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Use phase of wool apparel: a literature review for improving LCA

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Abstract
This paper presents results from a literature review on use phase of clothing with focus on wool. The aim of the review is to study if there is empirical grounding for assuming that the use phase is different for clothes made of different fibres, and if this information could be used in modelling the use phase. We will answer this question based on studies on wool, and see if use of woollen garments gives different environmental impact than use of garments made of other fibres.
The results show significant differences in how garments of different materials are maintained and used. Woollen garments are more likely to be either dry-cleaned or washed by hand than other textiles, and if washed in machine, the temperature is commonly about ten degrees lower than average washing temperature in Europe. Woollen garments are less likely to be dried in a clothes drier. Even the washing frequency differs, as woollen products are used about twice as many days between the washes than similar cotton products. The studies indicated that woollen garments had longer than average lifespans.
We conclude that fibre content contributes to the way consumers take care of and use their clothing, and should be taken into consideration in tools developed for comparing the sustainability of garments of various textile materials.

Introduction

Currently, several tools are in use for rating and comparing the environmental impacts of different textile fibres. These include among others Made-By benchmark (Made-By, 2013), Higg Index Material Sustainability Index Tool developed by SAC (Sustainable Apparel Coalition, 2017), and Defra's report that includes rating of textile fibres based on their environmental impact and social sustainability (Turley et al., 2010). These tools place little or no emphasis on the use phase of apparel. With this article we wish to contribute to discussions on modelling of use phase into such tools and Life Cycle Assessments (LCA) on clothing. Is there empirical grounding for assuming that the use phase is different for clothing made of different fibres, and could this information be used in modelling the use phase? We will answer this question based on studies on wool, and see if wool is used differently than other fibres in such a way that it gives a different environmental impact than other fibres.

Method

We collate previous empirical research on consumers' clothing behaviour and reanalyses existing research data. The study is limited to literature published after 1997, as clothing practices as well as the materials today are likely to differ from those of 20 years ago. Details of the included studies can be found in report by Laitala, Klepp, and Henry (2017), while this method section only lists data that has been analysed specifically for this study and not previously published elsewhere.

One of the main sources is a global wardrobe audit conducted by The Nielsen Company (2012). The study consisted of an online survey of 467 adult respondents (90 minutes) across seven countries: Australia (n= 56), China (n= 104), Italy (n= 51), Japan (n= 52), South Korea (n= 52), UK (n= 52), and USA (n= 100) (The Nielsen Company, 2012). They answered the same questions related to each of the clothing items they owned, including the age of the garments and maintenance practices.

Another source that has been used for acquiring new data for this study is a Norwegian project where a wardrobe audit was conducted on clothing going out of use from 16 households. All 620 garments that went out of use during a half year were registered with disposal reason and lifespan of the disposed items. The study included 35 household members, out of which eight were children, two teenagers, 16 women, and nine men (Laitala, 2014). The material was reanalysed to compare garments made of different fibers.

Results

This section includes a summary of the main findings that are relevant for LCA modelling of clothing use phase.

Maintenance

There are several alternative methods for cleaning clothes. Even though use of washing machines dominates, it is more common to wash laundry by hand in rural areas in developing countries (The Nielsen Company, 2016). Other alternative cleaning methods include washing by hand, airing, steaming, or dry-cleaning.

The results of the global wardrobe audit items show that consumers are more likely to either dry clean or wash wool garments by hand than those made from cotton or synthetics, and that there are differences between the practices of men and women (Table 1). Women reported washing laundry by hand more often, which is also confirmed by other studies (Aalto, 2003; Gwozdz, Netter, Bjartmarz, & Reisch, 2013). In contrast a larger portion of men's clothing is dry cleaned, mainly formal clothing such as suits, overcoats, coats, jackets and blazers.

Washing temperature

The average European washing temperature is about 43°C (A.I.S.E., 2014). When wool is washed in a washing machine, the washing temperature varies between cold and 40°C, but the median temperature across European countries is 30°C. This indicates that the washing temperature of wool is at least ten degrees lower than the average for laundry in Europe. The difference is less in countries where it is more common to wash all laundry at low temperatures.

Another difference is the used washing cycle/program, as a gentler wool wash cycle is used. For this cycle, the laundry load is smaller, usually recommended to be around 1/3 of the maximum capacity of the machine (Laitala & Klepp, 2016).

Even though the laundry load of wool wash is smaller than average, the energy consumption per kg textiles is still less than the average. The water consumption per kilogram of textiles per laundry load is higher in delicate and wool wash cycles than other commonly used wash cycles (Table 2). However, the use of water in washing machines is highly dependent on the type of machine (vertical axis top loading machines use a lot more than horizontal drum types), the age of machine (new machines are more efficient due to stricter energy labelling requirements and improved automatic water level adjustment to fit the amount of laundry), maximum capacity of the machine, and the selected program.

Dry-cleaning

Conventional dry-cleaning with Perchloroethylene (PERC) requires about twice as much energy compared to regular laundering, about 0.586 kWh/kg textiles (Table 3). In addition to high energy consumption, the solvents used in dry-cleaning have negative health effects and cause environmental hazards when not handled safely. Professional wet cleaning is more energy efficient than regular laundering and poses the least risk to human health and the environment of the cleaning methods listed in table 3 (Troynikov, Watson, Jadhav, Nawaz, & Kettlewell, 2016).

Cleaning process/solvent	Electricity use [KWh/kg textiles]
GreenEarth® (decamethylcyclo-pentasiloxane (D5))	1.195
Hydrocarbon	0.783
LCO2	0.681
PERC	0.586
Wet cleaning	0.205

Table 3. Estimated electricity usage of dry-cleaning and wet-cleaning processes/ solvents (Troynikov et al., 2016).

Drying

Drying wet laundry requires energy that is either "free" when the laundry is dried outdoors or in unheated rooms indoors, but comes at a cost if added heating is required. In general, drying laundry in a dryer uses more energy than washing the laundry. Due to wool's inherent properties, tumble-drying is usually not recommended to avoid shrinkage.

Washing method	Hand wash		Machine wash		Dry clean	
Fiber content	Men	Women	Men	Women	Men	Women
Cotton and cotton blends	6%	10%	82%	79%	9%	4%
Wool and wool blends	7%	15%	33%	37%	47%	25%
Synthetics and man-made materials	8%	11%	70%	73%	12%	6%

Table 1. Main washing methods for clothing made of different materials (The Nielsen Company, 2012).

Type	Temperature [°C]	Load user [kg /cycle]	Energy use per load [kWh /cycle]	Energy use per kg laundry [kWh /kg]	Water use per kg laundry [liters/kg]
Cotton	49.7	3.18	1.02	0.32	13.8
Mix	42.2	2.64	0.66	0.25	16.7
Easy care	39.3	2.8	0.67	0.24	15.7
Delicate	36.5	2.36	0.76	0.32	18.6
Wool	25	2.46	0.56	0.23	17.9

Table 2. Energy consumption as a function of washing programmes based on metering data from 100 households in Germany (Gooijer & Stamminger, 2016).

We did not find literature on consumer practices related to drying of garments made of specific materials. However, some product examples were found. A recent survey showed that over 80% of American consumers use a tumble dryer to dry their t-shirts and jeans, while the share in Germany and Sweden was about 20%, and even less in Poland, 12% (Gwozdz, Steensen Nielsen, & Müller, 2017). A Swedish survey showed that items that were most likely to be either tumble dried or dried in a drying cabinet/room were socks, underwear, and nightwear, while items least likely to be dried with extra energy were dresses, blouses, shirts, jackets, thick jumpers and skirts (Granello, Jönbrink, Roos, Johansson, & Granberg, 2015).

Number of days in use before laundering

The number of days in use before laundering varies between garment types. Table 4 summarizes studies that report average number of wears between washes of some specific garments.

Comparison of similar wool and cotton products shows that woollen products were likely to be used about twice as long between washes than cotton products.

Although there are too few data to make regional comparisons, we see that except for jeans, there is little evidence that would suggest there are regional differences between developed countries on the number of days in use before washing. The most recent surveys indicate the number of wearings before wash has increased. Hence, the difference may not primarily depend on geographic variations, but also to changes in general laundering frequency of jeans due to campaigns by several producers promoting less frequent washing (Nudie Jeans, 2015; O'Connor, 2016).

Clothing lifespans

The length of clothing use period is usually referred to as clothing lifespan or lifetime and often expressed in years, or sometimes as number of wears, or number of washes. Recently, use of the term "duration of service" has become more common. Effective life-time refers to the time the clothing is in active use, and can be shorter than the total use period when clothing is inactive and stored for periods of time. There are some differences in the way these terms are used.

Using real data on the actual service life of a product means that it can be determined how often a garment needs to be produced, to fulfil a functional unit. If for example a functional unit of 10 years of wearing for a specific use area was assumed, a garment that lasts two years only needs to be manufactured 5 times, whereas a garment that lasts one year would need to be produced 10 times (Slocinski & Fisher, 2016). Garments that remain unused do not contribute to any functional unit related to wearing.

	Norway [1,2] (3 surveys)	Netherlands 1,[3] (1-2 surveys)	Greece1	Spain 1	Other countries	Average estimate
Woollen sweater	8.9 (mode 10) >7.1 (mode >10 days)	10.3				10
Cotton sweater	4.7 (mode 2)	6.9				5
Woollen undershirt or thin sweater	3.4 3.9 4.3	3.2	2.8	2.7	3.2 USA[4]	3
Cotton T-shirt	1.8 2.1 2.8	1.4 1.7	2.0	1.5	2.26 USA, Sweden, Germany and Poland[5]	1.5
Jeans	4.7 >5.7	3.3 4.2	3.0	3.6	9.5 Canada[6] 5.4 Australia[7], 8.9 Sweden[8] 8.24 USA, Sweden, Germany and Poland5	5.5
Blouse/shirt	1.9	1.6 2.0	2.0	1.6		2
Sports clothing	2.3	1.5				1.5
Thin socks	1.5	1.3	1.4	1.1		1.5
Wool socks					2.3 USA4	2.5
Underpants/briefs	1.2 1.3	1.1	1.2	1.1		1

Table 4. Number of days different garments are used before wash. Average estimate rounded to closest half day.

[1] *Arild, Brusdal, Halvorsen-Gunnarsen, Terpstra, and Van Kessel (2003)*

[2] *Laitala and Klepp (2016)*

[3] *Uitdenbogerd, Brouwer, and Groot-Marcus (1998)*

[4] *Slocinski and Fisher (2016)*

[5] *Gwozdz et al. (2017)*

[6] *McQueen, Batcheller, Moran, Zhang, and Hooper (2017)*

[7] *Jack (2013)*

[8] *Granello et al. (2015)*

Most Western consumers own a large amount of clothing, and do not necessarily remember when each item was acquired. Therefore, estimating the total length of lifespan as well as the active service life of garments that are used a lot is methodically challenging.

The length of clothing lifespans has been discussed in some studies, but very little information is available of actual lifetimes and use times of clothing. For example, Beton et al. (2014) have estimated that all garments have a lifespan of 1-3 years based on expert opinions, but without referring to empirical research data. Results from various consumer studies on clothing lifespans are collected in Table 5, including the average and the range of values.

Some consumer groups are more likely to keep their clothing longer than average, including men, older people, people on low incomes, and people in higher social grades. Socks, tights and stockings as well as knickers and underpants have the shortest expected lifespans, while swimwear, jackets, blazers and coats have the longest expected lifespans (Langley et al., 2013).

Survey data from seven countries (The Nielsen Company, 2012) included a question of "When did you buy this clothes item or accessory?". The current age of the garments was multiplied by two to get estimated total lifespan. The results for various types of garments were given in Table 5. In addition, comparison of garments made of different fibers showed that garments made of silk had the longest lifespans, 9.4 years (mainly due to the high proportion of men's ties). This was followed by cashmere clothing (6.7 years), wool blends (6.6 years), synthetics (6.3 years), 100% wool (5.3 years), cotton blends (4.2 years), merino

Garment type	Wardrobe audit based on survey in seven countries (Nielsen Company, 2012)	Wardrobe audit with interviews Norway (textile waste) years (Laitala, 2014)	Survey, Norway (Klepp & Laitala, 2016)	Online survey,3244 respondents UK (Langley, Durkacz, & Tanase, 2013)	Survey, UK (Cooper et al., 2014)	Calculations 16 households based on ownership and purchases ,Netherlands (Uitdenbogerd et al., 1998)	Survey Netherlands (Uitdenbogerd, 2007)	Survey with 4617 respondents, 100 from each country (Germany, Poland, Sweden, & USA) (Gwozdz et al., 2017)	Online survey with 1060 respondents, Finland (Aalto, 2014)	Total lifespan, average and range
T-shirts	4.6			4.0	3.3	6.8		3-4	4.5	4.6 (3.3-6.8)
Blouses / shirts	4.6	4.2	5.6	3.3 / 4.3	3.6	7.2			5.7	4.8 (3.3-7.2)
Jumpers / sweaters	5.8		10.8 (wool)	4.5	3.7	7.1	6.17 (wool)			6.0 (3.7-10.8)
Suits	8.7									8.7
Jeans	3.9	4.3		3.8	3.1		2.45 (cotton)	3-4		3.5 (2.5-4.3)
Trousers / pants	4.9		4.4	5.4		6.2			5.3	4.7 (2.5-6.2)
Skirts	4.8	4.1		5.2		15.2				6.9 (4.1-15.2)
Dresses	4.5			4.7						7.1 (4.1-15.2)
Jackets / Blazers	5.3	4.0		6.5		11.5				6.8 (4.0-11.5)
Coats	6.3		6.4	6.2		11.6			7.6	7.0 (4.0-11.6)
Underwear briefs / boxers	2.5	4.4		2.4					3	3.1 (2.4-4.4)
Bras	3.0									3.5 (3.0-4.4)
Socks	3.6 (incl. stockings)	2.9		2.4	1.8				2.3	2.6 (1.8-3.6)
Average of all garments	4.7	4		3.3						4

Table 5. Summary of garment lifespans in years from various studies and estimated average lifespan based on these data (only the period with one current owner is used, not the total age of preowned clothes).

wool (4.0 years), and finally the shortest lifespans were reported for 100% cotton garments with 3.6 years.

Use frequency

The WRAP clothing longevity protocol estimated use frequencies of five different garment examples (Cooper et al., 2014). According to their assumptions that were validated by industry interviews, jeans have the highest wearing frequency of 75 wears per year, followed by socks (50 wears), knitwear (50 wears), t-shirts (25 wears) and finally shirts (16 wears). They indicated that each clothing item is worn 12 hours per wearing day, but this will also vary depending on how many times a day the user changes clothing. For example, sportswear is likely to be worn shorter periods per instance of wear, mainly during the activity. Many people also change to casual clothing after coming home from work. The authors consider also best practice scenarios, and suggest a target lifetime that is one third longer than the current practice (Cooper et al., 2014).

A consumer survey conducted in four countries (USA, Germany, Sweden and Poland) showed that the respondents estimated they kept jeans and t-shirts for about 3-4 years and wore them at least monthly, in total 36 to 48 times during their use period (Gwozdz et al., 2017). Another survey in Sweden reports a lot longer use period, as 93% of respondents said they wore their jeans at least 100 times before disposing of them (Granello et al., 2015). A survey conducted in the USA concentrated on woollen socks and garments, and these results indicate wear frequency of 9.2 wears per month for socks, and 8.3 wears for the next-to-skin garment (Slocinski & Fisher, 2016).

Conclusions

Consumer decisions during the use period of clothing are important from an environmental point of view, as they have an effect on the energy consumption during care, lifespan of clothing, as well as the potential for reuse and recycling. Many LCA studies on clothing have revealed that the consumer use phase often has the largest contribution to most environmental indicators, but also that the studies are often limited to small number of textiles and are not consistent which makes the comparisons difficult (Chapman, 2010). When it comes to LCA studies on wool, they often exclude the use phase of garments and are only performed as "cradle to gate" studies, stopping at the farm gate or factory gate and thus excluding the consumer stage (Henry, 2012). Therefore, there is a need for more information of the use phase of wool, but also of other fibres that enable comparisons of the environmental impacts of various materials.

The results from this review indicate that clothing made of different materials can be used, maintained and disposed of in different ways. Therefore, fibre content is a relevant property and should be considered when modelling the use phase in LCAs and tools based on a LCA approach.

To summarise, compared to other textile materials, the consumer use phase for wool is characterised by:

- about ten degrees lower washing temperature than the average for laundry;
- higher likelihood of either dry cleaning or hand washing;
- lower likelihood of tumble-drying;
- lower washing frequency, with about twice as many days between washes, then similar cotton products;
- longer average lifespan (especially for wool blends).

These studies show that clothing lifespan varies greatly in length depending on garment type and type of use, as well as fibre content and user related aspects such as the age, gender, income and area of living. They also show that empirical data is difficult to obtain, as most of the studies are based on consumers' own reported behaviour, and they may not know or be aware of how old all their garments are. In addition, estimating the lifespans of pre-owned and second hand clothing is challenging. It is easier to obtain data concerning the maintenance, but some knowledge gaps remain there as well. For filling these, studying the following areas should be especially prioritized:

- Obtaining information on the number of times and/or hours that each garment is used during its lifespan (service life).
- More studies in continents outside of Europe and USA where most studies have been conducted.
- More studies that combine surveys and practice-based methods in order to validate the survey data
- Development of a reliable method for measuring effective lifetime, where the unit is adapted to the clothes' function.

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