9. Summary of cotton and polyester comparison

Comparison	Cotton	Polyester
Cradle to gate	✓	✗
Cradle to gate + pyrolysis	✓✓	✗
Cradle to grave	= ¹⁰	=
Cradle to grave + re-use	✓✓	✗

Note: ✓ means cotton performs better
 ✓✓ means cotton performs much better
 ✗ means polyester performs worse
 = means cotton and polyester's performance is similar

Table 11 provides a summary of the GHG emissions in different life-cycle stages for cotton and polyester. Refer to Part 8 for an analysis of the results.

Table 10. GHG emission summary

Stage	Cotton (kg CO ₂ e/kg textile)	Polyester (kg CO ₂ e/kg textile)
Fibre production	3.2	8.9
Textile manufacturing	22.6	22.6
Use and disposal	370.1	370.1

Uncertainty analysis

An uncertainty analysis was undertaken using Monte-Carlo simulation to test the reliability of the product comparison. All the information used to produce the LCA results contains a given uncertainty. Monte-Carlo analysis resolves whether the uncertainty is high enough to make the results of the comparison unreliable. It does this by repeating the product comparison tens of thousands of times; the analysis is repeated for every possible value of input data within the uncertainty margins.

The result of the Monte-Carlo simulation showed how many times cotton outperformed polyester and how many times the reverse happened. The analysis concluded that more

⁹ Cotton performs better than polyester from a cradle-to-grave perspective, but only slightly. The table regards them as equal to highlight that the advantage is stronger in other comparisons.

¹⁰ Cotton performs better than polyester from a cradle-to-grave perspective, but only slightly. Table 3 treats them as equal to highlight that the advantage is stronger in other comparisons.

than 95% of the time cotton had a lower footprint than polyester, therefore confirming that the LCI results obtained are robust and reliable.

Recommendations

Several policies could assist consumers and improve their knowledge with respect to usage. An eco-label could be attached to every cotton t-shirt explaining what the footprint of t-shirt use and maintenance is and suggest ideas on how to reduce it. Eco-labels are gaining popularity and acceptance since the introduction of the European Eco-labelling Scheme. Information on treatments for garment 'freshening' could also be developed. A possible 'freshening' process would have to treat the garments so that they recover the hygienic properties they had prior to use. This treatment's environmental footprint would have to be much lower than that of washing.

Limitations

The currently available LCA methods are inadequate to assess Australia's most important environmental impacts, which is partly why this assessment only considers climate change, ozone depletion, minerals depletion and fossil fuel depletion. The most important indicators that require further research to be included are land use, soil life support functions, salination, human and ecological toxicity, water balance and biodiversity.

In the interpretation and use of the GHG emissions results it is essential to note that:

- The GHG emission figures are affected by the intrinsic limitations of LCA.
- This is screening LCA, not a detailed one.
- Standard LCA practice does not incorporate estimation of GHG emissions, so this exercise is unique. This means that it is not possible to compare the estimates' consistency with other similar studies.

In the future, GHG emissions accounting will be required to calculate the carbon tax payable by the cotton industry as part of the Australian Emissions Trading Scheme. By then a common methodology for GHG accounting in LCA will be needed.

Appendix A. LCIA methods for future research

The assessment of environmental impacts are determined on regional dependent parameters such as population density, sensitivity of the receiving environment, climate, soil properties, diet, sanitary conditions, proximity to sources (Thrane & Schmidt 2007; Goedkoop 2005) etc. in the area affected. The methods used to predict potential impacts therefore need to be either designed for global use or adapted to each area in which the biophysical characteristics are significantly different to those modelled. According to Goedkoop (2005) the differences between Europe and the South East Asian nations are very significant.

The Life Cycle Impact Assessment (LCIA) methods currently available have been designed for use in Europe. As most of the impact categories have a regional scope, they cannot be applied worldwide because of the lack of characterisation factors for other regions (Goedkoop 2005). Climate change, ozone depletion and resource depletion are exceptions to this and can be used in the Australian context without any adaptation. However, land use, salination, erosion, water use, biodiversity, human toxicity and eutrophication are also very relevant indicators for agricultural LCAs that either have not yet been integrated in the most popular databases and software packages or have not been adapted for use in Australia (Goedkoop 2005). An interesting addition to this report would be to incorporate those impact categories in the case study, which would require:

- finding impact assessment methods that can be used in the current region or characterisation factors for already existing impact assessment methods that were tailored for other regions
- collecting quite important amounts of site-specific data from local or national sources
- applying often complex modelling techniques to the data to obtain useful results.

Good quality site-specific data collection is problematic, and one cannot use low quality data because that affects the accuracy of the results critically. Similarly, the use of complex modelling techniques is very resource and time intensive. Moreover, ideally there are a few impact categories to integrate, therefore the volume of work is enough for a whole project by itself. To make matters worse, it would be necessary to collect twice the amount of data for a detail assessment, and for most of the mentioned indicators, even though methods have been created, there is still a lack of consensus on which method is most suitable. Therefore, even in the case that all the data collection and modelling could have been done, it would be difficult to assess the accuracy of the results.

This report suggests impact assessment methods that could be tested in the future and incorporated into common LCA tools. However, they have not been incorporated into the case study due to time and resource constraints. Appendix A summarises the findings and directs the reader to the latest LCIA methods on salination, erosion, water balance, biodiversity, and soil life support functions.

A1. Land use

Mila i Canals et al. (2007b) analysed the general requirements that a framework for land use impact assessment in LCA would need. In it, three impact pathways are identified: a) impact on biodiversity and the natural environment, b) impact on biotic production potential and c) the impact on ecological soil quality (Mila i Canals et al 2007b). The current section covers the findings on LCIA methods available for the defined impact pathways.

A1.1. Biodiversity

During the last few years several methods to evaluate the impact of land use on biodiversity have been proposed, although it is not the intention here to review them. A very recent study by Schmidt (2008a) analyses the main methods, compares them, and proposes a straightforward solution that can be applied for any land-use type and in any region in the world. The fact that this method is suitable for any region in the world and that it has considered previous research in the field is of great importance for this report. The method in Schmidt (2008a) is consistent with the consequential LCA approach.

Schmidt (2008a) has proposed a new method to develop LCIA characterisation factors for land-use impact on biodiversity, based on previous research and his own. His method focuses specifically on species diversity, through the use of easily accessible, commonly accepted data, that does not require large amounts of data manipulation (Schmidt 2008a). The method consists of calculating, for several land-use types as defined in Schmidt (2008a), the average 'species richness to area' relationship. This is done by collecting various species richness surveys for different land-use types and relevant regions, plotting the results by land use type, and calculating the regression line that establishes the average species-area relationship (Figure 48). Since species diversity is dependent on the area observed, Schmidt suggests choosing a standard area of 100m² for the calculations.

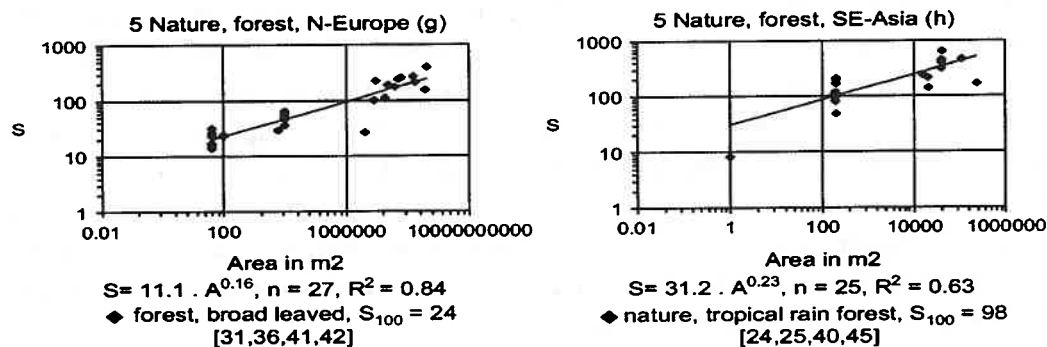


Figure 48. Example of regression line calculation, extracted from Schmidt (2008a)

The calculation of characterisation factors considers not only the region's species richness as described above, but also the calculation of the ecosystem's vulnerability, based on the proportion of high intensity land use (defined as arable land, permanent crop and built-on area, roads and barren land) and low intensity land use (defined as 'forest and other wooded land' and 'permanent pasture'), and the estimation of the affected area's renaturalisation time, based on data provided in Schmidt (2008a). The proportion of land dedicated to high and low intensity land-use types can be determined using readily available statistics, consistently with Schmidt's goal of minimising data manipulation requirements.

A1.2. Soil life-support functions (LSF)

The report by Mila Canals et al. (2007a) presents an LCIA method to assess the impact of agricultural land use on soil life-support functions. According to their research and previous studies, soil organic matter (SOM) is one of the most consistent indicators of soil quality. Their model uses SOM content as an indicator of soil's capacity to:

- maintain biotic production by enhancing:
 - physical fertility: dependent on a resilient soil structure that reduces erosion, soil compaction and soil aeration
 - chemical fertility: dependent on the preservation of the soil's chemical properties so that the nutrient pool, pH, and plant growth regulation capacity remain stable
 - biological fertility: dependent on the existence of soil biota and microbial activity
- maintain climate regulation by properly contributing to the carbon cycle and by preserving vegetation cover, which in turn not only contributes to global climate regulation through its GHG absorption but also to local climate regulation, as explained in section 1.2.2 of this report.
- Maintain substance cycles such as water balance and the carbon and nutrient cycles.

Mila i Canals et al. (2007a) propose a method to estimate the impact of land use on soil's life-support capability based on obtaining data on the SOM content at every stage of the land-use process, and comparing it to a baseline situation. Their recommendation is to choose the most likely land use, should the studied land use not be applied in the current area, as a baseline. By measuring SOM at different stages, it is possible to determine different types of impacts such as impacts on LSF due to land transformation or impacts on LSF due to land occupation (Figure 49).

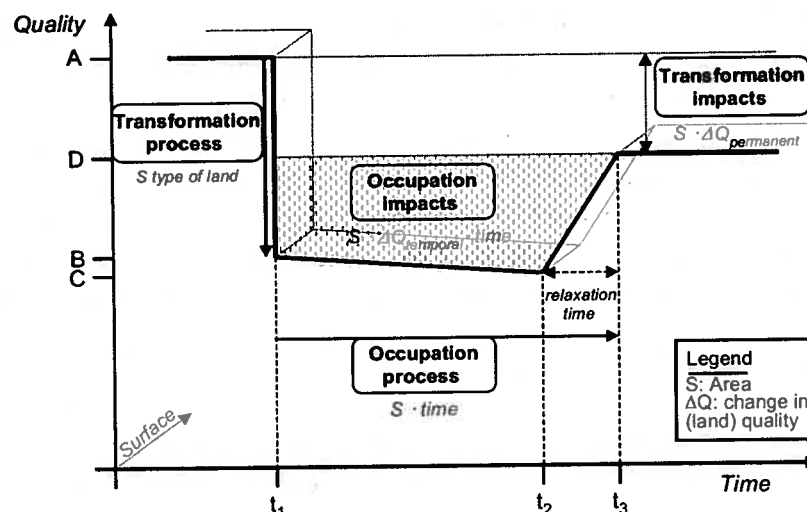


Figure 49. Aspects of land-use impacts (Mila i Canals et al. 2007a)

On the one hand, the method by Mila i Canals et al. (2007a) is interesting because it provides a way to measure the impact of production in a new and needed way, as justified in Part 1. However, it does not cover all possible issues regarding land use and would be outside the scope of their study. On the other hand, it would be interesting to find a link between their LSF indicator and the land-use impact on the land functions listed above. It could be argued that, should their method provide a direct estimation of a product's impact on biotic production, climate regulation and maintenance of substance cycles, the potential of the method to assist decision making would be greater.

A1.3. Salination

Feitz and Lundie (2002), proposed a preliminary soil salination impact model that can be used as an indicator for land degradation due to poor irrigation practices. Even though Mila i Canals et al. (2007b) do not specifically mention salination as an issue, they do mention the problem of erosion for biotic production. The method found in Feitz and Lundie (2002) is relevant to Australian LCAs in which agriculture plays a significant role because a direct link between salination and erosion can be established using studies similar to Ghadiri et al. (2007).

Their method consists in calculating the Sodium Adsorption Ratio (SAR) and Electrical Conductivity (EC) of a irrigation water from data on the concentration of sodium, calcium, and magnesium. The EC is then compared to the holding soil's threshold electrolyte concentration to determine the site-specific salinity, and thus the potential impact of the irrigation water on soil's structural integrity — the higher the site-specific salinity, the worse the potential impact (Feitz & Lundie 2002). Finally, the authors describe how to determine the Salination Potential (SP) by considering all site-specific factors, the total irrigation volume and the total sodium concentration. They provide a calculation and a brief case study as examples (Feitz & Lundie, 2002)

An alternative path to analyse erosion potential would be the use of the 'HowLeaky?' tool recommended by the Queensland Government Natural Resources and Water Department (now Department of Environmental Resources and Management - DERM) in order to evaluate the impact of land use on water balance and quality considering issues like erosion and sedimentation. The HowLeaky? software package provides an alternative to other more complex models and it has been integrated in another DERM application for catchment planning that will be mentioned in the next section.

A2. Regional water balance

In their paper, Heuvelmans et al. (2005) describe a method to assess regional water balance based on the calculation of three indicators: dynamic water reserve life, average downstream water availability/drought risk, and flood risk. Dynamic water reserve life estimates the number of years the water use associated with a product's life cycle can go on until exhausting the reserve. To make this indicator more comprehensive it would be useful to express this indicator as a percentage of the average water used by, in this case, Australians. This indicator uses statistics of total freshwater reserves, water use and precipitation to provide the estimate (Heuvelmans et al. 2005).

The calculation of average downstream water availability, and of drought and flood risk, requires the use of a hydrological model such as SWAT (Soil and Water Assessment Tool). SWAT assists in the creation of a land-use scenario using data on climate, topography, soil properties and land-use characteristics. It also provides analysis tools to determine the properties of stream flow, which have to be determined for the product's relevant land use and for the reference case of the potential natural vegetation present under low intensity land use (Heuvelmans et al. 2005). Once stream flow properties have been identified, a statistical analysis is necessary to determine the probability profile of stream flow changing from low to high value, and that is the raw input for the suggested indicators (Figure 50).

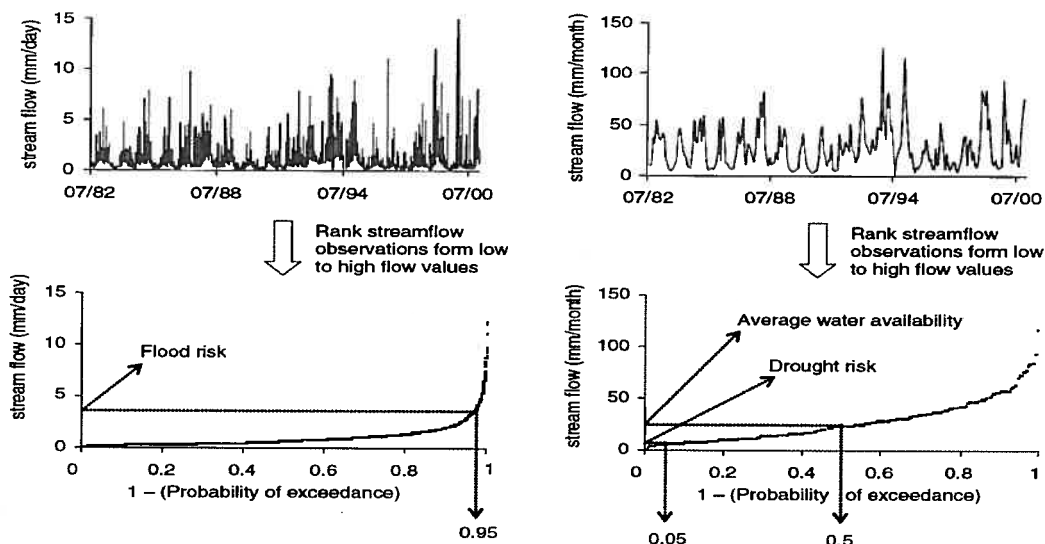


Figure 50. Example of calculation of water balance indicators (Heuvelmans et al. 2005)

Additionally, Heuvelmans et al. (2005) propose three indicators to assess the impact of land use on how excess water runs off: Change in precipitation surplus (precipitation minus evapotranspiration, assessing changes in control of water flow), change in surface runoff (infiltration minus evapotranspiration, assessing capacity to mitigate floods), and change in infiltration minus vegetation water withdrawal (assessing capacity to mitigate droughts). However, these last indicators are poorly explained in Heuvelmans et al. (2005), and it is argued that the paper could benefit from providing more guidance on how to follow the proposed method; for example, exactly what information SWAT requires as an input, suggestions on where it could be obtained or which assumptions could be made in case of poor data availability.

As noted in the salination section above, DERM recommends the use of HowLeaky? to analyse the impact of land use on water quality and water balance. Similarly, DERM also recommends the Risk Assessment, Prioritisation and Understanding Process (RAPUP) software as a simple alternative to SWAT to assess the impacts of different land uses and land management practices over issues like water balance, water quality and erosion. A potential disadvantage of RAPUP compared to HowLeaky? is that the latter is available online, whereas the availability of RAPUP has not been explored. Nevertheless, both seem interesting options that should be explored in future research.

Appendix B. Textile manufacturing data

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POWER CONSUMPTION AND WASTE GENERATION IN COTTON PROCESSING

This survey assumes long-run processing of average count all purpose yarn and fabric from clean export-grade Australian or US cotton by commonly-used modern textile processing machinery to the point of final fabric ready for garment manufacture. Cotton production and processing occur in same country (no material import/export costs).

Note costs are higher for lighter weight yarn and fabric and lower for heavier weight products.

Processes such as combing, mercerizing, bleaching, jacquard weaving, garment knitting and the application of fabric finishes/coatings, e.g. stain resist or flame retardant treatments, are not considered but add to power cost and waste production. Power costs such as lighting, office and laboratory power are also not considered, nor is internal transport i.e. trucks, forklifts etc, within the factory or city location.

It is noted the process power and waste costs (except for ginning) are equally applicable to polyester and other man-made fibres.

Consumption and waste are analyzed on a process basis; ginning, yarn formation, fabric formation (knitting or weaving), dyeing and fabric finishing. Transport (by road) of raw material to each process is calculated. Return (empty) loads are not considered.

The accumulative power after each process is calculated and the value appears in the last row of each power 'Table' presented through the report.

GINNING

Modules of (harvested) seed-cotton are delivered to gin operation.

One module = 15 tonnes and is transported an average of 50 km. Transport time is one hour including unloading. Power (of truck) is 400 kW and energy consumption per kg for transport to gin is 0.07 kWh/kg (of lint).

Assume modern Australian or US gin operation of four stands using module feeder with mechanical and pneumatic material transport, pre-cleaning, drying and (semi-)automated packaging.

According to US gin industry surveys¹¹ average power consumption is between 40 and 60 kWh/bale (227 kg) or between 0.18 kWh/kg and 0.26 kWh/kg of lint. The surveys note the same gin will operate at the outer limits of these power consumption levels through the ginning season depending on cotton variety, cotton grade, moisture levels, module density and module quality.

Water applied during ginning in regions where winter is dry, e.g. Australia. Rate of application can be as much as 2.5% on weight of lint baled.

It is noted that whilst modern gin production has increased this is a result of increased power input rather than efficiency gains in the gin system.

GIN POWER AND WATER CONSUMPTION

Cotton lint	kWH/bale	kWH/kg	Water l/kg
Transport		0.07	
AUS SM ¹²	40	0.18	0.03
"	60	0.26	
CUM. kWH		0.33	0.03

WASTE IN GINNING

Input	Product	For end-product	
	Seed-cotton		100%
Output	Lint	spinning	38%
	Seed	stock feed/oil	54.5%
	Mote	spinning/compost	2.5%
	Trash/dust	compost	5% ¹³
		waste total	(5%)

YARN PRODUCTION

Ginned bales are delivered to mill.

One semi-load (400 kW engine) brings 110 bales or 24,970 kg of lint (no tare) 1500 km from local cotton production area to mill. Delivery time is 18 hours including unloading and total energy consumption is 7200 kWh or 0.29 kWh/kg.

PRODUCTION CONSIDERATIONS

Assume medium sized, modern spinning mill producing carded singles cotton yarn, i.e. Ne 20 (30 tex)¹⁴ with average twist that operates 7 days per week 24 hrs per day. Consider

¹¹ See USDA Ginners Handbook No. 503, Anthony, W. S. and Mayfield, W. D. (eds.), Dec 1994 or gin survey reports published in proceedings of Beltwide Cotton Conferences

¹² SM = Strict Middling USDA Classers Grade 21 with little trash

¹³ Nominally not waste as trash is composted on gin site and then sold or returned to field.

balanced, i.e. throughput = input = output, reasonably efficient Murata Vortex (MVS), open-end (OE) or ring spinning mill using opening, carding, drawing, (roving), spinning, (winding) processes to yarn. Processes in brackets apply to ring spinning only. Assume machine efficiencies of ~80% (or as stated in Tables) including maintenance and machine changeovers. These efficiencies do not represent best production efficiency for single mill, which requires spinning efficiencies > 90% to be profitable.

Note no combing, assembly winding or twisting/folding. Combing is applicable to MVS and ring spun yarn only and adds between 5 and 7% extra kWh to power usage. No yarn dyeing or mercerizing is undertaken.

Mill operates in temperate climate and is air-conditioned/heated (AIR) to maximize quality and production.

OPERATING PROCESSES: OPENING & CARDING

	OPENING	CARDING
SET OUTPUT (kg/h/frame)	400	70
WEIGHT (ktex)		5
EFFICIENCY (%)	80	80
OUTPUT @ eff. (kg/h/frame)	320	56
REQUIRED frames	4	23
TOTAL OUTPUT (kg/h)	1280	1280

OPERATING PROCESSES: DRAWING

	DRAWING		
	1 st DRAW	2 nd DRAW	3 rd DRAW
SET OUTPUT (kg/h/frame)	243	205	134
SPEED (m/min)	900	900	700
Weight (ktex)	4.5	3.8	3.2
EFFICIENCY (%)	80	80	80
OUTPUT @ eff. (kg/h/frame)	194	164	108
REQUIRED frames	7	8	12
TOTAL OUTPUT (kg/h)	1280	1280	1280

OPERATING PROCESSES: SPINNING

	ROVING	MVS	OE	RING	WIND
SPEED (m/min)	55	380	172	20	500
SPEED (rpm)	1200	-	120K	14K	-
WEIGHT (tex)	800	30	30	30	30
EFFICIENCY (%)	80	80	85	80	85
OUTPUT (g/h/spindle)	2640	684	263	36	900
SPINDLES/frame	108	72	240	960	60

¹⁴ Ne 20 is close to world average yarn count; 80% of all yarn is produced in the Ne 5 – Ne 30 count range with the majority between Ne 18 and Ne 30 – ITS Newsletter website <http://www.its-newsletter.com>

OUTPUT @ eff. (kg/h/frame)	228.1	39.4	63.2	27.6	45.9
REQUIRED FRAMES	6	32	21	46	28
TOTAL OUTPUT (kg/h)	1280	1280	1280	1280	1280

POWER USAGE OF VARIOUS MILL TYPES

POWER USAGE OF VARIOUS MILL TYPES

			MVS	OE	RING			
			MOTOR = kW/frame x EFF. x No. frames AIR = MOTOR kWh x 0.4					
	kW/frame	EFFICIENCY	MOTOR	AIR	MOTOR	AIR	MOTOR	AIR
OPENING	65	80	208	104	208	104	208	104
CARDING	8	80	147	74	147	74	147	74
DRAWING	10.4	80	175	87	125	62	125	62
ROVING	27.9	80	-	-	-	-	134	67
RING	52.9	80	-	-	-	-	1947	973
WINDING	15	85	-	-	-	-	357	168
MVS	30	80	768	384	-	-	-	-
OE	90	85	-	-	1606	803	-	-
COMPRESS AIR	29.6	90	750	-	-	-	-	-
TOTAL kWh			2048	649	2086	1043	2918	1448
GRAND TOTAL			2697		3129		4366	

POWER USAGE PER KG YARN

Process	kWh/1280 kg	kWh/kg	% of world yarn production ¹⁵
Transport bale to mill		0.29	
MVS	2697	2.11	<10
OE	3129	2.44	>30
RING	4366	3.41	60
Total spin kWh		3.41	
CUM. kWh		3.70	

WASTE IN YARN FORMATION

Input	Lint	yarn	100%
process			waste
Output	Opening	clean fibre	3%
	Carding	card sliver	5%
	Drawing	drawn sliver	1%
	Spinning	yarn	1%
		waste total	10%

¹⁵ Based on no. of spinning positions of that spinning technology installed world-wide

FABRIC PRODUCTION

Griege cotton yarn is delivered to knitting/weaving mill.

One semi-load (400 kW engine) brings one 40 ft container with 12,000 kg of yarn (3,800 kg container tare) 1,500 km from spinning mill to knitting/weaving mill. Delivery time is 18 hours including unloading and total energy consumption for one load is 7200 kWh or 0.45 kWh/kg (inc. tare).

KNITTING

A modern knitting mill of 200 circular knitting machines converts Ne 20 yarn into 150 g/m² single jersey fabric for leisure and underwear. Need 1280 kg/h to achieve daily mill production. Each circular knitting machine produces 6.4 kg/h of fabric at an efficiency of 85%; or 154 kg/day/machine. This production rate represents current near-best circular knit conversion.

Circular knit machines produce bulk of world's knit fabric.

Air-conditioning of mill is required.

POWER USAGE OF KNITTING MILL

Process	kW/frame	No. frames	kWH total	kWH/kg
Transport bale to mill				0.45
Knitting	8	200	1360	1.06
AIR = MOTOR kWh x 0.4	3.2		544	0.43
Total knit kWh				1.94
CUM. kWh to knit				5.64

WASTE IN KNITTING

Input	Yarn	End-product	
		knit fabric	100%
	process		waste
Output	Knitting	knit fabric	1% ¹⁶
		waste total	1%
		Cum. waste	11%

WEAVING

A modern weaving mill of 210 rapier weaving frames (looms) Ne 20 yarn into 180 g/m² plain weave shirting fabric for casual wear. Need 1280 kg/h to achieve daily mill production.

Yarn is sized before weaving. Sizing range processes 10 warping beams per batch at 170 m/min. One warping beam holds 600 x 3.0 kg (100 km/package) of Ne 20 yarn = 1,800 kg of yarn; therefore range sizes 18,000 kg of yarn in cycle time of 10 hours or 1,800 kg/h. One

¹⁶ waste generated from poor fabric quality as a result of needle breaks and staining of fabric

sizing range uses 100 kW of electrical power and 1000 kW of gas heat; therefore power consumption is 0.61 kWh/kg. Water use in size application is 20,000 l per 18,000 kg batch or 1.2 l/kg.

Each loom receives a sized weaving beam from warping machine and produces 34 m²/h or 6.12 kg/h of fabric at an efficiency of 85%; or 147 kg/day/loom. This production rate represents near best conversion for rapier (shuttle) looms, which comprise 60+% of world looms.

Air-jet looms (shuttle-less) are faster by a factor of up to 1.8 but are confined to basic weaves.

POWER USAGE OF WEAVING MILL

Process	kW/frame	No. frames	kWH total	kWH/kg	Water l/kg
Transport bale to mill				0.45	
Warping	5	26	130	0.10	
Sizing ¹⁷	100	4	400	0.61	1.2
Weaving	12.5	210	2625	2.05	
AIR = MOTOR KWH x 7			1102	0.86	
Total weave kWH			4257	4.07	
CUM. kWH to weave				7.77	1.23

WASTE IN WEAVING

Input	Yarn	End-product woven fabric	100%
	process		waste
Output	warping	warp beam	0.5% ¹⁸
	sizing	sized beam	0.5% ⁸
	weaving	fabric	1% ⁸
		waste total	2%
		Cum. waste	12%

DYEING AND FINISHING

Assume dyeing and finishing is integrated with knitting/weaving mill.

DYEING

Dyeing is preceded by scouring in same dye machine but fabric is not bleached (requires additional water & power). Dyeing is undertaken using an exhaust dye approach using for example jet or air-flow dye machines in a liquor ratio of 5:1, which is current best practice.

¹⁷ No air-conditioning required in sizing area; sizing undertaken in batches

¹⁸ Assume long run processing – for short run processing percentages would be much higher

Productive dye machines have capacity of 1000 kg of fabric and require 75 kW of power to pump and cycle fabric and 150¹⁹ kW to heat dye liquor.

Scour and rinse cycle is 1.5 hours. Dye and rinse cycle is 5 hours; therefore power consumption is 0.49 kWh/kg.

The dye cycle for 1000 kg of fabric uses 5 x 1000 l of water (at the 5:1 liquor ratio) x 8 rinse/wash cycles = 40,000 l of water. Scouring adds 2 x 5000 l of water; therefore water consumption is 50 l/kg

No air conditioning or heating applied in dyeing area.

(Cold) pad-batch dyeing is better in terms of energy and water consumption; up to one 1/10th of the volume required for exhaust dyeing, although is limited to particular classes of dye-stuffs and shade depths, and lacks flexibility re: adjustment of shade.

No power consumption for calendaring (squeezing excess water) from fabric or, in case of knitted fabric, splitting of knit tube is assumed.

POWER USAGE IN (FABRIC) DYEING

Process	kW/frame	No. hours	kWH total	kWH/kg	Water l/kg
Scouring	225	1.5	338	0.34	10
Dyeing	225	5	1125	1.13	40
Total dye kWH				1.47	50
CUM. kWH knit				7.11	50.03
CUM. kWH weave				9.24	50.63

WASTE IN DYEING

		End-product	
Input	Fabric	dyed fabric	100%
	process		waste
Output	dyeing	dyed fabric	0.5% ²⁰
		waste total	0.5%
		Cum. waste	11.5%
		Cum. waste	12.5%

FINISHING

Dyeing is followed by stentering where fabric (knitted or woven) is dried and stretch relaxed into shape. The stenter assumed is a recent model with throughput of 50 m/min and using 100 kW of electrical power to convey material and circulate hot-air through a 5 chamber system plus 1000 kW of gas to heat air. Gas burn is reduced with re-circulating heat facility common in modern stenter.

¹⁹ Energy source for hot water dependent on factory set-up – energy usage highly variable between factories

²⁰ assumes long run without dye recipe change – waste rates can be much higher for shorter runs

Production rate in kg per hour is $50 \text{ m/min} \times 60 \text{ min} \times 1.6 \text{ m (width)} = 4800 \text{ m}^2/\text{h} \times 150\text{g/m}^2$ (knit fabric) = 720 kg/h; or $4800 \text{ m}^2/\text{h} \times 180 \text{ g/m}^2$ (woven fabric) = 864 kg/h. Power consumption is therefore 1.52 kWh/kg for knit fabric or 1.27 kWh/kg for woven fabric.

POWER USAGE IN FABRIC FINISHING

Process	kW/frame	No. hours	kWH total	kWH/kg	Water l/kg
Stenter (knit)	100	1	100	1.52	
Stenter (weave)	100	1	100	1.27	
CUM. kWH knit				8.63	50.03
CUM. kWH weave				10.51	50.63

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