Location-specific global product LCI: a textile case study

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ABSTRACT

This work describes the challenges of applying Life-Cycle Analysis to a global production-consumption chain for textiles, accounting for specificities of the production of cotton in India and polyester in China, with consumption in Germany. Such location-specific LCA is promising for understanding the environmental costs and benefits of globalized production-consumption chains. Since LCI data is missing for most emerging countries, location-specific LCA requires the adaptation of available local studies and existing process LCA from the OECD. Parts of the textile industry can be considered as standard factory processes because many of the machines and chemicals are identical in the OECD, India and China. In this case, the major divergences in environmental impacts come from the surrounding infrastructure (the electricity, fuel, feedstock and transportation sectors) and pollution abatement (water treatment, exhaust filtration, waste disposal). Existing studies, however, usually report only aggregate primary energy data, in such a way that "relocating" the process for comparison is difficult, if not impossible. Moreover, standard software tools like Simapro allow great flexibility at the assembly stage, but not in production infrastructure (eg. electric supply). This work describes the preliminary results from the globalized textile case study and argues for some adaptation in standard LCA reporting and software.

1. Introduction to project

The purpose of this research is the Life-Cycle Inventory (LCI) of global textile production-consumption focusing on two representative strands: cotton produced in India as a natural fiber and polyester made in China as a synthetic fiber, both consumed in an OECD country (Germany). Trade is increasingly global, with China and India emerging as significant economic forces, both producers of commodities and consumers of basic resources. The environmental impacts of this economic globalization are a matter of international concern. The extension of LCA approaches to emerging/developing countries raises significant challenges for both establishing inventories and estimating impacts. In particular, the inventory should specify the location of emissions in order to be able to model the fate and impact correctly. This is a departure from traditional LCIs, which tend to report aggregate emissions according to the process stage only.

2. Life-cycle inventories in emerging/developing countries: the data challenge

In industrialized countries, significant efforts have been made to compile and update inventories for product and process life-cycle analysis (EcoInvent (Switzerland), US Input-Output, Gemis or GaBi (Germany), etc). This work remains to be done for emerging/developing countries (see the UNEP-SETAC Life Cycle Initiative). However, the existing life-cycle work and methodological background in industrialized countries has the potential to be transposed to emerging/developing country contexts.

Data availability is a basic problem for establishing LCIs in developing countries. The origin for methodology and inventories in OECD countries comes from national environmental and statistical agencies. Since many emerging and developing countries lack effective environmental regulation and monitoring, the very foundation of LCI work is unavailable.

In this research, we use a combination of approaches to create life-cycle inventories for agricultural and industrial processes in India and China. We used data following a preference hierarchy of three broad categories. The first category consists of detailed *local* data (from publicly available sources, either LCA or other approaches). This is the case for most of the Indian and European data, and included agriculture energy studies [1,2], regional flow analysis [3,4], an industry energy study [5], governmental statistics [6-9], emissions studies [10-12], industry recommendations [13], LCAs [14], consumer advice [15-17].

The second category uses detailed *process* data, adapted to regionally-appropriate energy infrastructure. This is

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the case for the Chinese part of the study, where we used existing Indian data if no Chinese data was available, and existing European or USA studies [18,19], if neither Chinese nor Indian were possible.

The last category is an existing LCA database (EcoInvent [20]) when no detailed process data was found. This is the case for infrastructure components (buildings and machines) as well as some basic chemicals. For some processes, we used EcoInvent processes as a backbone, only substituting the electric origin and some known differences for inputs and emissions.

3. System description, functional unit, boundaries

The scope of the study encompasses the production, use and disposal of cotton garments manufactured in India and polyester garments manufactured in China. Cotton and polyester are the global textile industry's principal natural and synthetic fibers. The use phase is located in Germany. The specific garments are a colored cotton T-shirt and a colored polyester jacket. These correspond to two separate product and two separate functions which cannot be directly compared. However, the differences in their production and uses are illustrative of the importance and variability of the use phase in this product system.

The functional unit is taken to be <u>100 days of one garment being worn</u>. This corresponds to wearing a garment 2 days a week during half a year for 2 years and is understood to be a reasonable lifetime for a garment. Garment lifetimes are controlled not only by the durability and use of the product, but by fashion or appearance imperatives. No fabric recycling is considered.

The system boundaries include chemicals, packaging, water and commercial energy used at each principal phase (fiber production, spinning, knitting, dyeing, apparel manufacture, washing, drying), transportation between phases and infrastructure (machines and buildings) and resulting emissions to nature beyond the field or factory boundaries. The retail phase is not included, but is understood not to contribute significantly. A detailed description of textile manufacturing can be found in [21].

The use phase of a cotton T-shirt and polyester jacket differ considerably: the cotton T-shirt is washed much more often (every two wearings or 50 times, in this study), whereas the polyester jacket is only washed 2 or 3 times a season (6 times total in this study). Dryers are used roughly 75% as often as washers [22].

4. Summary of results: atmospheric emissions

This work was focused on a few major atmospheric emissions: CO_2, SO_2, NO_x and particulates. These tend to track with commercial energy use such as electricity and transportation. The results are shown for CO_2 and SO_2 in Table 1 for a cotton T-shirt (A,B,C,D) and a polyester jacket (E).

Table 1: CO_2 and SO_2 emissions from the production and consumption of a cotton T-shirt and a polyester jacket worn for 100 days.

Scenario *Functional Unit: 100 days of a garment being worn.*	**A: Cotton, warm washing, machine drying, inefficient**	**B: Cotton, cool washing, air drying, inefficient**	**C: Cotton, warm washing, air drying, efficient**	**D: Cotton, cool washing, machine drying, efficient**	**E: Polyester, warm-washing, machine drying, inefficient**
Material	**Cotton**	**Cotton**	**Cotton**	**Cotton**	**Polyester**
Function	T-shirt	T-shirt	T-shirt	T-shirt	Jacket
Weight (kg)	0.25	0.25	0.25	0.25	0.5
Appliance rating	C	C	A	A	C
Number of washings	50	50	50	50	6
Temperature of washing (degrees Celsius)	60	40	60	40	60
Number of machine dryings	37.5	--	--	37.5	4.5
Total Fossil CO_2 emissions (kg)	12.9	6.7	7.3	9.9	10.1
Fraction **producing** country (India or China)	37%	**70%**	**65%**	48%	**79%**
Fraction **consuming** country (Germany)	**63%**	29%	34%	**52%**	19%
Fraction Rest of World	0%	1%	1%	1%	1%
Total SO_2 emissions (g)	31.4	25.3	25.9	28.2	45.8
Fraction **producing** country (India or China)	**72%**	**89%**	**87%**	**80%**	**93%**
Fraction **consuming** country (Germany)	27%	9%	11%	18%	4%
Fraction Rest of World	1%	2%	1%	1%	3%

The CO_2 emissions track the electric consumption along the textile chains, since Germany, India and China all have coal-dominated power sectors. Despite the fact that the functional units of a cotton T-shirt and a polyester jacket are different, the contrast between the emission fractions of the production and consumption phases is noteworthy and striking. The CO2 emissions for a cotton T-shirt and polyester jacket washed and dried with C rated appliances (A and E)[16,17] show opposite behavior in the geographic distribution of emissions: the frequent washing and drying in the consuming country of a cotton T-shirt is responsible for over 60% of the total lifetime emissions, whereas since the polyester jacket is washed more seldom, the consuming country emissions account for less than 20% of the total. By examining scenarios B, C and D, we conclude the most important factors in reducing use phase emissions are (1) air-drying vs. machine drying, (2) the temperature of washing and finally the appliance rating. By switching to air-drying and reducing the washing temperature from 60 to 40 degrees, the total CO2 emissions are almost halved. This highlights the importance of developing laundry detergents which are effective at lower temperatures. Another consideration is the necessity of frequent washings. If a garment requires less washing (for example through resistance to stains or sweat), the use phase impact will be correspondingly lowered.

The SO2 emissions exhibit very different behavior, reflecting not only the coal-based source of the country's power sector, but the existence of emissions-control technology. The lack of effective emissions abatement in China and India causes the production phase to be responsible for over 70% of the sulfur dioxide emissions for both cotton and polyester garments.

The relative fractions of the production and use phase emissions is reflects the choice of the functional unit (see section (3)). If a garment is kept longer, the relative importance of the use phase will also increase. The environmental impact *per day* of a garment being worn will decrease, however, since the environmental impact of the initial production phase will be distributed over a longer use phase.

Overall, in terms of the main atmospheric emissions, the origin of the electricity is the most crucial factor. The key issues are the fuel source (coal being particularly problematic), filtration technology for SO2 and NOx, the efficiency of production and the transmission and distribution (electric grid) losses. In terms of life-cycle management of a globalized production-consumption chain, understanding the local electric sector's impact is of the highest importance. Despite the global nature of the production-consumption chains, transportation is much less significant (accounting for at most 6% of CO2 emissions, mostly domestic in India, and 3% of SO2 emissions).

5. Linking inventory and impacts in emerging/developing countries

Severe water pollution is a known potential consequence of the production and use of textile products: at the production stage, dye-laden effluents require treatment (lacking in India and in China), at the consumption stage, eutrophication results from discharge of laundry detergent.

The textile industry uses many specialty chemicals. Pesticides are massively used in cotton cultivation and reactive dyes are used for dyeing. The exact quantities and formulations are not publicly available, but the resulting severe health damage is documented [23-25] [26-28]. Previous LCA work has attempted to understand the production phase of such specialty chemicals [29,30] and their fate in a river system [31], but unfortunately does not address the topic of fate and impact when these chemicals are massively discharged into the environment. So far the most comprehensive effort at modeling pesticide impacts through a product LCA was done on bananas in Costa Rica [32]. This work relies on detailed data, in the absence of which a life-cycle approach cannot be expected to produce reliable health and ecosystem results. One must be cautious not to draw conclusions from lack of data and impact factors.

In India and China, workplace safety is much lower than in Europe or the USA. Worker exposure to dangerous chemicals and emissions is thus much more prevalent. Another health effect within the cotton workplace is byssinosis [33,34], a respiratory disease due to exposure to cotton fibers. An LCA assessing damage beyond the factory walls or outside the crop field will thus miss significant human health impacts. In these cases, health studies of affected populations are necessary to complement the LCA findings.

Salt is used in the reactive dyeing of cotton textile. Despite some efforts at salt recovery, large quantities are discharged in the wastewater. This has led to the salinization of local drinking and agricultural water [35] with health and ecosystem impacts. However, salinization is not a traditional impact category of LCA, despite being a severe problem in many emerging/developing countries. The volume of water used for textile is an environmental concern of its own. One of the largest scale environmental disasters, the drying up of Aral Sea, is a direct result of cotton irrigation in Central Asia. However, for such an impact to be brought to light by an LCA, the water usage of a process must be related to the local geographical conditions.

6. Recommendations for LCI reporting

Applying life-cycle approaches to global production-chains is very promising. In order to apply the existing databases and studies to emerging/developing country contexts, some modifications to standard reporting and database manipulation are necessary.

In the case of similar manufacturing processes, a LCI done in one country can be used for another where the data may be lacking. However, this is only the case of the data is reported in a way that permits transposition. In particular, instead of reporting only primary energy use, it is necessary to include intermediate commercial energy forms, such as electricity, heat and transportation.

In terms of process modeling, existing software allows flexibility at the assembly stage, but not at the underlying infrastructure stage. For the purposes of allowing the transfer of existing LCA inventories to emerging/ developing countries, new software developments should allow the rapid change of electricity mixes and transportation emissions.

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