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Examining Practices of Apparel Use and End of Life in New Zealand

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Abstract: Throughout a garment's life cycle, the use and end-of-life phases are crucial in determining its environmental impact, due to the resources that would be utilised and waste produced during maintenance and disposal. Consumption patterns differ among countries and cultures; however, in New Zealand, there is limited published information to date. To address this gap, an anonymous online poll was conducted examining laundry practices, lifetime wear events and disposal practices for woollen and synthetic-blend knitted jumpers, which are predominantly used as winter clothing in New Zealand. The survey revealed considerable differences in the ways woollen and synthetic garments were worn, maintained and discarded. Over its lifetime, although woollen garments were worn a greater number of times, they were washed less. At the end of life, both types of jumpers showed significant reuse percentages. This information is useful for accurately modelling the inventory needed for assessing the environmental implication of apparel, using the life cycle assessment (LCA) methodology. By comparing New Zealand's washing and disposal practises to those of other countries, this study found significant differences, highlighting the need for country-specific data for future LCAs.

Keywords: apparel use; LCA modelling; laundry habits; New Zealand; wool; synthetic; sustainability; consumer behaviour

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1. Introduction

The production and consumption of clothing and textiles have exponentially increased since the Industrial Revolution. Recently, the sector has been placed second to oil in regard to its detrimental impact on environmental sustainability [1]. The use and end-of-life phases of a garment's life cycle are critical, often with higher environmental impacts than those produced during the manufacturing processes [2]. Environmental systems are impacted by the excessive use of energy and water, as well as the release of toxic chemicals and harmful microfibres during laundering [3,4]. The use phase accounts for 50 to 80 per cent of the energy used in a garment's life cycle [5]. At the end of life, about 73 per cent of the textile fibres produced in 2015 (39 Gt) were landfilled [6]. When textile waste breaks down in open landfills and dumps, leachate and hazardous air pollutants such as methane and carbon dioxide gases are released into the environment [7,8]. Therefore, it is crucial to measure and formulate an inventory for the maintenance and disposal of clothing when considering sustainable development.

Internationally, researchers have examined the environmental profile of using and caring for clothing with varieties of fibre contents [9,10]. Electricity and water consumption during laundry [11], sustainable laundry technologies [12] and recommendations for improving resource efficiency in household laundry [13] have been studied to reduce impacts.

The garment lifespan is the other key factor that influences a garment's environmental footprint. Consumer surveys have identified factors such as gender, age and income as influencing clothing use [14]. Clothing use patterns in Germany, Poland, Sweden and the United States of America change depending on income [15]. Quantitative wardrobe surveys and qualitative laundry diaries conducted in China, Germany, Japan, the United Kingdom and the United States of America demonstrated that country-specific cultures dominate impacts associated with the use and end-of-life phases [16]. These factors influence the overall impact of materials and resources required and emissions to air, water and soil made across these stages of the garment's life cycle [17]. Thus, a variety of factors impact how a garment is consumed, with national and cultural behaviours having a high influence [18,19].

An in-depth analysis of the literature on the use and disposal practises of clothing revealed a paucity of studies in New Zealand [20]. The annual consumer spending on clothing and footwear in New Zealand was estimated to be about NZD 7 billion in 2021 [21], which is high given the country's small population of only 5 million [22]. Furthermore, it is acknowledged that New Zealand's textile waste recycling infrastructure is underdeveloped [23,24]. In this context, garment use and its consequences demand further consideration. Determining where the country is positioned in terms of apparel consumption is fundamental to supporting a sustainable future. The focus of this study is illustrated in Figure 1.

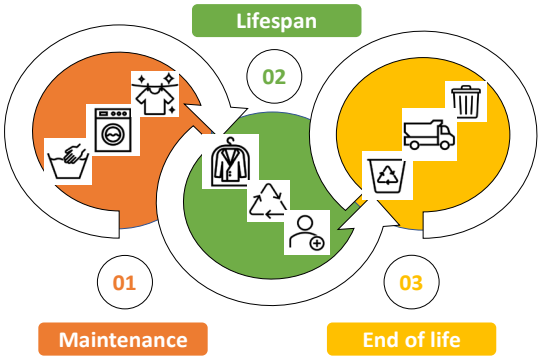

Figure 1. Focus of this study.

1.1. Selection of Material

New Zealand is the world's third-largest producer of wool [25]. Fine Merino wool fibre used in apparel production is produced in New Zealand and in the neighbouring Australian region [26]. A Consumer New Zealand research report, published 19 September 2019, identifies that cheap synthetic apparel predominates the country's retail market. New Zealand imports over 13,000 tonnes of synthetic textiles per annum [27], which is of concern, considering the negative environmental impact across its use and disposal [4,28]. In the use phase, synthetics show increased greenhouse gas emissions compared to natural materials [29] and also contribute to microfibre pollution in aquatic bodies [30]. About 87 per cent of the synthetic microfibre pollutants found on the beaches in Auckland, New Zealand's most populated city, come from clothing [31]. However, some higher environmental impacts are associated with the production of wool fibre [2,28]. Knitwear manufacturing is a modest industry in New Zealand. Knitted goods manufactured here are sold both at domestic and foreign markets. According to the World Integrated Trade Solution (2022), New Zealand's gross export of knitted items such as waistcoats, cardigans, pullovers and jerseys made of wool and fine animal hair was over USD 6.4 million in 2019. However, both wool and synthetic materials are used in winter clothing in New Zealand. Given New Zealand's reputation as an "outdoors playground" (N Z Govt, 2022) it is important for apparel companies and consumers to understand the environmental impacts associated with their use and disposal.

1.2. Life Cycle Assessment Method

Life cycle assessment (LCA) is widely recognised as a tool for estimating the environmental impact of products and services. Conducting an accurate LCA requires comprehensive, reliable data on the environmental performance of key inputs through extraction and processing of raw materials, manufacturing, distribution, use, reuse and/or maintenance and end of life [32]. There are four phases to any LCA: Goal and Scope Definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation. The LCI is the process of developing a thorough list of crucial inflows (resources) and outflows (emissions) from the product over its life cycle in relation to the functional unit studied [33]. When examining the effects of a product such as apparel that uses resources once during production but repeatedly during consumption, it is essential to model the inventory in accordance with its use. In a cradle-to-grave LCA of jeans and T-shirts, the consumption inventory was modelled based on country-specific consumer profiles in Germany, Poland, Sweden and the United States of America [19]. The study discovered major differences in clothing-related environmental consequences between nations. Thus, more extensive consumer behaviour data for each geographical region is needed for accurate LCA modelling [18].

The use of scientific techniques such as LCA to quantify the environmental implications of locally grown Merino wool garments compared with their global synthetic counterparts are critical in New Zealand in order to inform the choice of local designers and consumers. However, there is a substantial information gap due to the lack of inventory data on local use and end-of-life phases of clothing. This study investigates this issue through a consumer survey on apparel consumption patterns. The results provide New Zealand-specific data and insights. This paper reports on the survey findings and addresses the following questions:

1. Does the type of material a garment is composed of impact how it is washed and worn?
2. Do New Zealanders care for and discard garments differently from people in other countries?
3. How many times are woollen and synthetic jumpers laundered over their lifetimes, and what happens to them at the end of their useful life?

2. Methods

The study used a questionnaire for collecting data. An anonymous online consumer survey was carried out between December 2021 and January 2022. The survey was distributed among the currently popular social media platforms, such as Facebook, Linked In and Neighbourly and people were invited to participate. Social groups that seemed to be aware of the differences in textile material types were mainly approached. A confidence level of 95 per cent and a margin of error of ± 3 per cent were determined as variables. The formula employed to estimate the optimal sample size [34] was based on New Zealand's population of 5 million in the year 2020 [22].

$$\text{Necessary Sample Size} = \frac{(\text{Z score})^2 \times \text{Standard Deviation} \times (1 - \text{Standard Deviation})}{(\text{margin of error})^2}$$

where Z score for 95% = 1.96; Standard Deviation = 0.5; margin of error = 0.03.

$$\text{Necessary Sample Size} = \frac{(1.96)^2 \times 0.5 \times (1 - 0.5)}{(0.03)^2} = 1066.66 = 1067 \text{ respondents required}$$

The online poll received replies from 1094 New Zealanders, which was 27 more than the minimum requirement (with a margin of error of 0.03) for accurate results. All respondents were New Zealand residents, over the age of 18 and responsible for doing laundry. Participants were asked to respond if they had previously owned both woollen and synthetic knitted jumpers and thus were aware of their differences.

Thirty multiple-choice questions were included, however, some questions also contained text entry boxes for additional detail. The participants were asked to recall a woollen and a synthetic jumper, sweater or cardigan they had owned and provide information about how they were cleaned, how long they had been worn or would be worn in future and how they were to be disposed of. There were participants who laundered both wool and synthetic jumpers in the same manner. These respondents were put into a subgroup and were given access to a supplementary set of five questions on common laundry practices. Figure 2 depicts the survey flow in the form of a chart.

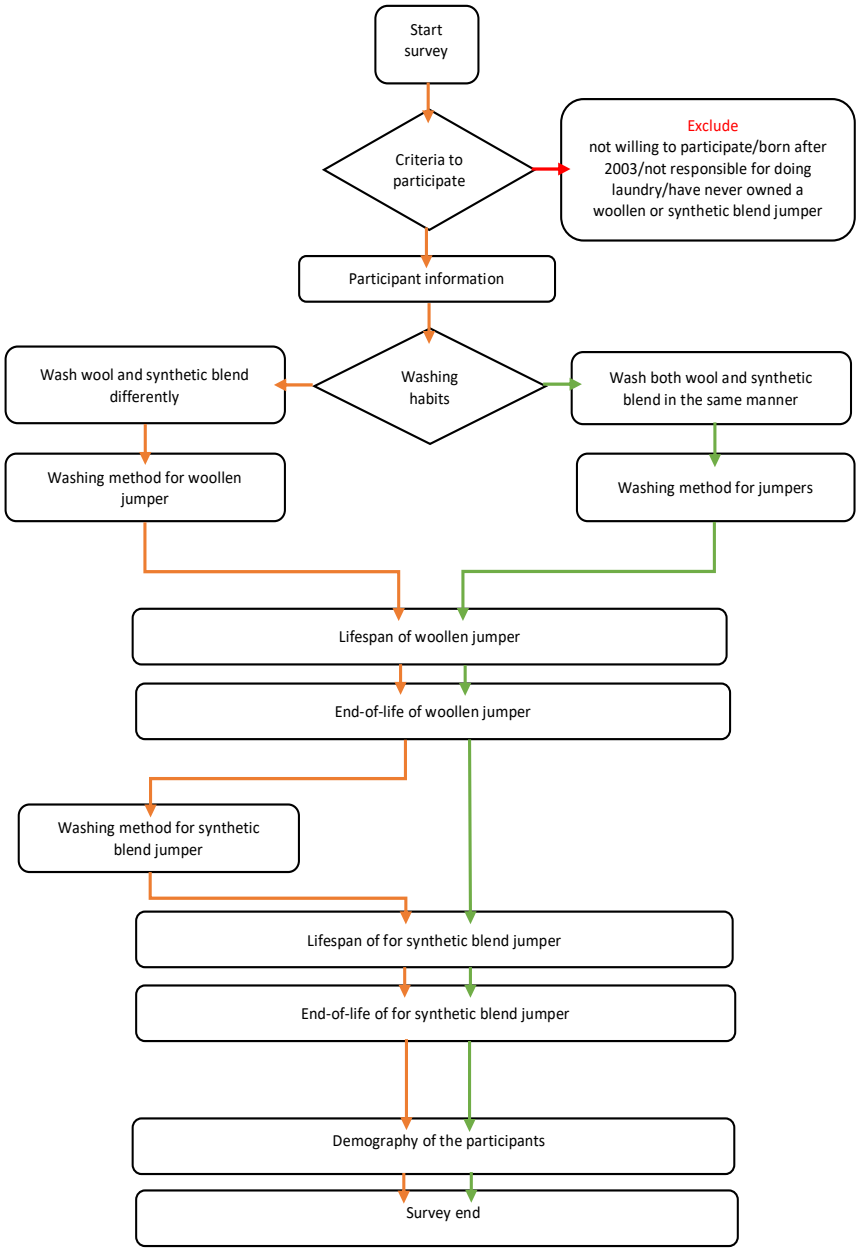

Figure 2. Survey flowchart.

The survey questions related to the woollen and synthetic-blend jumper and their relationship to the discussion of results in this paper are presented in Table 1. The survey data were mathematically analysed and divided into categories. The outcomes were then compared with available published material. Based on Wiedemann et al. (2020) [35], the study calculated the number of wears and washes per lifespan (including reuse) and end-of-life scenarios necessary to estimate the inventory requirement for an LCA.

Table 1. Survey questions on the two jumper types and their placement in this article.

No.	Questions on Woollen Jumpers	Questions on Synthetic Jumpers	Reference in Results Section
1	Have you owned a woollen or/and a wool blend synthetic jumper/sweater/cardigan before? ○ Yes ○ Probably yes, but not sure about the composition ○ No (I am sorry, but you are not part of the study's target group. Thank you for taking the time to participate)		
2	Do you follow the same or different washing method for both woollen and synthetic blend jumpers? ○ Yes, I wash both wool and synthetic jumpers the same way (this survey sub-group was given a separate questionnaire for questions 3 to 6 on washing habits) ○ No, I wash woollen jumpers different from how I wash synthetic blends ○ Can't say, I sometimes wash them the same way and sometimes separate ○ Don't know		
3	How do you usually wash this (woollen) jumper/sweater/cardigan? ○ Hand wash it ○ Wash it in washing machine ○ Send it for dry cleaning ○ Sometimes hand and sometimes machine wash ○ Sometimes hand wash and sometimes dry clean ○ Sometimes machine wash and sometimes dry clean ○ Don't know	How do you usually wash this (synthetic blend) jumper/sweater/cardigan? ○ Hand wash it ○ Wash it in washing machine ○ Send it for dry cleaning ○ Sometimes hand and sometimes machine wash ○ Sometimes hand wash and sometimes dry clean ○ Sometimes machine wash and sometimes dry clean ○ Don't know	Section 3.2.1 Washing methods.
4	Identify the washing machine settings you use for washing this (woollen) jumper/sweater/cardigan? ○ Quick/Fast Cycle ○ Delicate Cycle ○ Normal Cycle ○ Heavy-duty Cycle ○ Don't know	Identify the washing machine settings you use for washing this (synthetic blend) jumper/sweater/cardigan? ○ Quick/Fast Cycle ○ Delicate Cycle ○ Normal Cycle ○ Heavy-duty Cycle ○ Don't know	Section 3.2.3 Washing machine settings.
5	Which detergent would you normally use for washing this (woollen) jumper? ○ Synthetic detergent powder (e.g., Persil/Dynamo/Fab/Surf/Pams/Shotz/Essentials etc.) ○ Eco-friendly detergent powder (e.g., Ecostore/Eco Planet/Earthwise/Natural laundry etc.) ○ Special wool detergents (e.g., Woolskin wool wash/Softly premium wash etc.) ○ Synthetic detergent liquid ○ Eco-friendly detergent liquid ○ Laundry pods or tablets ○ Other [Text entry option]	Which detergent would you normally use for washing this (synthetic blend) jumper? ○ Synthetic detergent powder (e.g., Persil/Dynamo/Fab/Surf/Pams/Shotz/Essentials etc.) ○ Eco-friendly detergent powder (e.g., Ecostore/Eco Planet/Earthwise/Natural laundry etc.) ○ Special wool detergents (e.g., Woolskin wool wash/Softly premium wash etc.) ○ Synthetic detergent liquid ○ Eco-friendly detergent liquid ○ Laundry pods or tablets ○ Other [Text entry option]	Section 3.2.4 Washing detergents.
6	How would you dry this (woollen) jumper? ○ Dry it in wind or sun ○ Use a dryer	How would you dry this (synthetic blend) jumper? ○ Dry it in wind or sun ○ Use a dryer	Section 3.2.5 Drying methods

Table 1. *Cont.*

No.	Questions on Woollen Jumpers	Questions on Synthetic Jumpers	Reference in Results Section
7	When in use, how often do you or someone else typically wash this (woollen) jumper? ○ After every wear ○ After every 2 wears ○ After every 3–5 wears ○ After every 6–10 wears ○ After every 11–19 wears ○ After every 20–29 wears ○ After every 30 wears or less often ○ Never ○ Don't know	When in use, how often do you or someone else typically wash this (synthetic blend) jumper? ○ After every wear ○ After every 2 wears ○ After every 3–5 wears ○ After every 6–10 wears ○ After every 11–19 wears ○ After every 20–29 wears ○ After every 30 wears or less often ○ Never ○ Don't know	Section 3.2.6 Laundry frequency/days per wear wash.
8	Can you approximate the number of times to date you have worn this (woollen) jumper? An approximate indication will work. ○ 1–2 times ○ 3–4 times ○ 5–9 times ○ 10–19 times ○ 20–49 times ○ 50–99 times ○ 100–199 times ○ More than 200 times ○ Don't know	Can you approximate the number of times to date you have worn this (synthetic blend) jumper? An approximate indication will work. ○ 1–2 times ○ 3–4 times ○ 5–9 times ○ 10–19 times ○ 20–49 times ○ 50–99 times ○ 100–199 times ○ More than 200 times ○ Don't know	Section 3.3.1 Lifetime wear events (based upon consumers' estimates).
9	Can you please inform the approximate number of times do you expect to wear this (woollen) jumper in future? ○ 1–2 times ○ 3–4 times ○ 5–9 times ○ 10–19 times ○ 20–49 times ○ 50–99 times ○ 100–199 times ○ More than 200 times ○ Don't know	Can you please inform the approximate number of times do you expect to wear this (synthetic blend) jumper in future? ○ 1–2 times ○ 3–4 times ○ 5–9 times ○ 10–19 times ○ 20–49 times ○ 50–99 times ○ 100–199 times ○ More than 200 times ○ Don't know	
10	How would you dispose of this (woollen) jumper/sweater/cardigan when you no longer want it? ○ Donate to charity ○ Donate/give to family/friends ○ Put it in the rubbish bin at home ○ Recycle at home (e.g., use it as a cleaning cloth) ○ Sell (e.g., Garage sale, Trade Me etc.) ○ Don't know ○ Other [Text entry option]	How would you dispose of this (woollen) jumper/sweater/cardigan when you no longer want it? ○ Donate to charity ○ Donate/give to family/friends ○ Put it in the rubbish bin at home ○ Recycle at home (e.g., use it as a cleaning cloth) ○ Sell (e.g., Garage sale, Trade Me etc.) ○ Don't know ○ Other [Text entry option]	Section 3.5 End-of-life practices.
11	Thank you for taking the time to respond to the questions above. This survey has come to an end but I have one more request. Can you tell me the brand and model number of your washing machine (or, if that is not possible, it's capacity in kilograms)? [Text entry option]		Section 3.2.2 Washing machine type

3. Results

Survey data on the use and end-of-life phases for woollen and synthetic knitted jumpers are presented in this section. The survey demographics are described in Section 3.1, followed by Section 3.2 on the differences in laundry practices for the two jumper types. These laundry practices are examined by focusing on washing methods, washing machine settings, washing detergents, drying methods and days per wear wash (Sections 3.2.1–3.2.5, respectively). In Section 3.3, the lifespans for the two jumper kinds are estimated, while their launderings per lifetime are evaluated in Section 3.4. The disposal practices of the two knitted jumpers are presented in Section 3.5.

3.1. Survey Demographics

The 1094 poll participants were all adults, responsible solely for laundry or sharing it with someone at home. Women made up a sizeable percentage of respondents (around 92 per cent). This is not representative of the country's population, which is 50 per cent male [22], but likely reflects gender norms that still involve more women than men doing laundry. According to a survey of New Zealanders' washing habits that was published in Waikato Times on 25 March 2013, women did more laundry than men.

3.1.1. Participant Information

Five age groups were identified. The largest group of responders was 41 to 56-year-olds, followed by the slightly younger 26- to 40-year-old age group. These demographics correspond with the median age of New Zealand, which was 37.4 years in 2018 [22]. Most participants were in the country's middle to upper-income brackets, but 16 per cent of those who took part in the study did not identify their annual income. The average household size of the poll was three to four persons. Figures 3 and 4 depict survey responses on the age and household size of participants.

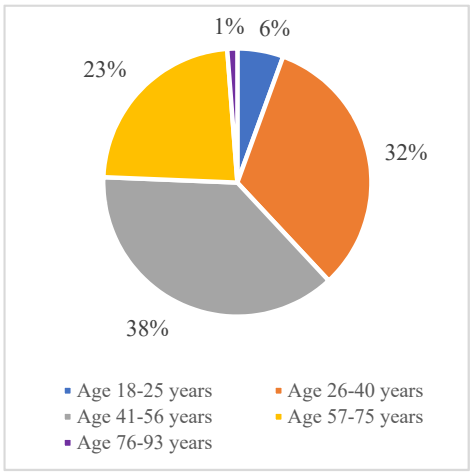

Figure 3. Age group of respondents.

3.1.2. Geographical Distribution

The survey had an acceptable geographic distribution that included both urban and rural homes (Figure 5). In New Zealand, 51.2 per cent of the population live in urban areas [36] and the poll exhibited a similar ratio, with 47 per cent of respondents living in the main centres of Auckland, 11 per cent in Canterbury and 9 per cent in Wellington, with the rest distributed across the country's provinces districts.

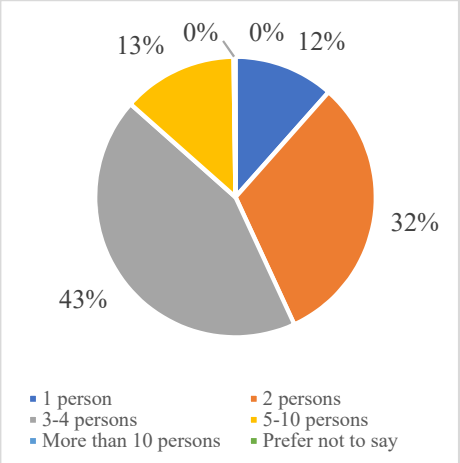

Figure 4. Household size of respondents.

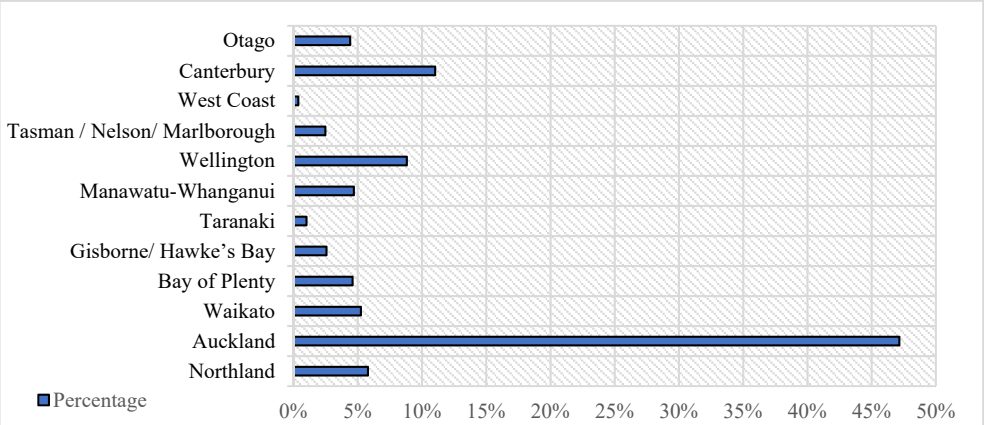

Figure 5. Geographical distribution of survey respondents.

3.2. Laundering Practices

In determining the environmental consequences of the use phase for apparel, it is essential to understand the methods employed for cleaning and the number of wears before each laundering. Both these characteristics fluctuate depending on a garment's material type and can also be influenced by the cultural or regional circumstances where it is used [20]. The following section considers the ways jumpers made of wool and synthetic material are laundered in New Zealand. Laundry comprises washing, drying and ironing. The survey included questions on washing methods, machine settings, machine types, washing detergents, drying practices and days per wear wash. Ironing data were not sought because typically it is not required for knitted jumpers.

3.2.1. Washing Methods

There are several ways to wash a garment and each method plays a role in determining the environmental impacts associated with the use phase. While machine washing is the most prevalent method used, hand washing is widely practised in the rural areas of many developing nations [37]. The usage of shared laundry facilities or laundromats is also common in many countries [18]. For woollen items, hand washing, airing, steaming or dry cleaning are considered appropriate to preserve their properties [20] but may have different environmental implications than cleaning by washing machine. Hand washing uses far less energy and emits fewer greenhouse gases than machine washing [38], positively affecting a garment's overall environmental profile. Participants were questioned about their typical washing routines for woollen and synthetic jumpers. Their responses are depicted in Figure 6.

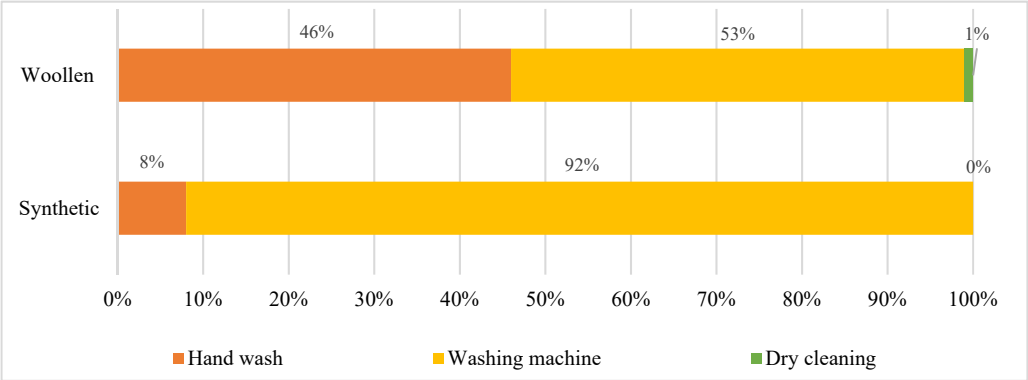

Figure 6. Washing methods in New Zealand.

Results showed washing behaviours for the two jumper types were distinctly different. About 46 per cent of New Zealanders washed woollens by hand, while 53 per cent used washing machines. In contrast, synthetics were machine washed by 92 per cent of respondents and the remaining 8 per cent were hand washed. Dry cleaning was not popular and only a few respondents dry-cleaned both jumper types. In the survey subgroup that laundered both types of jumpers in a similar fashion, 22 per cent hand washed and 78 per cent machine washed.

The findings on the washing methods for woollen jumpers in New Zealand do not align closely with international data. In Germany and the United Kingdom, 27 per cent of woollen sweaters are hand-washed, 63 per cent machine washed and 10 per cent dry-cleaned [35]. In Norway, 19 per cent of woollen garments are hand-washed and 70 per cent machine washed [20]. New Zealand's data for woollen jumpers was almost a 50/50 split between hand and machine washing, which is distinct from other international findings and would influence the LCI in modelling the use phase for apparel consumed in New Zealand. No global studies were identified to compare other countries' washing methods for synthetic jumpers to New Zealand's.

3.2.2. Washing Machine Type

Washing technologies are important factors in determining how a garment's life cycle is evaluated during the use phase. Distinct types of washing machines are utilised in different countries. Horizontal drum or front-loading machines, for example, are more frequent in Europe than vertical drum or top-loading machines, which are more common in the U.S.A., Australia and Asia [20]. Resource utilisation differs greatly between the front and top-loading washing machines, with horizontal drum front-load washing machines using far less water than vertical [20]. The energy intake of these devices varies as well, however, this is more dependent on the machine's age. Having better data on washing machine types in New Zealand would help estimate energy and water consumption. Survey respondents were asked to specify the type and load capacity of machines employed at home. Both top and front-load washing machines with capacities ranging from 5 to 10 kg were observed used in New Zealand, however, a front-loading machine with a load capacity of around 8.5 kg was the most popular.

3.2.3. Washing Machine Settings

In machine washing, the setting selected to launder is critical as it determines the energy and water consumed. Washing machines are available with various programmes such as heavy, normal, delicate or quick wash. A wool wash setting may not always be available on washing machines [20]; thus, a delicate wash programme was chosen for this study. Participants were asked to list the washing machine settings that they employ for cleaning woollen and synthetic jumpers. Figure 7 presents their responses.

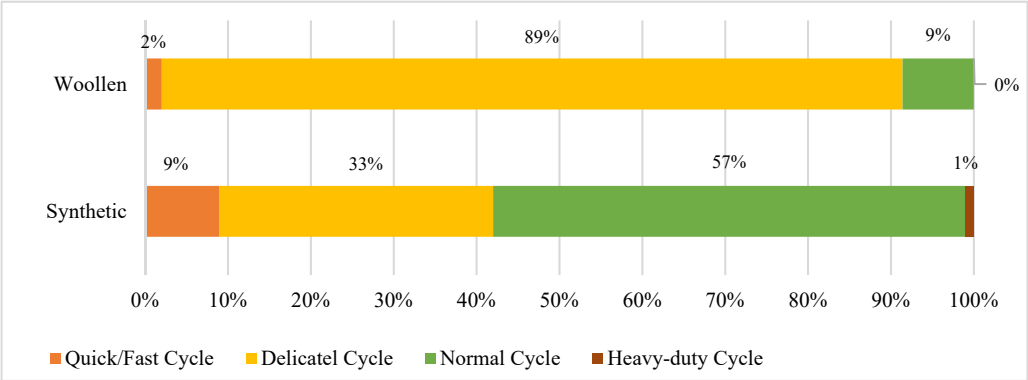

Figure 7. Frequency of washing machine settings in New Zealand.

A delicate wash programme was most preferred for woollens, chosen by 89 per cent of New Zealanders. For synthetics, 57 per cent chose a normal wash, while 33 per cent chose a delicate cycle. The subgroup who washed both materials, in the same manner, preferred a delicate setting (52 per cent), followed by a normal wash cycle (40 per cent), quick wash (7 per cent) and heavy-duty wash (1 per cent).

There is a scarcity of international data on the utilisation of various washing programmes based on material types. However, some studies have indicated that most people do not alter wash cycles to match laundry material [39]. Different washing settings impact the use phase inventory. A 4 kg load delicate wash cycle in a typical 8.5 kg capacity front-load washing machine uses 0.29 kWh of energy and 63 litres of water, compared to 0.93 kWh and 53 litres for a 4 kg load in a normal wash cycle [40].

3.2.4. Washing Detergents

The type of laundry detergent employed to clean clothes also has a sizeable environmental cost in the use phase. Detergents can require additional energy to dissolve in hot water and are made of chemical surfactants releasing toxins into the environment [41]. Detergents are made of different ingredients to suit different material types and can cause pollution in water bodies when drained out [20]. The survey sought to find out the detergents used in New Zealand and understand the differences in detergent use in washing woollen and synthetic clothing. Participants were asked to identify their preferred detergents for washing the two materials. Their responses to the detergents used are depicted in Figure 8.

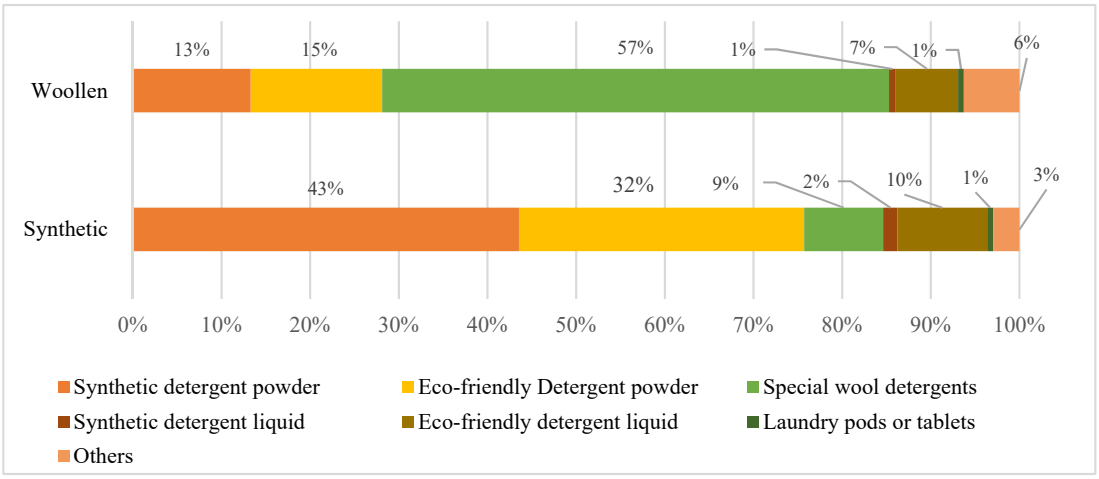

Figure 8. Detergents used in New Zealand.

In New Zealand, wool and synthetic sweaters were laundered with a variety of detergents. Most woollen sweaters were washed with wool-specific detergents (57 per cent) that mainly contain lanolin to preserve the properties of wool [20]. Synthetic jumpers in New Zealand were washed with either chemical-intensive synthetic powder detergents (43 per cent), or milder eco-friendly detergent powder (32 per cent). Other kinds of detergents were applied for both material types but the response percentages were small. The survey group that cleaned both wool and synthetic materials the same way employed synthetic detergent powders (32 per cent) followed by eco-friendly detergent powders (28 per cent), special wool detergent powders (25 per cent) and others in small quantities.

3.2.5. Drying Methods

The method of drying clothing is another factor that impacts the environment during the use phase. Line or air drying is widely regarded as the most environmentally efficient method of drying clothes, as it does not rely on artificial energy sources. Tumble drying is said to consume four times as much energy as washing clothes in a washing machine at 40 degrees Celsius, consuming the most energy during the laundering process [42]. Drying methods differ depending on a country's environment, economy and culture, as well as the type of garment or its fibre type [37]. Knowing the drying method and variances for woollen and synthetic clothing is vital for LCA. We asked the participants how they dried their woollen and synthetic sweaters.

Most participants preferred natural air drying for both woollen and synthetic jumpers, with 99 per cent of woollen and 88 per cent of synthetic jumpers dried in the air, while the rest employed a tumble dryer. The survey subgroup washing both in the same way similarly utilised air drying (90 per cent), while the rest used tumble drying.

These results are in line with most available data on the global use of tumble dryers. However, no studies were found on drying practices for specific fibre types. Sparse use of dryers was reported in Europe and Asia (12 per cent in the U.K. and Germany, 4 per cent in Italy and 3 per cent each in China and Japan), with a very high percentage in the United States of America employing tumble drying for 73 per cent of wet laundry [18]. Both wool and synthetic jumpers were primarily dried naturally in New Zealand without the use of energy-driven dryers, resulting in significant energy input savings for the use phase.

3.2.6. Laundry Frequency/Days per Wear Wash

Laundry frequency/days per wear wash is the number of days a person wears a garment before washing it. Many factors impact it. Base layers such as underwear and socks are washed more frequently than outerwear garments such as jackets and sweaters [20]. Clothing made of synthetic materials such as polyester accumulates odour faster than natural fibres such as cotton and thus requires more cleaning [43]. Even within the same garment type, days per wear wash varies by country or culture. Before each washing, a T-shirt was worn for 2.4 days in China, 1.6 days in the United States, 1.9 days in the United Kingdom, 1.8 days in Japan, 2.0 days in Italy and 1.9 days in Germany [18]. Thus, days per wear wash is an important parameter in calculating an item of clothing's cradle-to-grave environmental impact. It suggests the inventory that goes into cleaning over its lifetime. Participants were asked to recollect a woollen and a synthetic-blend sweater that they owned and answer how often they or someone else washed it. The results are depicted in Figure 9.

Woollen jumpers were found to be worn twice as long as synthetic ones before being washed. On average, a woollen jumper was worn 11.5 times and a synthetic jumper was worn 6.4 times before washing. This is crucial to take into account when creating the inventory for the two jumpers as it will influence the quantity of input materials and output emissions related to laundry.

The days per wear wash for woollen jumpers in New Zealand was slightly higher than the global average, with 6 to 10 wear events before washing [20]. In another survey in Germany and the United Kingdom, 5.2 wear events before wash were estimated for

woollen sweaters [35]. Furthermore, 8.9 days of wear in Norway and 10.3 days of wear in the Netherlands were identified [37]. There is a lack of published studies comparing days per wear wash for woollen and synthetic garments.

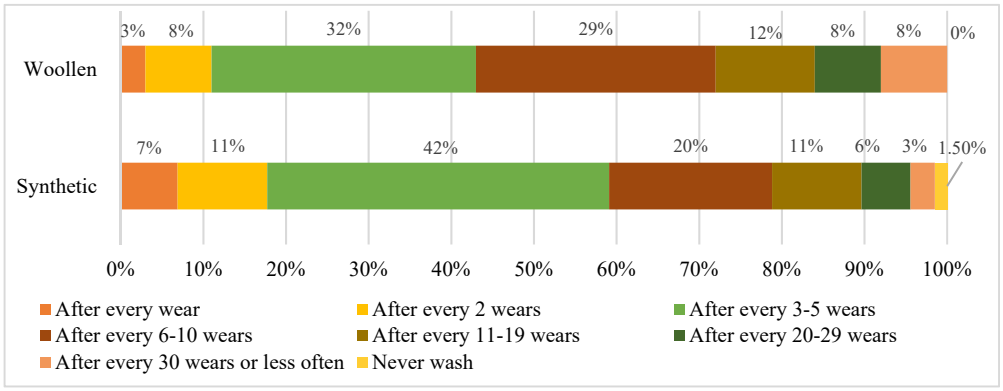

Figure 9. Laundry frequency in New Zealand.

3.3. Lifespan

The lifespan of a garment has a significant impact on its environmental footprint. The longer a garment is worn, the lower its environmental impact. The primary environmental benefits of extended product lifespans are realised through a decrease in the overall number of clothing items needed, i.e., the user does not need to purchase a new sweater. Moreover, the effects of garment manufacture are spread over a larger number of uses [44]. However, identifying a garment's lifespan is a difficult undertaking, as clothing does not have a date of production or expiration. A multitude of measures can be used to determine how long a garment might last, including counting the years of use, number of wears, number of users, or the number of wash cycles it has gone through [17]. Estimating the number of wear events has been cited as the most efficient way of calculating a garment's lifespan [35]. Our study calculated the lifespan of woollen and synthetic jumpers based on the number of wear days they received over their lifetime. Given that a substantial percentage of clothing was donated or sold for reuse, the number of wear events through reuse was also estimated.

3.3.1. Lifetime Wear Events (Based upon Consumers' Estimates)

A lifetime wear event is the number of times the first user, along with subsequent users, wears a garment from the time it is bought until it reaches its end of life [17]. Participants were asked to recall a specific woollen and synthetic-blend jumper they owned and respond with approximately how many times they had worn it in the past and the number of times they expected to wear it in future. The number of times each category was answered ranged from one or two times to over two hundred times. To calculate lifetime wear, mean values for each wear category were coded [35].

Past and future wear events for woollen jumpers were higher than that for synthetic jumpers. Woollen sweaters were worn on average 71 times while synthetics were worn 61 times. For future use, 110 wear times for wool and 74 times for synthetic were estimated. Integrating the past and future wear values, the lifetime number of wear events for a woollen jumper was 181, whereas, for a synthetic jumper, the number of wear events was 135. The wear events for a woollen jumper in New Zealand were almost double the 79 wear events indicated for Germany and the United Kingdom [35]. No comparative international data were found on wear events for synthetic jumpers.

3.3.2. Subsequent Use

According to the end-of-life findings (see Section 3.5), a good proportion of clothing in New Zealand is considered for reuse. A considerable percentage of the poll participants supported donating used jumpers either to charity, family and friends, or reselling

them. Reuse was forecast for 83 per cent of woollen jumpers and 72 per cent of synthetic jumpers. However, not all clothing designated for reuse gets acquired by a subsequent user [17], with approximately 25 per cent left unused [45]. Hence, the survey's reuse rates were adjusted using these proportions. The lifetime wear events for the two jumpers were calculated with L1 being the first life of clothing and $L2_s$ [35]. The adjusted reuse rate for the woollen jumper (RW) was 62 per cent and for the synthetic (RS) was 54 per cent. The formula applied to identify the lifetime use (U) for both jumper types was

	U =	L1+ (L2 × R)
Total use of woollen jumper	U_W =	$L1_W + (L2_W \times R_W)$ 181 + (90.5 × 0.62) = 237
Total use of synthetic-blend jumper	U_S =	$L1_S + (L2_S \times R_S)$ 135 + (67.5 × 0.54) = 171

During their lifetime, including reuse, the woollen jumpers were estimated to be worn 237 times and synthetic 171 times. The total lifetime wear for both jumpers along with past, future and reuse events is shown in Figure 10. This statistic was greater than the total number of wear events estimated for woollen jumpers in Germany and the United Kingdom (109 wear events with a reuse rate of 76 per cent) [35].

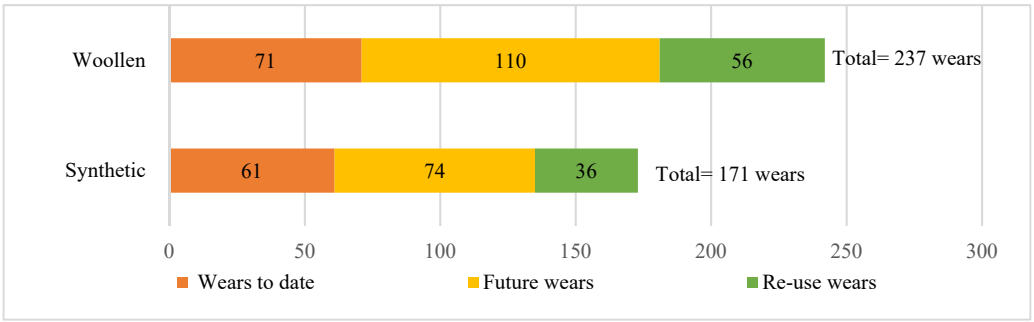

Figure 10. Lifetime wear events in New Zealand.

3.4. Laundering per Lifetime

The laundering per lifetime for both jumpers was estimated through their total lifetime wear events and days per wear wash. Woollen jumpers were estimated to be washed 21 times and synthetic 27 times during the entire course of their lives, including reuse. It was interesting to note that although woollen jumpers were worn more times during their lifetime, they were washed less. It is crucial to take this into account when creating the LCI inventory for the two jumpers as it will influence the quantity of input materials and output emissions related to the use phase.

3.5. End-of-Life Practices

Users discard clothing when it reaches the end of its useful life, resulting in a massive amount of wasted material [44]. Thus, the methods involved in the disposal of apparel play an important role in modelling the cradle-to-grave environmental impact. A global study from Germany, Sweden, Poland and the United States reported that 14 per cent of clothing sold is deposited in landfills every year [46]. The final destination of a garment is largely determined by the consumer and the facilities available to them [18]. The current survey attempted to identify what New Zealanders do with their jumpers when they no longer had use for them. Participants were asked how they preferred to dispose of their woollen and synthetic jumpers when they no longer desired them. Their response percentages are presented in Figure 11.

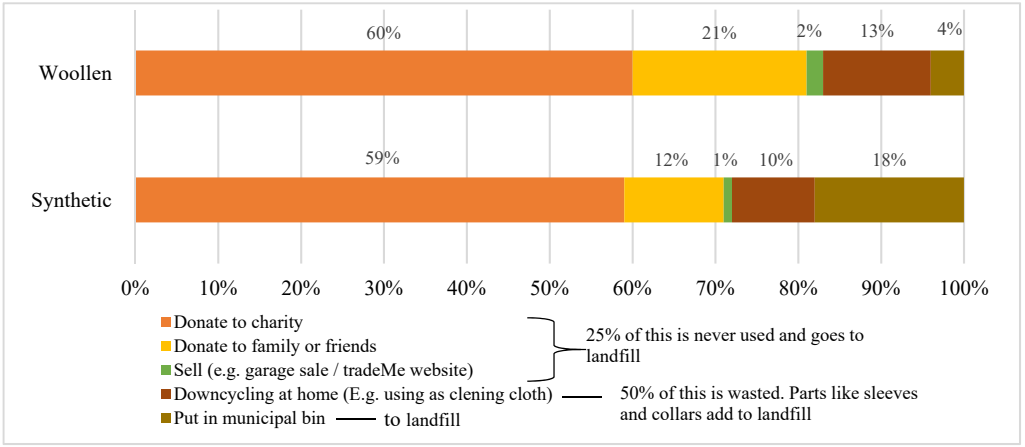

Figure 11. Disposal methods in New Zealand.

In New Zealand, charitable contributions were the most typical destination for both garments. A total of 83 per cent of wool and 72 per cent of synthetic jumpers were donated either to charity, family, friends or resold. This reuse rate for woollen clothing was a little above the rate stated for Germany and the United Kingdom, where 76 per cent of consumers donated or sold garments for reuse [35]. Removing 25 per cent from reuse, as garments that would never be worn [45], a new reuse rate was formulated, which was 62 per cent for woollen and 54 per cent for synthetic-blend jumpers (discussed previously in Section 3.3.2). According to the survey, 13 per cent of woollen and 10 per cent of synthetic jumpers were downcycled at home (mainly used as a cleaning cloth). However, not all of the jumper is downcycled; many of its parts, such as the neck and sleeves, would be cut off before use. So, for this study, 50 per cent of the downcycled jumper was anticipated to be thrown into municipal trash disposal. As a result, a new percentage breakdown for the end-of-life scenario was produced, differing from Figure 11 and presented in Table 2.

Table 2. End-of-life (EOL) scenarios for woollen and synthetic-blend jumpers.

Survey Response	Woollen Jumper (N = 727)		Synthetic-Blend Jumper (N = 706)	
		Adjusted Percentage		Adjusted Percentage
Donate to charity	83%	62% reused	72%	54% reused
Donate to family or friends				
Sell (e.g., Garage sale/Trade Me website)				
Dispose in municipal bin	4%	35.5% landfilled	18%	41% landfilled
Downcycling at home (e.g., using it as a cleaning cloth)	13%	6.5% downcycled	10%	5% downcycled

Responses have been adjusted to split between reuse, landfill and downcycling.

As the survey also provided a text entry option for respondents to explain their decisions on disposal, some participants communicated they would never want to part with their woollen jumpers because they last forever. A few participants specified passing on their woollen jumpers to their children or grandchildren or unravelling them to re-knit something new. A few respondents also talked about composting woollen jumpers. Regarding synthetic jumpers, some participants commented on re-knitting them or returning them to retailers from where they had been purchased, specifically mentioning H&M's stance on material recycling [47].

When looking at international data on disposal to municipal bins for woollen apparel, a 71 per cent disposal rate was observed in Germany and the U.K. [35], which was considerably higher than New Zealand's 35.5 per cent. European countries have well-developed

fibre recycling facilities [48]. Present systems for recycling textiles from municipal waste or specific textile recycling systems are limited in New Zealand [23,24]; hence this option was not included in the poll.

The overall environmental performance of apparel in New Zealand is significantly impacted by the inventory modelled for the end-of-life phases for the two knitted jumpers. Compared to synthetic clothing, wool exhibits a lower disposal-to-landfill ratio. Wool is completely biodegradable [49]. However, microplastic fibres released from the degradation of synthetic textiles have been identified as creating noxious gases and leachate causing environmental pollution [50]. Thus, the environmental benefits of reusing and downcycling along with the differences in the landfilling scenario for woollen and synthetic jumpers will impact their overall life cycle performance. The LCA process heavily relies on the accuracy of this data and its modelling to assess the environmental impacts of the apparel over its lifespan. Table 3 summarises the key survey results comparing the consumption practices for woollen and synthetic-blend jumpers.

Table 3. Consumption practices for woollen and synthetic-blend jumpers.

Results	Woollen Jumper	Synthetic-Blend Jumper
Washing methods	Both hand and machine washing are practised equally	Washed primarily using a machine
Washing machine settings	A delicate wash cycle is used. However, there is uncertainty regarding the load size as it is possible that woollens are washed with only half of the machine's capacity [20]	A normal wash cycle is used
Washing detergents	Mainly by detergents made specifically for wool that contain lanolin	Almost equally by chemical-based and eco-friendly detergent powders
Drying methods	Both primarily dried naturally	
Days per wear wash	Worn more often before each wash. 11.5 times before washing.	Worn less often before each wash. 5.2 times before washing.
Estimated lifespan	237 wears in total, including reuse	171 wears in total, including reuse
Reuse rate	62 per cent	54 per cent
Downcycling rate	6.5 per cent	5 per cent
Landfilling rate	35.5 per cent	41 per cent

4. Discussion

Consumer use and end-of-life practices substantially impact the cradle-to-grave life cycle of clothing and thus should be appropriately accounted for while conducting an LCA [2,19]. These practices vary considerably between countries, garment types [18] and materials [37]. There is, however, a dearth of consumer data for estimating inventory for LCA of apparel products in New Zealand. This study addresses this gap by collecting the necessary data and, in the process, identifies several interesting facts and specific practices related to garment wear and care in New Zealand.

4.1. Critical to Account for the Use and End-of-Life Phases

The impact of clothing consumption on an LCA is not well understood among academics [19]. In order to assess the environmental impacts of knitted jumpers, this research gathered an inventory of their use and end-of-life phases. An extensive consumer survey provided detailed insights into how New Zealanders wear and care about their winter clothing. Jumpers constructed of two different materials, wool and synthetic, showed

varying washing procedures, lifespans and disposal patterns, which alter the resource flow related to inputs (energy, water and chemicals) and outputs (emissions and waste, aside from the final product) in an LCA. Furthermore, compared to other countries, this study found substantial disparities in New Zealanders' consumption habits for clothing. The study affirms that using generalised worldwide data or making assumptions about consumer behaviour patterns regarding usage and disposal practices will not produce valid localised LCA results.

4.2. Various Wash and Wear Approaches for Different Materials

The environmental impacts of garments made using different fibre types vary as they are maintained differently [37]. Laundering requires various resources, including energy for washers and dryers, water for cleaning, chemical-based laundry detergents and waste disposal. Synthetic clothing is cleaned more frequently [43], utilising more resources, releasing microfibre waste into water bodies [50] and thus, having a greater negative environmental impact. Therefore, it is crucial to recognise the differences in days per wear wash of clothing made of various material types when evaluating the life cycle.

The material also impacts the garment's lifespan. The environmental implications diminish by increasing wear events since this utilises fewer resources than would be needed to produce new apparel [51]. Extending the life of a garment by three months would see an 8 per cent reduction in its carbon footprint (3 MtCO2 equivalents), 10 per cent lower water consumption (600 million cubic metres), a 9 per cent fall in waste (150,000 tonnes) and a 9 per cent reduction in its manufacturing cost (GBP 2 billion) [52].

4.3. Discrepancy in Use and End-of-Life Data across Nations

Compared to more popular machine-washing methods for woollens in Europe [20], a high percentage of New Zealanders hand wash. Although New Zealand's drying practices for jumpers are comparable to European and Asian nations (being mainly air-dried), they contrast with data from the United States of America (mainly tumble dried) [18]. Further, while many European nations have established fibre recycling facilities [48], New Zealand facilities are undeveloped [24]. However, this research shows that many New Zealanders intend to donate the clothing they no longer use. Donating used clothing to charity is largely practised in the country. Consumers make effort to travel to charity shops or clothing donation bins rather than simply placing their old clothes in the rubbish [53]. Comparatively, this is lower than what has been reported in other countries such as Germany and the U.K. [35].

This study was able to quantify the number of times a jumper was worn and washed in its lifetime and how it was disposed of in New Zealand. Establishing wash-and-wear events for woollen and synthetic-blend jumpers allows country-specific modelling of the resource flow for LCA.

5. Recommendations for Future Use

To assess the environmental impact of knitted jumpers in New Zealand, inputs from nature, such as the land and water utilised during their care and disposal, may now be accurately measured. Additionally, it is also possible to model the material and resource inputs from the technosphere, such as the chemicals (soap and other auxiliaries) and energy that are utilised for washing and drying the two jumper types. By applying these inventories to widely accessible databases such as Ecoinvent, CML and TRACI, the use and end-of-life phases can be modelled. These databases evaluate the environmental consequences throughout the life cycle of products and processes. It is now possible to make better comparisons between measurable values in many impact categories, such as kilogram carbon dioxide equivalent emissions for assessing the global warming potential and more. This study, however, focused on a specific product, the knit jumper. For the expansion of scope, further investigations on the use and disposal of a range of garment

products in New Zealand would be helpful. There is also a need to explore other popular textile fibres and blends.

6. Limitations

The authors identified some anomalies in this study. While the survey met its target size, most participants were female, which may influence the findings. Furthermore, participants were asked to estimate past and future wear events, which may or may not be comparable to actual wear events. Instead of depending on surveys, practice-based methods such as maintaining laundry diaries and wardrobe studies [54] could be employed to address some of the survey's limitations. There were some assumptions made for reuse that were based on European statistics, such as halving the number of wear events of the first life for estimating the second [35], which might not be the case in New Zealand. Moreover, in drying, natural air drying methods sometimes may require energy, if it is conducted in a heated house where extra heat is required for evaporating water [39], which was not considered in this study. Finally, collecting more detailed information such as washing temperature and laundry load size would be valuable for improving the inventory modelling in the LCA.

7. Conclusions

The goal of this study was to acquire New Zealand-specific inventory data for the use and disposal phases of knitted jumpers that can be utilised for modelling the resource flow in an LCA. This study conducted a comprehensive consumer survey of 1094 New Zealanders to identify their clothing consumption habits. Three important findings were identified:

1. The washing practices, lifetime wear events and disposal methods of clothing made from various textile materials vary significantly. Woollen jumpers in New Zealand are worn and cared for differently from synthetic-blend jumpers.
2. Unique maintenance and disposal practices for garments evident in New Zealand are distinct from those reported in other countries. Different regions or cultures have different ways of handling clothing, and thus, these habits cannot be generalised.
3. Data on comparative lifetime wear events, wash counts and modes of disposal were quantified. For a meaningful LCA, the inventory used in washing and drying and their impact on the environment when disposed to a landfill can be worked out using these figures.

These findings are important for future LCAs in the garment industry, as they show the impact of modelling inventory for the use and end-of-life phases. The study identified the resource flow for the LCA and the method applied to obtain the data. These distinctions will enable a more comprehensive cradle-to-grave life cycle for woollen and synthetic jumpers, allowing an accurate comparison of their environmental impact.

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