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Wool Wash: Technical Performance and Consumer Habits

This paper discusses consumers' wool washing habits and the possibilities for improving the laundering process with the aim of reducing the total environmental impacts of clothing consumption. Wool has great potential when compared to other fibres, such as cotton, especially when the energy per day of use is compared to energy per washing cycle. Wool products can be used longer between washing cycles due to the natural soil repellence, some washing can be replaced by airing, and the wool wash programs have lower washing temperatures and shorter washing cycles. Two surveys supplemented with in-depth interviews were conducted to study consumers' clothing maintenance habits in Norway and Sweden. Results confirm that consumers use woollen products longer between washes than similar products made from cotton. However, there is still a potential to reduce the energy consumption from wool wash further both through technical washing program development and through changes in consumer behaviour.

Key words: Wool, laundry habits, washing temperature, washing frequency, sustainability

Wollwäsche: Technische Leistung und Verbraucherverhalten. Dieser Beitrag behandelt die Verbrauchergewohnheiten bei der Wollwäsche und Möglichkeiten zur Verbesserung des Waschverfahrens mit dem Ziel, die gesamte Umweltbelastung aufgrund des Verbrauchs an Kleidung zu reduzieren. Wolle hat im Vergleich zu anderen Fasern wie etwa Baumwolle große Möglichkeiten, insbesondere wenn der Energieverbrauch pro Tag mit dem pro Waschzyklus vergleichen wird. Wollprodukte können zwischen den Waschzyklen aufgrund der natürlichen Schmutzabweisung länger getragen werden, einige Wäschen können sogar durch Lüften ersetzt werden. Wollwaschprogramme haben niedrigere Waschtemperaturen und kürzere Waschzyklen. Zwei Studien, ergänzt durch ausführliche Interviews, wurden mit dem Ziel durchgeführt, das Verbraucherverhalten bei der Aufbereitung von Kleidung in Norwegen und Schweden zu untersuchen. Die Ergebnisse bestätigen, dass die Verbraucher wollene Kleidung länger zwischen den Wäschen gebrauchen als vergleichbare Produkte aus Baumwolle. Jedoch gibt es immer noch Möglichkeiten, den Energieverbrauch bei der Wollwäsche durch eine technische Entwicklung des Waschprogramms und Änderungen des Verbraucherverhaltens weiter zu reduzieren.

Stichwörter: Wolle, Waschgewohnheiten, Waschtemperatur, Waschhäufigkeit, Nachhaltigkeit

1 Introduction

Wool counts for about 1.4–3% of global textile fibre consumption [1, 2]. Over half of it is used in apparel, and rest in interior textiles and industrial applications [3]. Textile maintenance requires high input of resources including energy, water and detergents. Wool has great potential for reduction of environmental effects from textile maintenance when compared to other fibres such as cotton. Wool products can be used longer between washing cycles due to the natural soil repellence and odour inhibiting properties, some washing can be replaced by airing, and the wool wash programs have lower washing temperatures and shorter washing cycle [4]. Tumble-dryer uses more energy than a washing machine, and wool should not be tumble-dried, and thus energy from drying is also saved. Therefore, the energy consumption in the laundry is less than on other fibres, especially when the energy per day of use is compared to the energy per washing cycle [4].

Potential for increasing the use of wool and reducing households' environmental impact has been considered before. Uitdenbogerd studied Dutch consumers' response to different potential changes in washing to reduce the environmental impact [5]. One of the aspects she studied was the possibility to increase the use of woollen garments, as the use could reduce the average washing temperature and frequency, as well as potentially lead to having lower indoor temperatures. About 30% of respondents found the increased use of wool acceptable. The remaining respondents did not want to use more wool because they considered it itchy or too warm, more difficult to maintain and dry, more expensive, or thought it gets dirty as quickly as cotton garments. The washing of wool is often considered as difficult, as it does not tolerate the same treatment as most other textile fibres such as cotton. Therefore, different chemical treatments have been developed to improve wool properties such as shrink-proofing which can be done either by abrading or covering the scales on the surface of wool fibres [6]. These barriers to use of wool have also been recognized by others that documented that main barriers were the prickle and itching sensation, warmth, and that it is difficult take care of [7]. However, there are national differences between which barriers dominate [8].

In order to achieve this potential benefit of using wool, changes in consumers' habits are required. Such changes are not simple, as laundering practices are a part of everyday life that is largely based on routines and not only fully a conscious, rational behaviour [9]. Therefore, discussions of how to change practices are relevant in sustainability studies. Practices are constituted of elements such as competencies, materials and meanings, and change can occur if unfamiliar elements, such as new materials are introduced to the practices [10, 11].

This paper discusses the consumers' wool washing habits and the technical possibilities for improving the laundering process, and motivations for increasing the use of wool with the main aim of reducing the total environmental impacts of textile use. We compare two neighbouring North-European countries, Norway and Sweden, which are similar in many ways but have a different uptake of wool and variations in the cultural use of wool. Norway has much higher consumption level of wool [12]. This way, we can get more knowledge

on barriers for use in countries that have different levels of expertise in use of wool.

2 Methods

A combination of quantitative and qualitative methods was selected in order to get information of both the magnitude of the studied phenomenon as well as more detailed knowledge on consumers' opinions and motivations they give for their behavior. The results of consumer studies are discussed against knowledge on technical properties of wool wash based on published literature.

2.1 Quantitative consumer studies

Results from two different consumer surveys are presented. Survey A is a land representative survey conducted yearly in Norway where some questions are repeated yearly while others are changed. Questions related to woollen clothing maintenance were new and answered by a total of 1 124 people that completed the web questionnaire. These cases are weighed to present the Norwegian population.

Survey B was specially conducted for collecting quantitative information of consumers' experiences and opinions concerning clothing use, maintenance and disposal habits. The recruitment of respondents was done in several steps and through different channels, including personal and work related networks, publicity in the media, and by sending paper questionnaires to randomly selected Norwegian households. A total of 546 answers were received. Due to the self-selection bias and uneven gender and age distribution, the sample is not representative for the whole population. In addition, the respondents have higher education and a larger share is employed than the average Norwegian population. However, it still is a large number of respondents that can be compared with each other in the sample, even though not used for generalizations for the Norwegian population as a whole. This has been taken into account when conclusions are drawn. Table 1 gives the gender and age distribution of the respondents in both samples. Data from both surveys has been analysed with SPSS software. The relevant questions are included in the appendix.

2.2 Qualitative interviews

To get a more in-depth knowledge on consumers' wool wash habits and cultural differences between Norway and Sweden, we chose to perform qualitative interviews. In selection of our informants, we did not strive for a statistically representative sample, but rather finding informants who mirror variations in barriers (purposeful sampling). We wanted to include informants from both countries, of both sexes and various age groups. An important parameter in the sample was informants' previous experience related to use of wool. In order to find suitable informants with such diversity, we developed an internet survey that included questions related to wool; use of the fibre, laundering frequency, and various opinions and experiences. A link to the web survey was sent to our professional networks and private contacts, and it was made available on our homepage and a selection of social media webpages. We encouraged the respondents to send the link to the survey to their contacts in order to achieve snowball effect. We received 131 complete responses (90 from Norway and 41 from Sweden), and chose 30 informants out of which half were Norwegian and half were Swedish. Table 2 gives an overview of age, gender, and country distribution of the informants we interviewed.

The interview themes included the use of wool in general, but we paid special attention to two different product groups, woollen underwear and bedlinen. These products were chosen as all consumers have such products but more commonly made of other materials than wool (mainly cotton) and there is little research on use of wool in these areas and great variation in consumers experience level in using them. Another advantage in concentrating on these product groups was that these products in cotton are regularly laundered and often in higher temperature than average laundry, and therefore change to wool has a greater environmental saving potential than within many other product groups.

Country	Age group	Female	Male	Total
Norway	25–34	7	1	8
	35–49	1	3	4
	50–72	3	0	3
Sweden	25–34	2	0	2
	35–49	7	1	7
	50–72	5	0	5
Total		25	5	30

Table 2 List of informants divided by country, age and gender

Background variables		Survey A	Survey B	Norwegian population
Number of respondents (N)		1 124	546	–
Gender	Male	50 %	23 %	50 %
	Female	50 %	77 %	50 %
Average age		45.2	39.2	45.9[3]
Age groups	Below 24 years	10 %[1]	9 %[2]	16 %[3]
	25–39 years	29 %	48 %	25 %
	40–59 years	38 %	33 %	33 %
	60+ years	23 %	9 %	26 %

1) All respondents were 18 or older
2) All respondents were 15 or older
3) Figure applies for population above the age of 15

Table 1 Survey respondents divided by background variables and compared to Norwegian population (15 years and older) [9, 10]

A semi-structured interview guide was used, where the topics were fixed, but not the exact order or wording of the questions. The interview guide questions are included in the appendix of this article. The questions were formulated in a manner that made the informants describe and reflect on their experiences in a form of a conversation. The interviews lasted usually a bit under an hour, but varied between 30 and 130 min. They were recorded, and analysed by the selected topics. The informants are cited to with their pseudonyms, a letter indicating their gender (F for female and M for male), age, and country (N for Norway and S for Sweden), for example "Mikkel, M37, N".

We refer to "informants" when talking about the people who participated in the qualitative interviews, and "respondents" for those that have answered the quantitative surveys.

3 Wool Wash Habits

In the following section, results from surveys and interviews are given for respondents' wool wash habits including washing frequency, temperature selection, washing method, detergents used, alternatives to laundering, as well as barriers and problems related to the use and laundering of wool. National differences between Sweden and Norway are discussed along the way based on the interview material.

3.1 Frequency

One of our main interests in the study was to find out whether there are differences in the washing frequency of wool compared to similar garments made of different fibres, and how large these differences are. Therefore, we asked how many days the respondents wore specified items before they were laundered. This question was asked in both of the surveys, although the included garments as well as answering options varied some.

In survey A, any answer between zero and 999 was allowed, and some answers with very high numbers seemed unrealistic (i. e. 500 days use before wash for a cotton t-shirt). However, it was not easy to draw a line between realistic and unrealistic answers, and a few higher numbers affect the mean result significantly. It was decided to include answers up to 99 days, as less than 2% of answers were above this. These results are given in Fig. 1. In survey B, the highest given answering option was "over 10 days". These results are given in Fig. 2.

The results show that there is only little variation in the washing of cotton t-shirts, underpants and synthetic sportswear, as most of the respondents wash these products frequently after one to three days of use. Washing of outerwear and woollen products is much more varied. Washing of cotton is much more standardized and the decision to launder is included in daily rituals. The wash of wool is much more varied. It has been shown previously that such difference exists between different textiles, for example briefs are washed daily based on fixed rituals, while most outerwear are washed based on evaluation of cleanliness [15].

To be able to compare the results of similar products in wool and cotton from both surveys, they are combined in Table 3 where we have also tried to calculate the average use time before washing. This was not straightforward due to the selected answering categories especially in Survey B, where "above 10 days" was the most selected answer for woollen sweaters. Due to the difficulties in calculating the mean (average) value, also median (middle value of the data set) and mode (most often-occurring value) results are included in the table.

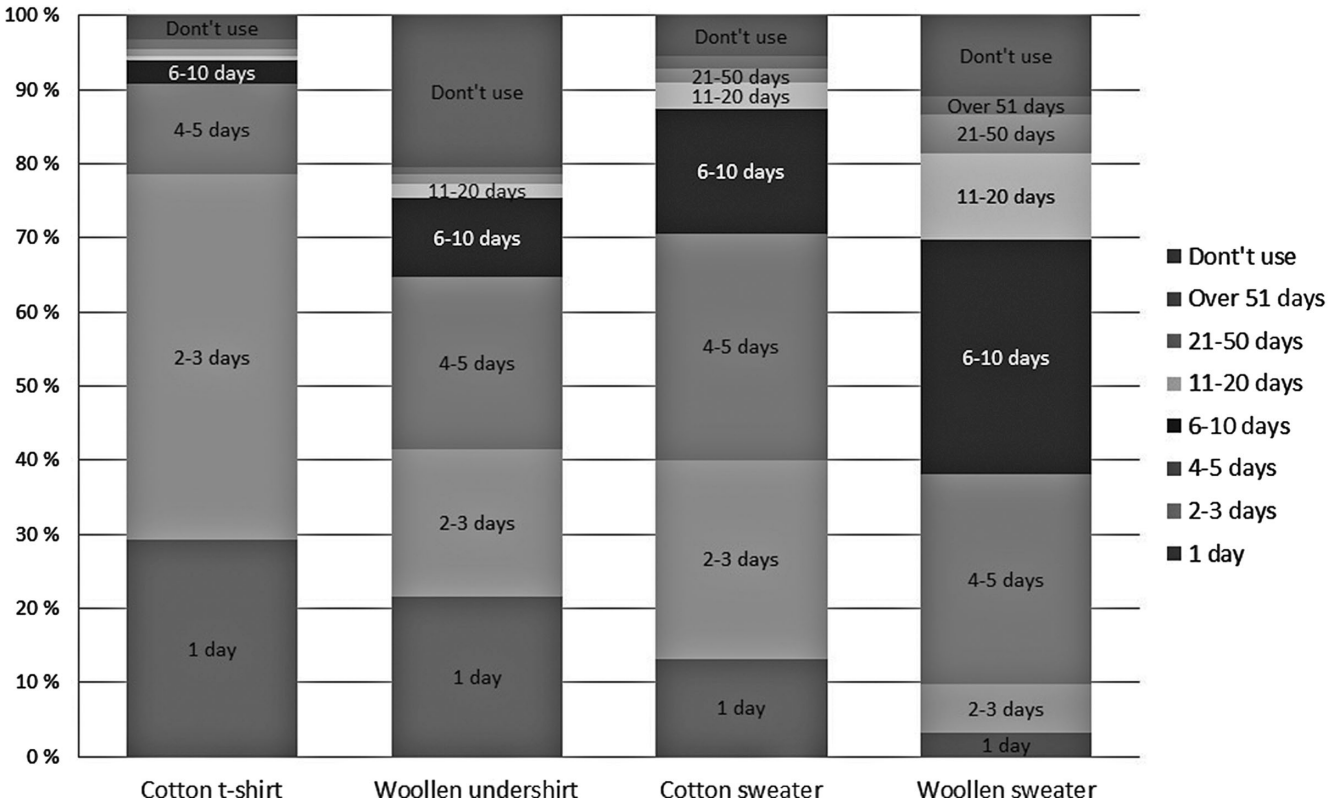

Figure 1 Number of days different cotton and wool garments are used before wash based on Survey A (N = 1105)

The results indicate that woollen undershirts are on average used about one to two days longer than cotton t-shirts. Woollen sweaters are often used 6–10 days and cotton sweaters 2–5 days before washing. This means, as expected, that consumers use woollen products almost double as long between washes than similar products in cotton. 21% of respondents said that they don't use woollen undershirts, and 5% did not use woollen sweaters. Only 1% did not use cotton t-shirts (N = 546). There was also a difference between genders. Men were likely to wear sweaters (both cotton and wool) 2–3 days longer between washes than women.

The interviews also showed that the frequency of laundering of wool underwear varies. It varies from Kari's (F50, N) practice, with laundering woollen undershirts once or twice a year "I feel that they never get dirty. But when the winter season is over I wash them", to those who launder after each use. How often these garments are washed, is related to their use. "What I have closest to skin for two or three days, it depends on the use. If I've used it for exercise I wash it immediately but if I've only used it to go to work, I do not wash it as often." (Sara, F33, N).

We see that the informants have knowledge about wools natural soil repellence and odour inhibiting properties. As Sara argues, it is the reason that the level of cleanliness of wool underwear is evaluated, while for cotton it is taken for granted that it is dirty. "I think wool stays fresher longer. The self-cleaning effect works. But cotton I think quite quickly becomes disgusting and should be washed after each use." (Sara, F33, N). Mikkel disagrees partly: "Laundering? If things are used for exercise, they are washed after each use. But if it is used daily on cold weekdays, not as often. When something has been wet with sweat it needs a rinse." (Mikkel, M37, N).

It is a common belief that wool can lose the sweat odour through airing, but this knowledge is mostly activated in situations where it is difficult to wash often. This applies not least of all to cabin trips and other outdoor leisure activities where physical activity is combined with limited access to washing facilities. "At the cabin this is perhaps different, when you use the clothes for several days, but you hang them to dry. They don't lie in a wet heap on the floor. Then it would be disgusting to put

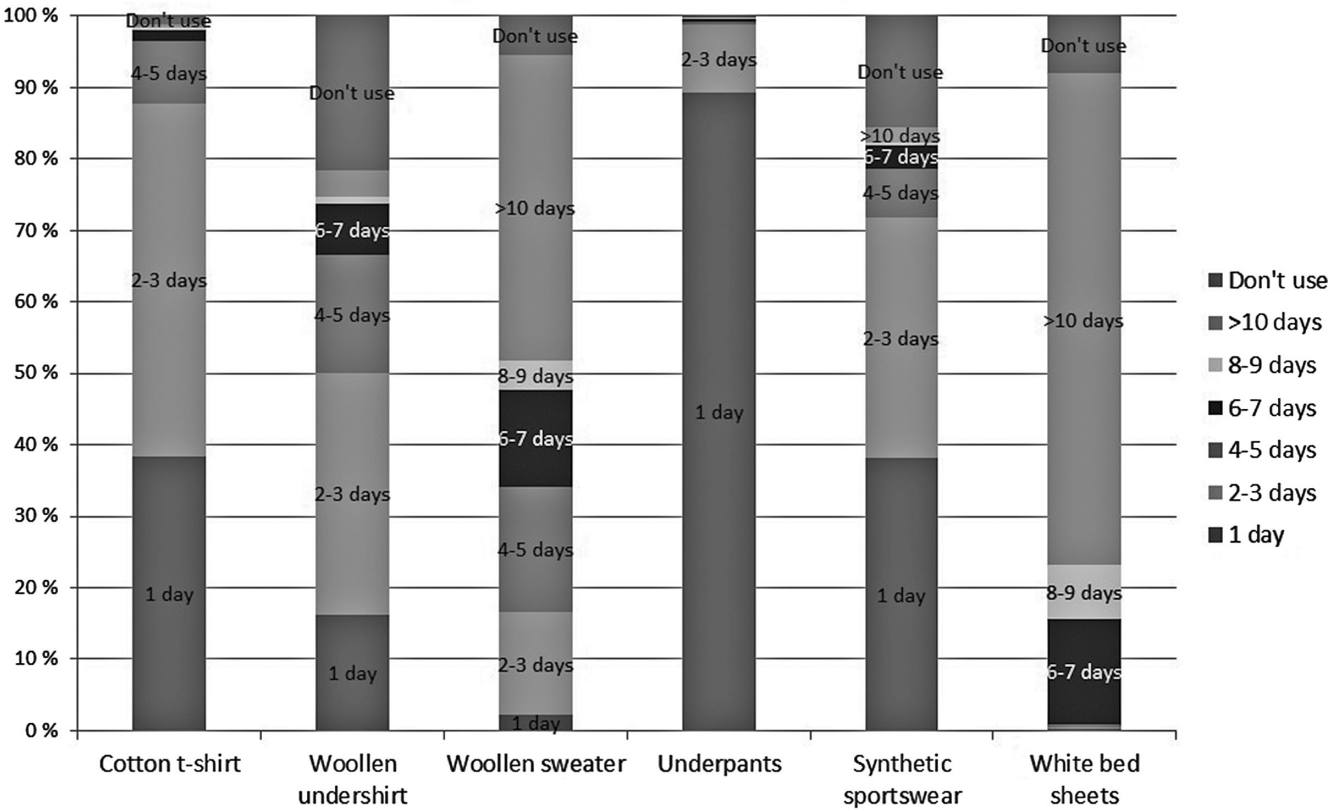

Figure 2 Number of days different garments are used before wash based on Survey B (N = 546)

Product	Cotton t-shirt		Woollen undershirt		Cotton sweater	Woollen sweater	
Data source	Survey A	Survey B	Survey A	Survey B	Survey A	Survey A	Survey B
Mean	2.8	2.1	3.9	3.4	4.7	8.9	>7.1
Median	2	2	3	3	3	5	7
Mode	1	1	1	3	2	10	>10

Table 3 Average numbers of days in use before wash (Survey A results above 99 use days are excluded)

them on the next day. But when they are dried it feels all right." (Ove, M32).

Our Norwegian informants had about twice as many next-to-skin wool products (average 9.3 per person) compared to the Swedish informants who had on average 3.8 garments. Even larger differences were observed in a qualitative study that compared a small selection of British and Norwegian families with small children. The Norwegians had on average 21 wool underwear garments per person (many were the children's), while the British had none. When all different woollen garments were taken into account, the Norwegians had on average 47.1 garments which was about five times more than the British who had 9.1 garments [16, 17].

It takes longer to fill up a wool laundry load for the informants that do not own much wool, and therefore they are also more likely to wash wool laundry less frequently. Mona is one of them. She uses wool for shorter periods when she "washes wool slightly more often than once a month during the winter. As you use the clothes for short periods and then you take them off and then air them and then you put them on the next time you go out. And the point is that they do not smell, they do not absorb sweat in the same way, so laundering is much rarer than for other garments." (Mona, F30, N).

3.2 Temperature

Survey B respondents answered which washing temperature they usually used for different textile products. The percentage of washes in different temperatures and the average washing temperature for different products made of cotton and wool are given in Fig. 3. The average washing temperature of woollen garments was significantly lower than for similar products in cotton. In calculation of average temperature, wash in cold water was estimated to be 16 °C. Most woollen textiles are washed at 30 °C. Products worn against the skin are more often washed at higher temperature than the outer garment layers such as sweaters. The average washing temperature for underpants was 56.0 °C (most underpants on the market are made of cotton and cotton blends).

Our informants were generally rather concerned about wool hygiene due to the lower washing temperature of wool wash programs (from cold water to 40 °C). We asked them what cannot be made of wool, and the great majority answered spontaneously briefs or underpants. Miranda says: "All textiles that I want to occasionally boil are not wool. So I have no underwear or panties or next-to-skin apparel in wool, but I know that wool is a good choice." She says that she "knows that wool is partly self-cleaning, but still... the same with kitchen rags and cloths and stuff, I launder these at 60 degrees" (Miranda, F60, S). Again we see that she knows about wool's natural soil repellence and odour inhibiting properties, but that she does not trust this. How she "knows" that wool cannot be boiled and that temperature is so critical for cleanliness, she does not say, but she is very sure of the veracity of this relationship. Eva agrees, but adds "at the same time wool gets ... it's like antibacterial. I'm still sceptical though." (Eva, F33, N).

Several informants would consider to use more wool: "If I was assured that it would be perfectly clean. At 30 or 40 degrees, I would consider wool underwear. I had to be convinced it was absolutely clean, then I would be convinced to buy more wool." (Miriam, F31, N).

Many informants are positive to the idea of woollen bed linen, but they are uncertain on how such textiles should be washed. "There is a crash, for bedlinens, I launder at

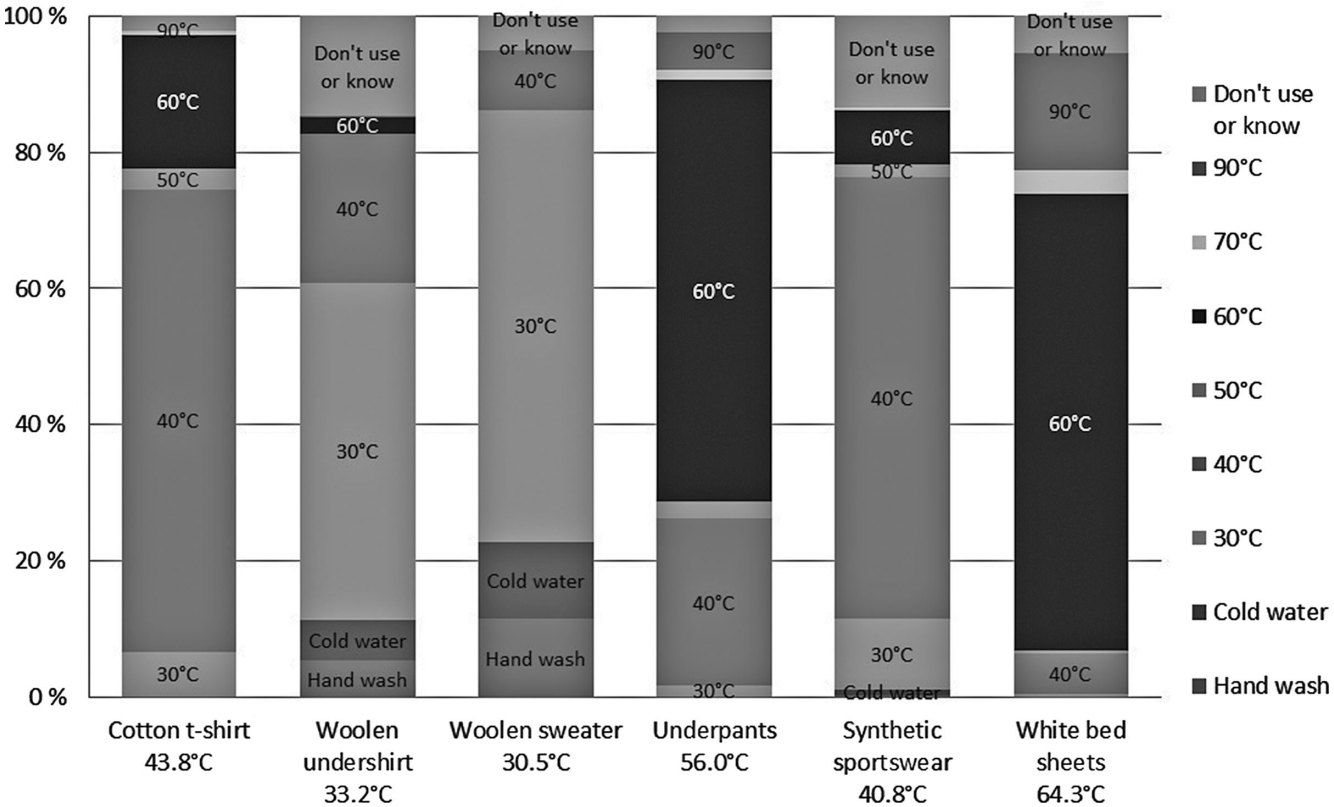

Figure 3 Most used temperatures for different textiles and average washing temperature (Survey B, N = 546)

60 degrees with *Omo* (a Norwegian detergent) normally. Wool I tend to wash at 30 with *Milo* (a Norwegian wool detergent). I am unsure. I don't want to wash it at a low temperature. But heat and wool, one thinks that the fibres are actually ruined if you wash it at a high temperature." (Mona, F30, N). Laila would also "like to be able to wash bedding at 60, because that's what I launder other bedding at. But I don't with panties, as they are changed so frequently it doesn't matter. With bedlinens I tend to assess how dirty they are, as when I wash clothes (and textiles). With wool I often feel that it is not so dirty, as it has cleansing properties. And then there's the fact that I tend to take better care of my clothes in wool." (Laila, F32, Norwegian living in Sweden). But even if these very positive informants all see problems, they also mentioned that they would have to experience the actual user-situation. It is also about how often they feel their bedding actually needs laundering.

3.3 Hand wash and machine program

The respondents were asked to estimate the use and frequency of different programs in the washing machine in Survey B. The most commonly used washing program was the cotton wash cycle (3.4 washes per week). Use of short programs was second most popular (1.6 cycles per week) and more common than eco-programs (1.1 per week). Use of wool wash was fifth most common program with 0.6 cycles per week, right after synthetics program that was used about 0.7 times in a week. Wool program use frequency may have been more difficult to estimate, as there is a variation between the seasons when it comes to use of wool. All of the respondents stated that they have a wool/silk wash program available in their washing machine.

Survey A respondents were asked whether they usually wash their woollen products in the washing machine or by hand, and the answers show that in Norway, it is a lot more common to wash woollen products in the washing machine (70%) than by hand (19%). Even Per (M40, N), without a single garment in wool knows "that wool must be washed on special wash cycles, but given that I have no wool this has not been an issue, but I assume that most washing machines have a special program for wool." However, the issue that wool should be washed separately, or at least in a certain way, can itself be experienced, if not as difficult, as "a little stressful. One is supposed to use a separate detergent and cannot throw them in the 40 wash with the other clothes." (Cecilia, F30, N).

Tina is not that satisfied either: "I think the laundry programs do not work. No, the wool program washes too gently and too poorly. And the other programs are too tough. Fine woollens are fine to launder but not thick woollens. They generally don't become clean. It does not work properly." Felting? we ask. "No, not nowadays. That was before, but if I wash by hand the woollens become clean and nice. But if I buy someone like a sports woollen top, they can be machine washed without trouble. That works fine." (Tina, F51, N).

Among the Swedish informants, wool laundering is more varied. Some do as the Norwegian informants and wash it in machine. "I think it is fairly easy to launder wool. I don't do it very often. I now live in a house with a balcony and it is very easy to air the clothes outside. And the washing machines where I live have a good washing programs so I launder the clothes mostly in the machine and it's super easy, I collect some woollens and run the machine with wool detergent and the wool program." (Mia, F25, S).

Roy (M45, S) wants the clothing to last and is careful with how materials and clothing are treated. We ask him if it is difficult to wash his woollen underwear. "No. Not really. Because they can be laundered at a high temperature and some can even be tumble-dried carefully." Do you? we ask. "No, I always hang them up, I don't dare to tumble-dry." He washes using the wool program, or a short program (20 min). What is experienced as easy or difficult is dependent on how often it is done. We see that the washing method is chosen both based on what is understood as practical, and what the textiles tolerate and require.

3.4 Detergent

We did not include any questions of use of different types of detergents in the surveys discussed in this article, but the topic was discussed in the interviews. In Norway there is a clear and simple standard for a wool laundering program which all are familiar with. "30 degrees and Milo." (Mona, F30, N). Milo virtually reigns supreme in the Norwegian market for wool wash detergents and is sold in all grocery stores. Lilleborg (the manufacturer) also advertises a lot, most famously they have collaborated with Vegard Ulvang (cross country ski hero and figurehead for an iconic wool brand) and recently Kari Traa (freestyle ski-champion and figurehead for a sports brand for women). The advertisements are both informative and at the same time humorous and have undoubtedly helped to consolidate Milo as the number one choice for wool laundering in Norway. Our informants use Milo synonymously with wool detergent. An international survey conducted in 2002 showed that it was more common for Norwegians to own a specific detergent for delicates (82%) than for Spanish (74%), Dutch (60%) or Greek (59%) respondents [18].

Not everyone is completely satisfied with the recipe "wool program and Milo". Sara is one. She wants a more powerful and agitated wash. "I look at the washing instructions. If it's 40 degrees I launder using the 40 degree program with Milo. And if the label says 30, I use the wool program with Milo. You can set the wool program on 40, but I think the wool program is so incredibly gentle. I think that if the clothes can withstand 40, they can certainly tolerate a tougher cycle. I wish that they could be washed at 60 degrees." (Sara, F33, N). When she is not happy with the washing result, she thinks the wool wash program is to blame, not the detergent. None of our Norwegian informants doubt or question the use of Milo for wool.

All our Norwegian informants knew about wool detergents, while this was not the case with all Swedes. And even if informants knew about wool detergent, not all owned or used it. Miranda (F60, S) explains that she washes "woollen underwear in the machine at 40 degrees with a normal detergent. I know that one should actually use a special detergent." Roy (M45, S) washes wool otherwise carefully but uses a regular detergent "Because I don't have wool detergent. I didn't know it existed. When I buy detergent I'm concerned that it should be a gentle detergent without perfume, that it should be environmentally friendly and without allergens. So those are the premises. I may have some difficulty in changing habits. When I have found something that I think is good, then I just choose it. I have not seen if there is something new on the market." (Roy, M45, S). His reflections are pertinent. Consumption is often a manifestation of routine actions. The conscious choices are not made every time you are in the store, but once in a while. Thus it becomes a big question why the 'routine' of wool being laundered with specific detergent dominates in Norway and not in Sweden.

3.5 Spin drying

Spin drying textiles after the wash reduces the moisture content and thus the drying time. The prevalence of machine washing indicates that most spin dry their woollens on the speed at which the machine manufacturer has decided. Even if the spin drying speed can be selected on some machines, the wool wash program still has a threshold that cannot be exceeded. It is different when woollens are washed by hand, as they can be spin dried in machine after hand wash. Information about this has been given increasingly in the recent years. We do not know how large percentage of consumers follow this advice, but our impression is that they are increasing. One of the Swedish informants studied textiles in her adulthood and learned then about the possibility of spin drying even after washing by hand. She likes to wash by hand "It as a kind of meditation when you are hand washing" explains Mille. Washing has become easier by the fact that she "can spin the clothes and then it is much easier to hang them to dry and stuff. Easier than before when I used newspapers and towels and rolled the clothes up". (Mille, F72, S).

3.6 Filling grade and shrinkage

That wool can shrink in the wash is something that has contributed in perceiving wool washing problematic [8]. However, this is not a major problem in our material. Based on Survey A, only 7.7 % of respondents experienced often problems with wool shrinkage. When the answers to this, were compared with the answers to whether the same respondents wash wool in a machine or by hand, a significant difference was found ($p < 0.05$). 80 % of those that did not have problems with wool shrinkage with wool washed in the washing machine. Where as only 65 % of those with problems did the same. However, it is not known whether the respondents have started to wash wool by hand because of experienced problems, or if the hand washing could be too rough and causing the problems, or if they use different kinds of wool products (i. e. with or without shrink-proofing). Another option is that washing by hand contributes to higher level of shrinkage than wool program in washing machine. The way people wash by hand varies greatly [19, 20] and therefore not a guarantee against shrinking, even though it can be done in a gentle way.

Most informants that were interviewed only had problems with wool shrinkage when the wool had been washed somehow in a wrong way. It could be that they had not noticed it was wool or that the garment had sneaked into a wrong laundry load.

There seems to be a connection between washing wool seldom and understanding wool wash as problematic. One example is Cissi (F42, S) who owns no wool, but recalls wool washing as problematic. "I find it difficult to launder. I've felted a sweater once … I cannot remember if it was that it was because the water was too hot or it was because I spin-dried …" Her notion that spin drying and heat cause wool shrinkage are both partly wrong, as discussed in 4.2 and 4.3. Owing less wool makes it also less important to acquire new knowledge related to wool.

When it comes to the sorting of laundry, it seems that woollen products are often washed separately from other fibre types. 73 % of survey B respondents stated that they do not wash wool together with other textile materials. For some consumers, the use of several different sorting categories made it more difficult to collect sufficient amount of clothing to fill the machine. This was also the case with some of the families that were interviewed.

Tony (M43, N) explains that "the reason why I do not use wool more often is that it has to be washed separately. And I like to fill up the washing machine, and I may have used some wool socks and not anything else in wool, and they lie around for a long time before they are washed. I need to collect more than just the socks, you could say I have a problem as I do not hand wash". Because he does not own much wool, the wool he has is not used. It becomes impractical to wash. Tony himself sees this as a result of that he does not wash by hand. In addition, Tony has a notion of how wool needs to be washed that also makes the laundering more problematic. "So when I have used it (a thinner wool sweater) a few times, I can launder it in the machine. But the timing has to be right. And I have to dry the sweater flat and stuff so it's a little more complicated." (Tony, M43, N).

Many of the informants think laundering is rather simple, and even less complicated during winter. Because there is "enough wool to be laundered" (Sara, F33, N). Because if there are only a few items, it does constitute a problem with laundering when one does not fill the machine.

The consequence of only having a few woollen garments to be washed at once is that the wool garments either have to wait in the laundry basket for long periods of time, or that they get washed with only one or two garments at time. It is usually advised against storing textiles dirty over long periods of time, and it is more resource demanding to wash with unfilled machines.

3.7 Stains

Soiling of textiles may occur in a number of ways including accidental spillage of liquids, static attraction of dirt and dust, and re-deposition of soils during laundering. Spots can be a bigger problem for garments that are washed less often. Stain removal can be understood as part of the laundering process, or as a separate process where the garment as a whole is not washed. Survey B results showed that it was more common to remove stains as pre-treatment to washing (54 % did this at least sometimes) than to only remove stains without washing (31 %), or to use separate stain removal agent in washes (28 %).

We asked respondents' opinions on the cleaning effect of different washing programs (Survey B). They were asked to estimate how well a specified washing program would clean a jam-stained white cotton shirt. The cotton program's cleaning effect was trusted the most. That was followed by the eco program, short programs, washing by hand, synthetics program and delicates program [21]. The wool and silk program was considered to be the mildest with the lowest washing effect of all seven options, suggesting a potential trust problem related to washing of wool.

We see the same in the interviews. The informants are the least satisfied with stain removal from the woollen garments. "I have young children. And it's a bit annoying when you cannot wash the clothes. Some things you can wash at 40 degrees. You are supposed to use a wool detergent and then you do not get the stains out. Unless they are laundered at high enough temperatures and with a stain remover. (…) But wool also has self-cleaning qualities …" (Sara, F33, N) Typical for the responses is Sara's somewhat hesitant way of describing this as if she is not quite sure.

Three of our Swedish informants swear to 'untreated' wool, which for them means wool without 'super-wash' treatment. Irene (F40, S) believes the untreated wool is pre-

ferable when it comes to washing. "I can't get rid of stains on the treated wool, I throw it in the machine since it can withstand the machine-treatment. But despite of the washing, I do not get the stains out." The untreated clothes, which is what she uses mostly, she only handwashes. If necessary, she can then use soap on the soiled spot. Washing by hand gives an alternative to concentrate the soap and mechanical processing to the areas that need it the most.

3.8 Airing

Airing has traditionally been a central method in keeping woollen products clean, combined with stain removal and brushing. As we will see, airing is still used and it is an effective method for odour removal. The respondents in Survey B were asked whether they air woollen or non-woollen textiles for freshening them up. The results are given in Fig. 4. This indicates that this is more commonly used for woollen products than for other textiles. Respondents above the age of 40 were slightly more likely to air woollen textiles than the younger respondents.

There may be several reasons to air wool, and we are most concerned about whether this is utilized to reduce laundering frequency. We have already seen how Ove (M32, N) used wool underwear over and over again at the cabin by hanging it up to dry, which is of course similar to airing. Vanja thinks that less frequent laundering requires more airing. But "It's difficult when you live in a city to air, if we had lived one floor up it would have been easier. I'd like to wash it less frequently if it was easier to air." (Vanja, F40, S). She expects that airing has to be done outdoors, and not inside like Ove (M32, N) previously explained.

4 Discussion

In this section, we will discuss the reduction of environmental impacts by improved utilization of wool washing properties. This is done by summarizing the washing habits and discussing them against technical possibilities of wool wash based on previously published literature. The discussion focuses on washing frequency, methods as well as level of wool use.

4.1 Washing frequency

The washing frequency is decisive for energy consumption in laundry. Uitdenbogerd has calculated that the potential saving of using all clothing items one extra day would be 100 wash cycles per year in family households [5]. Our results on consumers' washing habits have shown that wool

Figure 4 Airing of woollen and non-woollen textiles Survey B (N = 268)

garments are used almost double as long as similar cotton garments between washes, and the laundering decision is more often based on evaluation. There are larger variations in washing frequency of wool than cotton.

Studies on perspiration odour in textiles confirm that airing reduces the odour intensity of wool, and that it is not necessary to air textiles outdoors for airing to function [22, 23]. Wool is not antibacterial as it does not kill microorganisms, but it has inherent properties that reduce odour formation [24]. Even though the informants would know that the sweat odour of woollen garments can be reduced through airing [22, 23, 25], they do not utilize this property to as large a degree as it would be possible. This knowledge is activated in situations where it is difficult to wash, while the regular everyday practices are affected by the routines developed for washing other materials. The informants are also uncertain about this knowledge. They have heard it, but don't completely believe it, even if they have experienced themselves some of wool's natural soil repellence and odour inhibiting properties. In addition, some believe that the airing must occur outdoors, and that regular drying of sweaty textiles is not enough to remove the sweat odour.

Some of the wool washing could potentially be replaced by other cleaning methods such as stain removal, airing or brushing. Other benefits of greater use of wool may also be the warmth, which could lead to reduced need of heating indoors.

4.2 Washing method

The washing temperature and drying method are also decisive for energy consumption in the laundry. The fact that wool is washed differently from other materials contributes to it requiring less energy to wash, but also that it is understood as more difficult to wash. The latter is used as an argument against the use of wool, and will be discussed further in section 4.3.

Our results on consumers' wool washing habits have shown that wool is washed at lower temperature than similar products in cotton. There is a clear idea that there is a direct correlation between washing temperature and cleanliness. This perception is independent of the fibre. Due to the reduced temperature of wool wash programs, many consumers think that the wool does not tolerate higher temperature. This is a misconception, because wool does tolerate to be cooked, as long as minimal of mechanical action is used during the cooking to avoid shrinkage [26]. Even the dyeing of wool is often done with high temperature in the dyebath. Achieving the same cleaning effect when the washing temperature is lowered requires longer washing times, more mechanical agitation or more efficient detergents [27]. In professional laundry systems chemical disinfection is usually used for wool instead of thermal disinfection, for example by using peracetic acid (PAA) containing detergents [28].

The capacity of washing machines in Europe has increased during the past decades from average of 4.8 kg laundry load to over 7 kg today [29]. Then, using the full capacity may become difficult for some textile groups that require use of special washing program, such as wool, and increase the CO_2 emissions. Previous research on the topic has showed that if the wash load is filled with other textiles in addition to wool, wool gets as clean independent of whether the wash load consists of mixture or only one type of fibres [30]. In addition, the wool samples did not show any additional significant pilling or shrinkage during five washes [31]. However, more research in these themes is needed with more varying materials and higher number of washing cy-

cles in order to draw final conclusions. The importance of machine filling grade, where the maximum recommended level for wool is usually $^1/_3$ of machine's maximum capacity, could also be studied further. Also, as the delicate's program washes more efficiently than the wool program and in general, the regular detergents are more efficient than the wool detergents, the materials that are used to fill the wool wash may not get quite as clean as they would get on delicate's wash program. However, delicate garments that are not heavily soiled could be washed with wool and the cleaning effect would probably be considered as satisfactory.

Wool, and especially woollen fabrics without super wash treatment show good soil repellence against water based soils. Even though wool is hygroscopic, it is also naturally water repellent because the fibres have a very thin, waxy, lipid coating chemically bonded to the surface. However, if the staining occurs it is more difficult to get wool clean than synthetic fabrics [31]. This can be especially challenging in toddlers' clothing. Some of the informants are aware that different fibres have different resistance to dirt and soiling. Stains/soiling from body liquids contain the proteins that 'set' with body heat. Developing effective bleach and stain removers for wool is therefore something we think would be useful, especially if the opportunity to long use before wash is utilized. For example, transglutaminases can be used to stabilise the proteins in order to increase the wool's resistance towards detergents with proteases [32].

The informants exaggerated the importance of washing temperature as a cause for shrinkage. We also saw that there was a correlation between washing by hand and having had problems with wool shrinkage. Unfortunately we do not have material on that could explain the cause of this correlation. What in any case is certain is that most of the problems with shrinkage are caused because wool is not washed as wool, but mistakenly placed in other types of wash. This problem cannot be solved through changing laundering methods, but by making wool easier to recognize and improving the laundry sorting systems.

4.3 Level of wool use

The level of wool use has an impact on energy consumption directly through lower washing frequency, temperature and avoidance of tumble-drying, but also indirectly as increased use of wool potentially gives a better utilization of wool washing properties. Changing practices can be done through introducing new elements to the practices [33]. The article is built on material that discussed increased use of wool in underwear, bedlinen and nightwear.

It's a somewhat surprising that the focus on the "inner layer" for sports outside during winter as well as children's clothing in Norway hasn't resulted in a more extensive debate or reflection on what materials are suitable to underwear such as briefs and boxers. Discussion of wool as a good next-to-skin material is mainly based on knowledge about warmth and moisture wicking. Knowledge gaps appear to be larger in terms of what contributes to cleanliness. The ability to wash clean is an important argument against the use of wool in these product groups. It is one of wool's major advantages that it can be washed less frequently – but there is an argument against using wool in products such as underpants because they 'must' be washed after each use. Thus, the logic suffers. Our informants do not seem ripe for discussing the 'laundering after each use' norm. They think frequent laundering at high temperature is the only guarantee for cleanliness. However, it also appears that informants are not confident in their perceptions about hygiene, odour and purity. More research on the relationship between cleanliness, health and washing of different fibers, and better information about the current knowledge status will be important to change these perceptions.

Long drying time may be perceived as one of the obstacles for using wool. This can be affected by spin-drying of garments. Washing machines' wool programs usually have a pre-installed reduced spin drying speed in the area of 400–1 000 rpm [4]. However, previous research on this topic shows that woollen test materials did not shrink more when the spin-drying speed was increased to 1 400 rpm. The effect on residual moisture was significant, as specimens spin-dried at 400 rpm had much higher moisture content than the specimens spin-dried at 1 400 rpm (47 % as opposed to 24 %) [34]. This indicates that the drying time of garments can be significantly reduced by increasing the spin speed, and that wool can be spin-dried at high speed without causing additional shrinkage [35]. Increasing the spinning speed reduces the drying time but can also improve the cleanliness through more effective removal of rinsing water that contains residuals of dirt and detergents. However, acceleration speed is important, because wool does shrink readily if the mechanical action is performed in the way that the wet fibres move and get entangled. Therefore, the spinning program has to have a rapid acceleration and slowing-down phases. Washing machines' wool wash programs could be improved by having a possibility to increase the spin-drying speed. Comparative tests of wool wash programs could be an opportunity to create competition in this market and enable consumers to make informed choices.

5 Conclusions

Our results on consumers' wool washing habits have shown that wool is washed more seldom and at lower temperature than similar products such as cotton. There are larger variations in washing frequency for wool, and the laundering decision is based on evaluation of need. Knowledge gaps appear to be larger in terms of what contributes to cleanliness. Informants that used a lot of wool were likely to use woollen products even longer between washes than informants that used little or no wool. The decision to launder was based more on evaluation of the level of soiling than a norm of frequent washing. This means that not all of potential for reduction has yet been extracted, and this could be a good starting point for change.

When regularly used textiles are made of materials that have not been used there before, two laundering norms collide. Knowledge of wool wash was lower and more varied among our Swedish informants than the Norwegian informants. Most Norwegian respondents washed wool in the machine instead by hand and used the wool washing program and detergent. However, the interviews revealed that some consumers washed wool with regular detergent, but often just used less of it. This shows there is need for better knowledge among the users, but also that additional wool fibre treatments may be helpful. When the informants owned only little or no wool, the knowledge level about wool laundering was also lower. This resulted in the washing procedures becoming unnecessary time-consuming, inefficient and rarely done. Thus, wool became difficult to wash. For those with lots of wool and up to date information of maintenance, this contributes to wool being used longer and laundered less, with a longer time-span between laundering and thus perceived as easier to care for. As filling a wool wash load can be difficult for consumer that own only little

wool products, other delicate garments can be washed together with wool without reducing the cleaning result.

The understanding of hygiene has much in common with the understanding of warmth. Even here, our informants have knowledge, although they do not quite trust it. This results in more frequent washing than what had been optimal especially for those who use less wool. This indicates that the cleaning frequency would decrease with increased use of wool. Hygiene is probably a major barrier to increased use of wool underwear, especially in briefs. The reasons for, and remedies to overcome this, however, are probably the same. More research is needed on the relationship between fibre, temperature and cleanliness both understood as the absence of odour, stains and undesirable microorganisms. Washing machines' wool wash programs could be more varied to suit for wash of different types of wool, how much can be washed at once, increased spinning speed, and so on.

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Appendix

Survey A

Q1. How many times do you usually use the following garments before they are laundered? Please answer a number only. If you do not use such clothes, please indicate that with "0".

- Cotton T-shirt __ times
- Woollen underwear __ times
- Cotton sweater __ times
- Woollen sweater __ times

Q2. Do you agree with the following statements? Answering alternatives: Yes, No, or Don't know.

- I wash wool more often in washing machine than by hand
- I have often problems with wool shrinkage

Survey B

Q1. How often do you use the different programs in the washing machine for washing clothes and textiles (applies for the whole household). Answering alternatives were:

- 7 or more washes per week
- 6 washes per week
- 5 washes per week
- 4 washes per week
- 3 washes per week
- 2 washes per week
- 1 wash a week
- about once or twice a month
- more seldom
- never
- don't know.

The given laundry programs were:

- Cotton washing program
- Synthetics washing program
- Delicate's washing program
- Wool and silk wash program
- Short cycle
- Eco-program
- Wash by hand

Q2. Which temperature do you usually use for washing the following textiles? The given alternatives were:

- Cold water
- 30 °C
- 40 °C
- 50 °C
- 60 °C
- 70 °C
- 90 °C
- Wash by hand
- Dry clean
- Don't use
- Don't know

The given textiles were:

- White bed-linen
- Jeans
- Woollen sweaters
- Cotton T-shirt
- Woollen undershirts
- Briefs or boxers
- Synthetic sportswear
- Terry towels

Q3. How many times do you usually use the following textiles before they are laundered? Answering alternatives were: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 or more, and Don't use

- White bed-linen
- Jeans
- Woollen sweaters
- Cotton T-shirt
- Woollen undershirts
- Briefs or boxers
- Synthetic sportswear
- Terry towels

Q4. How often do you use the following methods for textile maintenance? Please give one answer each line.
Answering alternatives were

- Almost always
- Often
- Sometimes
- Seldom
- Never
- Don't know

The given methods are:

- Separate stain removal (without laundering the garment)
- Stain removal right before the laundering as pre-treatment
- Stain removal agent that is added together with detergent to the laundry
- Airing of woollens
- Airing of garments that are not made of wool

Q5. Think that you have a white cotton shirt that has been stained by jam. To which degree do you trust that the following washing programs will wash the shirt clean? Please answer on a scale from one to five, where one means not clean (still stained) and five means completely clean.

- Cotton washing program
- Synthetics washing program
- Delicate's washing program
- Wool and silk wash program
- Short cycle
- Eco-program
- Wash by hand

Interview guide

Tell us about your relationship with wool and what kind of woollen clothes you wear?
Has there been a change in it?
Is this different from other people you know?
When and how do you use wool?
What types of wool do you know? (merino, cashmere, lambs wool, etc.)
Which of them do you have?
Which clothes MUST be wool?
Are there things that cannot be made of wool and if so, why?
What do you think are the advantages of using wool?
Is there something that is problematic with use of wool? (i.e. itchy, allergen, too hot, hard to care for …)
What would help to change this?

How many items do you have of the following garments in wool?

- Short underpants
- Long underpants
- Singlet
- T-shirt
- Long sleeved shirts
- Nightwear/pyjamas

How and how often do you wash these garments?
Do you have something made of wool in your bed today?

Do you think the Norwegians and Swedes are different when it comes to use of wool?
Do you have any examples?
And what could be the reason?
Do you think this will change?
Do you have something made of wool from the other country?
Is your use of wool at normal level to be a Norwegian/ Swedish?