fibers

Article

Reducing Plastic in Consumer Goods: Opportunities for Coarser Wool

Lisbeth Løvbak Berg [1,*], Ingun Grimstad Klepp [1], Anna Schytte Sigaard [1], Jan Broda [2], Monika Rom [2] and Katarzyna Kobiela-Mendrek [2]

[1] Consumption Research Norway (SIFO), Oslo Metropolitan University, 0130 Oslo, Norway
[2] Faculty of Materials, Civil and Environmental Engineering, University of Bielsko-Biala, 43-309 Bielsko-Biala, Poland
* Correspondence: lisbethl@oslomet.no

Abstract: Production and use of plastic products have drastically increased during the past decades and their environmental impacts are increasingly spotlighted. At the same time, coarse wool, a by-product of meat and dairy production, goes largely unexploited in the EU. This paper asks why more coarse wool is not used in consumer goods, such as acoustic and sound-absorbing products, garden products, and sanitary products. This is answered through a SWOT analysis of results from a desktop study and interviews with producers of these products made from wool, as well as policy documents relating to wool, waste, textiles, and plastic. Findings show that on a product level, the many inherent properties of wool create opportunities for product development and sustainability improvements and that using the coarser wool represents an opportunity for replacing plastics in many applications as well as for innovation. This is, however, dependent on local infrastructure and small-scale enterprises, but as such, it creates opportunities for local value chains, value creation, and safeguarding of local heritage. The shift to small-scale and local resource utilization requires systemic change on several levels: Here the findings show that policy can incentivize material usage transitions, but that these tools are little employed currently.

Keywords: resource utilization; wool; plastic; synthetic fibers; fiber properties; policy; sustainability; product innovation; SWOT analysis

Citation: Løvbak Berg, L.; Klepp, I.G.; Sigaard, A.S.; Broda, J.; Rom, M.; Kobiela-Mendrek, K. Reducing Plastic in Consumer Goods: Opportunities for Coarser Wool. *Fibers* **2023**, *11*, 15. https://doi.org/10.3390/fib11020015

Academic Editor: Mourad Krifa

Received: 20 November 2022
Revised: 13 January 2023
Accepted: 19 January 2023
Published: 28 January 2023

1. Introduction

Wool has a complex fiber structure, which gives it multiple properties, such as moisture- and sound-absorption, temperature-regulation, and odor-prevention. In addition, it has the potential to be used in knitted and woven as well as non-woven materials. All wool, regardless of fiber diameter, possesses these properties, which combined make wool suitable for a large variety of applications. Still, coarse wool is underexploited in the EU. It should, however, be possible to find uses for this wool.

The starting point for this study is coarse wool from Polish mountain sheep [1]. This is particularly coarse wool that is not being used. Similarly to a lot of wool in the EU, where as much as 80% of the wool production is estimated to be treated as waste [2], this wool is a by-product of meat and dairy production. To investigate the use of this coarse wool, a wide range of product groups that do not require the softness of Merino wool, nor the strength of plastic fibers were examined. These products, therefore, had the potential to be or were made from coarse, surplus wool. This included acoustic and sound-absorbing products, products for garden and cultivation products, insulation, sanitary products, funeral products, and fiberglass replacements. Many of these products are commonly made of plastic, mostly in the form of synthetic fibers. In addition, many of them are single-use, such as sanitary products and plant pots.

While the use of plastic is increasing, many farmers are struggling to sell their wool at a price that covers their costs. This article seeks to connect these two problems, the plastic problem, and the surplus wool problem, by asking: Why is not more coarse wool used in consumer goods? The focus is in particular on products that are currently made of plastic.

To answer this question, the obstacles and opportunities for replacing plastic with coarse wool are examined using a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis. The analysis is based on data from two studies of the potential for utilizing Polish mountain sheep wool in consumer goods [3,4]. For these studies, product searches were done within newer product types such as sound-absorbing installations and hygiene products but also among more traditional utilization of wool. Findings indicated that coarse wool has the potential to be used successfully in several products which today are mainly made of synthetic fibers and other plastic materials. The studies further indicated that practical issues, such as infrastructure, availability, and price were general obstacles for producers to use wool in their products. However, the specific obstacles and opportunities for replacing synthetic materials with coarse wool have not been identified and analyzed. This is in line with previous research, which has focused on the technical properties of wool and product development, leaving out a qualitative understanding of the wool system and the political framework it sits within. Therefore, an analysis of policy documents that relate to wool, plastic, waste, and textiles is included in this study, to substantiate the discussion by incorporating a contextual perspective.

1.1. Background

Before the COVID-19 pandemic, about 8 million tons of plastic waste ended up in the ocean every year [5]. Decreasing the adverse effects of plastics, i.e., microplastic pollution, and removing single-use plastic are measures receiving increasing attention and that are seen as political goals [6]. However, in many areas, the opposite is happening. One example is personal protective equipment (PPE) related to the COVID-19 pandemic, made of synthetic fibers, another is clothing—that is not only used less and less but is increasingly made of plastic [7].

Synthetic textiles are an important, but often forgotten part of the increasing plastic waste problem [8]. Synthetic fibers, such as polyester, elastane, acrylic, and polyamide, are not biodegradable and synthetic microfibers and textile waste are increasingly going astray in nature. The textiles contain environmental toxins added during the processing of fiber and fabric and through microfiber shedding synthetic textiles contribute up to 35% of the released microplastics which have been shown to end up in our lungs, oceans, animals, and even placentas [7,9–16]. There is increasing knowledge and concern about these microplastics and in particular their negative effects on health and the environment [17,18].

The use of plastic, including in the form of synthetic textiles, has grown rapidly. Synthetic fiber production grew from 30 to 68 million metric tons between 2000 and 2020 [19], and today represents 64% of global fiber production [20]. Global clean wool fiber production decreased from 1.3 to 1 million metric tons in the same period [21] and currently represents only 1% of global fiber production. Most of this is Merino wool, that with its very fine, soft fibers dominates the global wool market. It is also what is mainly used by the European textile industry [22]. In comparison, the annual EU (including the UK) wool production is reported to amount to about 200 thousand metric tons [23,24], an estimated 160 thousand metric tons of which are discarded [2]. This wool is buried or burned instead of used and represents an expense to the farmers, rather than a potential income.

Only a small amount of European sheep are reared for milk production [22]. This is the case of the Polish mountain sheep [1]. Maintaining the milk quality does not allow for breeding for wool qualities to any significant extent. This makes this already coarse wool the most complex to use because of the varying wool quality between each sheep. Much can, however, be gained from better handling and sorting of the wool, to avoid contamination and thus separate the different wool qualities for different uses.

Reducing the amount of plastic in circulation would be the most efficient way to reduce microplastic and plastic pollution and there is political will to reduce plastic pollution on a global level [6,25]. Consumers have, however, grown accustomed to the various plastic products that have improved our lives in many ways, and simply eliminating them would be difficult. Therefore, finding good replacements in natural materials is an important avenue to explore.

1.2. Previous Research

Academic efforts to utilize and valorize surplus, coarser wool, range from creating wool powders and keratin [26,27], fertilizers [22,23,27,28], substrates for biogas production [22], regenerating fibers from waste keratin [27,29], insulation [27,30,31], water purification [32,33] to bio-composites [34–36]. A common factor is a focus on wool utilization as a waste management process in non-textile products [22,23,26–31,34,36], rather than using the material in high-value textile products.

Some academic efforts are being made to increase wool usage from a broader perspective, e.g., in Italy [30], Kenya [37], and Iran [38]. This research is often based on examining the technical aspects of the wool, measuring various properties, and classifying it. Though this is an important knowledge base for creating wool products and value chains, it only provides a partial picture and leaves out important information needed to restore and develop future value chains and markets. There is a need for a qualitative understanding of the wool systems and their regulatory context, seeing the various elements in connection with each other in order to create a more complete picture of why the wool remains unused.

The Norwegian KRUS project, however, applied a broader approach of mapping, product development, and working closely with businesses and other stakeholders in the wool value chain, in addition to examining the technical qualities and breeding strategies to improve wool quality [39]. It has resulted in higher usage of Norwegian wool, including Norwegian crossbred (30–40 μ) and even coarser wool (≥40 μm), in textile products and a growing appreciation for the variety of qualities of different wool types. The WOOLUME project is continuing this approach from the Polish perspective [40].

While wool usage has had a slight decline globally, the global sheep population is currently growing, because of increased meat demand [21]. This will increase the amount of coarse wool available and adds to the urgency of improving the utilization of this resource. Utilizing more wool in products currently made of plastic, but that benefit from the advantageous properties that all wool possesses, from biodegradability to temperature and moisture regulation, could contribute to better resource utilization, less waste, and in many cases less use of plastic.

The academic research around plastic replacement is mainly focused on the development of bioplastics, e.g., [41,42]. The examples of studies that examine the replacement of plastics with natural materials are few and focus on material innovation for packaging using cellulose, starch, or algae [42–47], or exclude animal fibers [48]. The exception is research related to the development of natural fiber-reinforced bio-composites, where wool is one of the fibers examined [34–36].

1.3. Properties of Wool and Plastics

The many benefits and versatility of plastics are touted by plastic manufacturers and researchers alike, e.g., [42,49]. Similarly, wool is touted as nature's performance or super fiber when promoted by businesses using it, e.g., [50,51]. The latter suggests that synthetic fibers are what are rather commonly thought of as performance fibers [49].

For wool, these are innate, while for synthetic materials, these are created through production processes or added chemicals, as Table 1 shows. Several of these chemicals also have negative effects on our health and the environment.

The properties in Table 1 apply to all types of wool, with slight variations for different fiber diameters and pigmentation. The main differences between Merino wool and coarser wool are that coarser wool is stronger and often pigmented. Merino has white and very fine, fibers (17–30 μ). What is called coarse wool has a fiber diameter of 22–32 μ: The surplus Polish wool is in general much thicker with an inner coat of 36 ± 9 μ, and guard hairs of

67 ± 12 µ. The average Polish mountain sheep has 54.5% guard hair. The strength of the wool also depends on other properties such as fiber length, crimp, kemp, etc.

Table 1. Comparison of properties for sheep wool and synthetic materials, both untreated.

Property	Sheep Wool	Synthetic
Tenacity	Abrasion strength—medium Tenacity: 1.6 cN/tex [52]	Abrasion strength—high Tenacity: Polyamide (PA): 3.5–5.6 cN/tex; polyester (PET): 2.4–7.0 cN/tex [52]
Moisture absorption	Hydrophilic: Moisture regain: 14–18% [52] Hygroscopic: Absorbs up to 35% of its weight in moisture from the air [53]	Hydrophobic: Moisture regain: PA: 4–5%. PET: 0.2–0.4% [52] Polypropylene (PPE): Low hygroscopicity (0.4 ± 0.1%) [54]
Endothermic properties	Produces heat during absorption [54]. High heat production (+77 °C) and stays warm [54] Mulch greatly reduces variability in soil temperature and helps the soil retain moisture [55]	PPE: Low heat production (+0.5 °C) and cools quickly [54]. Synthetic mulch has little effect on soil moisture and temperature.
Thermal properties	Does not melt.	Thermoplastic: Melting temperature: PA 215 °C; PET 255 °C [52]
Flammability	Burns slowly; self-extinguishing Ignition temperature: ≈600 °C [56]	Melts. burns, high smoke. Ignition temperature: PA 530 °C; PET 440 °C [52]
	Heat of combustion: 21 MJ/kg [52]	Heat of combustion: PA—3.1 MJ/kg; PET 25–30 MJ/kg [52]
	Limited oxygen index (LOI): 24–25% [52]	LOI: PA 20–24%; PET 20–22% [52]
Thermal insulation	Comparable to currently used commercial synthetics [57]	Thermal resistance: PET 0.51 °C m^2/W; Cotton (CO)/PET 0.49 °C m^2/W [57]
Sound absorption	Similar or better acoustic properties than synthetic alternatives [58–61] Polish coarse wool: acoustic properties as Merino [62]	Fiberglass and polyurethane (PU) foam are less absorbent than wool [58–61].
Sound isolation	Increases transmission loss of stud walls by up to 6 dB [59] Extremely good [57]	Similar to wool [57]
Antistatic ability	Residual voltage of ~42 from 90 starting voltage [63]	Residual voltage of ~88 from 90 starting voltage [63]
VOC-absorption	Absorbs volatile organic compounds (VOCs) and darkly pigmented fibers absorb more [64].	Leaks VOCs [65]
Hypoallergenic properties	Lanoline in wool can cause allergies. Wool is hypoallergenic after scouring. Coarse wool fibers (≥30–32 µm) can cause cutaneous irritation (itching) [66].	PET is used as an allergy-friendly alternative to, e.g., down in bedding.
Odor-prevention	The least odor retaining and lowest odor build-up of textile materials [67]. Airing has a good effect on the smell of sweat in wool [68]	PET and CO are the most odor-intensive textile fibers [67]. Airing does not affect the smell of sweat on synthetic materials [68].
Biodegradability	Biodegradable; decomposes in 1–3 seasons depending on the type of soil [69–71]	Non-biodegradable; become microplastics in approx. 400 years [72]
Fertilizing capacity	Contains 10–12% nitrogen and 3–4% potassium, nitrogen compounds are released into soil during biodegradation; promotes growth of grass and other crops [69–71,73–75]	Fibers are not biodegradable and do not release nutrients promoting plant development
Herbicidal effect	Mulch decreases weeds in the fields [76]	Decreases weeds as a cover/blanket

2. Materials and Methods

This paper presents data concerning products made of wool collected during two series of desk research and interviews, combined with a document analysis examining policy and definitions concerning the use of wool in the EU. For the analysis, a SWOT method was applied. The research design is illustrated in Figure 1.

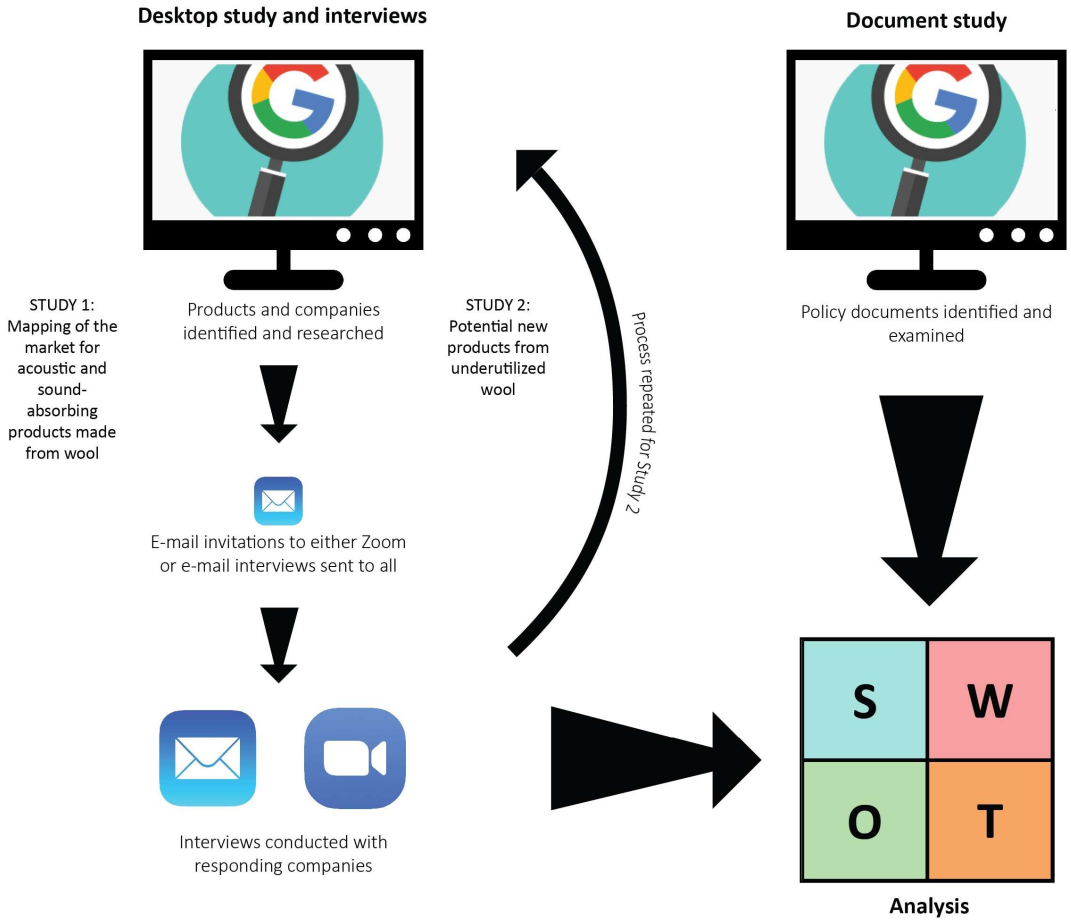

Figure 1. Research design. Data from desktop studies and interviews were combined with data policy document analysis in a SWOT analysis of the market for coarse wool products vs. products made of synthetic materials.

2.1. Desktop Studies and Interviews

The first study mapped the European market for acoustic and sound-absorbing wool products and the second examined the market for alternative wool products [3,4]. For these studies, products had been identified through online searches, wool-related events and seminars, and recommendations from interviewees. They were chosen because they were made from or had the potential to be made from the coarse, surplus wool that is often discarded. About 23 producers of acoustic and sound-absorbing products and 19 producers and distributors of other wool products were identified (see Table 2). Available information, such as company size, location, and product range, was collected from websites and public documents and analyzed. Resulting from the desktop studies, six producers of acoustic and sound-absorbing products were interviewed, three by email and three over Zoom, and eight producers or distributors of other wool products, four by email and four over Zoom.

Table 2. Wool products by category, product type, wool type used, location and competition.

Category	Product Type	Wool Type	Location *	Competition
Acoustic and sound-absorbing products	Wool felt Wool screens and panels Wool rugs and carpets	Merino wool, some coarser wool	AU, CH, DE, DK, ES, IE, IS, NL, NO, SE, UK	Screen dividers made from polyester felt or polyurethane acoustic foam. Rugs and carpets from polyester or other synthetic yarns.
Garden and cultivation	Wool garden felt	Unspecified	UK	Polypropylene textiles geotextiles for, e.g., erosion control during road construction and for garden felt to prevent weeds from growing. Burlap.
	Wool garden felt	Unspecified RS wool	RS	
	Wool plant blanket	Unspecified AU/EU wool	AU	
	Wool fertilizer pellets	Surplus US coarse wool	US	Synthetic fertilizers from by-products of the petroleum industry or manure.
	Wool plant pots	US faulty wool hats	US	Plastic plant pots.
	Wool slug-repellent pellets	Unspecified wool waste	UK	Toxic slug repellents containing iron(III) phosphate, metaldehyde or methiocarb.
Insulation	Batt or loose-fill insulation	Unspecified NZ wool	US	Stone or glass wool insulation for cars and housing. Polyester insulation for housing.
	Wool roll insulation	Unspecified UK wool	UK	
	Insulating packaging for transport	Unspecified	UK	Plastic cooling elements and insulation.
	Bubble wool	Unspecified EE wool	EE	Plastic bubble wrap.
	Wool duvets	DK Shropshire wool	DK	Polyester or down duvets.
Sanitary products	Technical wool materials for sanitary products	NZ strong wool	NZ	Polypropylene fabrics, polypropylene/polyester/cellulose fiber mix with chemical treatments.
	Sanitary, makeup pads and diapers	Merino wool	CA	Single-use diapers and sanitary pads, mainly of plastic.
	Hygiene products (pads etc.)	Organic NZ wool	NZ	Single-use cotton pads and disposable wipes made of polyester or polypropylene mixed with cellulosic fibers.
Other new products	Wool coffins	Merino wool	UK	Wood or plastic coffins: oil-based varnishes, synthetic fabric interiors.
	Felted wool urns	Merino and DK wool	DK	Non-biodegradable urns, made of metal, ceramics, or polymer resin.
	Bio-resin "fiber wool" chair	UK Herdwick sheep wool	UK	Products made of conventional fiberglass using synthetic resin.
	"Fiber wool" boat	NZ strong wool	NZ	
	"Fiber wool" surfboard	NZ strong wool	USA/NZ	

* The country where the producer(s) is(are) based.

For each study there were two standard interview guides; one set of questions for email interviews and another for Zoom interviews adapted to a semi-structured interview approach. These were customized before each interview to fit with the producer and updated as a deeper understanding of the market was acquired. The market for acoustic and sound-absorbing elements was found to be rather competitive and many companies were reluctant to respond to questions about company turnover, therefore these questions were left out later in the study.

During the interviews, questions were asked about:

- Business setup and product offering;
- Type and origin of wool;
- How the wool was purchased;
- Wool supply and value chain;
- The market for the product(s);
- The customers for the product(s);
- Advantages and challenges of using sheep wool;
- The potential for using coarser wool if using Merino wool.

To alleviate any competitive concerns, the products and producers have been anonymized and full quotes are not presented. Instead, Table 3 shows an overview of the producers, sorted by the definition of the European Union of enterprise sizes and by what type of products they make.

Table 3. Overview of producers by company size (number of employees) and type of products.

Products/Size		Micro (<10)	Small (<50)	Medium (<250)	Large (>250)
Acoustic and sound-absorbing products	Felt			1 *	1
	Screens and panels	6 *	3 *	3	2
	Rugs and carpets	2	1	2	2
Garden and cultivation		2 *	2		1
Insulation		4	1 *		
Sanitary products		3 *			
Other new products		4 *	1 *	1	

* Companies of this size, supplying this type of product were interviewed.

2.2. Document Analysis

Policy documents are a specific type of document, that is defined by language and writing style, type of information, type of argument, design (length, use of figures and tables, etc.,), and so on [77]. As with any document, they can be understood as “social facts”, meaning that they are produced, shared, used, etc. within a social context [78]. Their analysis is therefore dependent on an understanding of their purpose, author, and addressee [79].

Analysis can be done of the policy context, the policy text, or the policy consequences [80]. The study of the policy text is here used to complement the desk research and the qualitative interviews, as a means of triangulation [81]. This allows for an understanding of policy context and consequences, namely the underpinnings of the policy, what political solutions the author foresees, the context within which the policy plays its role, and how it affects the use of coarser wool and synthetic materials.

Polish wool usage is regulated through EU policy. Therefore, the analysis builds on European policy documents along with a central international document on resource efficiency. These were identified through Google and the European Commission (EC) website, using the following key word searches: Resource efficiency, wool, plastic, waste, textiles, sustainable, regulation, and directive. The documents below have been examined:

- International Resource Panel report: “Resource Efficiency: Potential and Economic Implications” [82];
- EU Waste Framework Directive [83];
- Regulation (EC) No 1069/2009 health rules as regards animal by-products and derived products not intended for human consumption [84];
- EU Directive on single-use plastic [85];
- EU Circular economy action plan [86];
- EU Strategy for Sustainable and Circular Textiles [87];
- EC: Microplastic pollution from textile consumption in Europe [88].

Documents were screened manually and searched for key words and themes such as wool, natural fiber, resource utilization, local production, textiles, etc.

2.3. SWOT Analysis

A SWOT analysis is a business strategy tool used to identify internal strengths and weaknesses, alongside external opportunities and threats [89]. The explicit inclusion of internal factors and categorization of aspects in terms of expected impact (positive or negative) in the model facilitates strategic planning and decision-making [90]. It is also a useful tool to give an overview of and communicate the situation of the entity analyzed [90].

The method was chosen to provide a holistic view of the business situation of the coarse wool to explain the low usage.

In this study, the different aspects were first listed and then placed in the different quadrants of the SWOT table. Afterward, they were grouped into themes: Properties and Product Performance, Price and Availability, Sustainability, and Regulations and Policy. As common in SWOT analysis, one aspect can be both a positive and a negative aspect, e.g., coarser wool being more labor-intensive to use means that it creates more jobs, but at the same time it makes it more costly, as will be examined in the following. Following the SWOT logic, the findings were divided into internal and external factors. Internal factors define the strengths and weaknesses of the internal environment, in this case, the material itself and its value chain directly, and external factors, define opportunities and threats that are determined by the external environment operated in, i.e., the overall market and competition. The themes all had both internal and external factors to them, except "Definitions and policy" which, by definition, are external factors not decided by the raw material itself.

2.4. Limitations

Difficulty in contacting and obtaining responses from producers limited the number of interviews. In addition, the interviews were not recorded or transcribed verbatim, so the reanalysis relies on notes from interviews written by interviewers. In contrast to the first study of acoustic and sound-absorbing products, the second study did not consist of a mapping of all alternative wool products and does not include Norwegian examples as another research project was examining the use of downgraded Norwegian wool in horticulture [91]. It may therefore leave out important examples. There may also be other relevant political documents than those that have been analyzed, and policy could also have been examined using other methods, e.g., a specific policy impact study could have been done.

3. Results

The SWOT analysis of the material gave insight into the obstacles and opportunities for using coarse wool, where positive aspects give room for opportunities and negative aspects represent obstacles. Figure 2 is an overview of the themes found during the SWOT analysis that will be detailed and discussed in depth in the following.

3.1. Properties and Product Performance

The difference in innate properties between wool and plastics shown in Table 1 was reflected in the interviews and desk research, where the producers highlighted additional functional benefits compared to conventional materials due to wool's many different functional properties [3,4].

Figure 3 details the findings related to properties and product performance.

The thermal insulation of wool, and as a consequence its heating capacity, is possibly what most people associate with wool and as such, it is not surprising that many of the products put forward this benefit of the material, including producers of roll insulation, wool duvets, plant blankets and thermic insulation for packaging. One producer of roll-insulation did however blend the wool with 25% recycled polyester, claiming improved insulation properties. Wool's connection to heat is more dynamic than just heat insulation, being thermoscopic and at the same time also hygroscopic, it in addition reacts endothermically, releasing heat when absorbing moisture. Together, these properties ensure that wool retains its insulating capacities even when wet, as opposed to cellulose and synthetic fibers.

When companies create packaging materials from wool, they also take advantage of the insulating properties. Wool packaging can, in addition to absorbing shock, provide benefits that plastic does not have, such as better heat and moisture control important in e.g., transportation of vaccines. The hygroscopic capacity also contributes to the wool's naturally antistatic properties, pointed out by packaging producers as beneficial especially for the packaging of electronics.

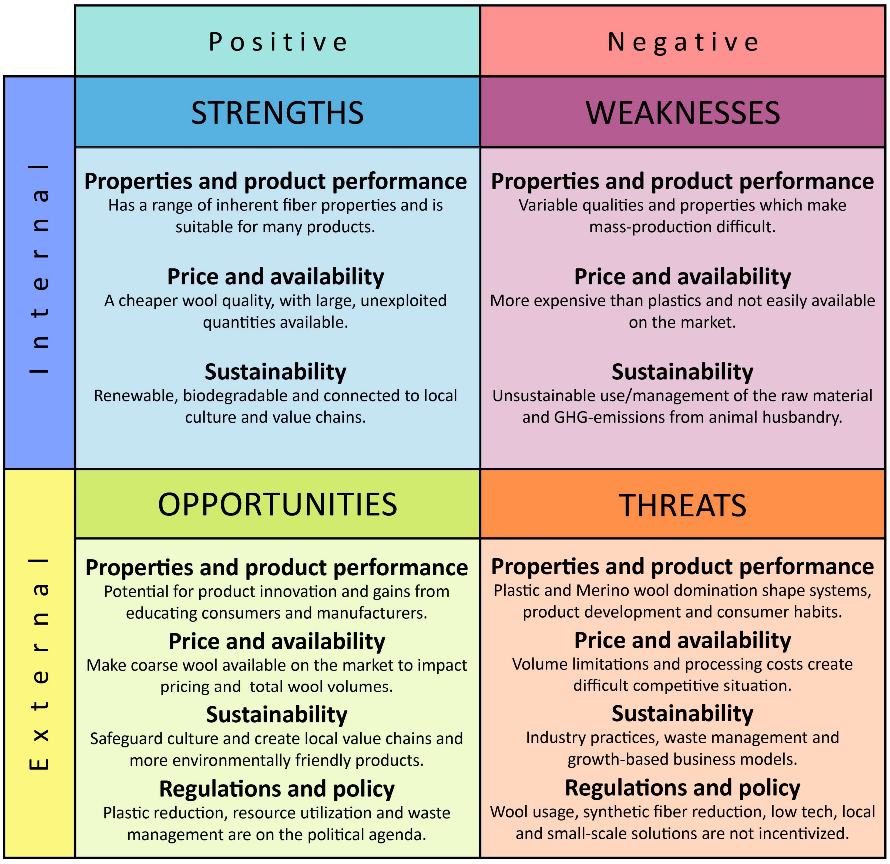

Figure 2. Overview of SWOT analysis of coarse wool.

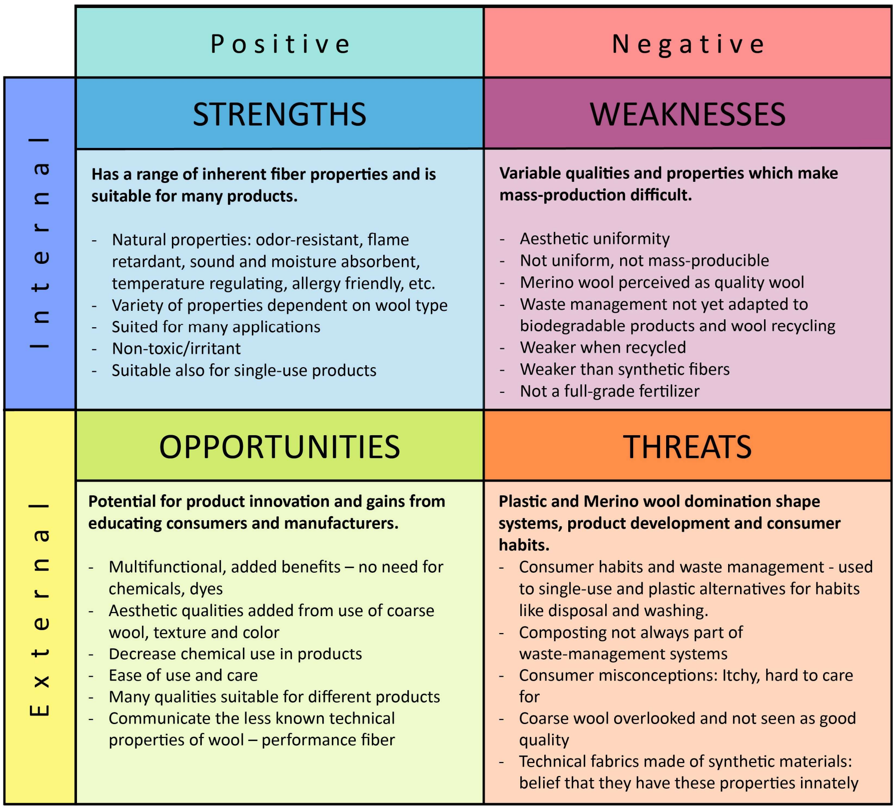

Figure 3. SWOT—Properties and product performance.

This hygroscopic property is also important for supporting plant growth for the garden and cultivation products that were examined. The UK-based producers of garden felt used wool from Herdwick sheep in a combination with a layer made of jute fiber. Their main selling point was that the products are hygroscopic. In soil, wool residues and other wool products can effectively absorb and retain moisture which facilitates water conservation [55]. For the wool plant blanket, the material's thermoscopic properties are an additional bonus, further protecting plants from cold nights or winter frost, and the product is branded on its natural heat insulation.

Concerning its hygroscopic properties, wool is furthermore a complex fiber, as the core absorbs and retains moisture, while the outer scales wick water droplets away, limiting absorption. In comparison, plastics have to be treated chemically to become retain moisture. In the study, companies taking advantage of the natural hygroscopic properties of wool to create sanitary towels and diapers, as well as make-up removal pads, face cloths, and body sponges, were identified. One of the companies had also developed technology to make the wool even more absorbent by altering its hydrophobic surface. This way the material became super-absorbent and went from absorbing 0,35 times to 2500 times its weight. This resulted in products that outperformed conventional diapers in tests. In addition, the producer highlighted temperature regulation as an added benefit of wool diapers, preventing children from waking up cold at night. Furthermore, conventional diapers have chemicals added to prevent odor, while wool diapers do so naturally. Smell is an important aspect of personal hygiene and sanitary products and potentially also for other products that come in contact with the skin, such as upholstery in vehicles and furniture.

The producers of insulation for houses and cars put forward the additional benefits of wool naturally having low flammability, and not requiring the additional chemical treatment that synthetic fibers do in order to achieve this property. Therefore, wool insulation materials can be used for floor, ceiling, seat, and door coverings and in the engine compartment of the vehicle. Fire safety is important in vehicles, but it is also put forward by producers of acoustic and sound-absorbing products.

Acoustic and sound-absorbing products usually take the form of rugs, carpets, screens, and panels, but may also comprise sculptures or other installations intended to improve the acoustic qualities of the rooms or areas in which they are placed. Here the wool and synthetic variants perform on similar levels, but the wool products can also improve indoor air: Wool also can absorb volatile organic compounds (VOCs) instead of emitting them and does not shed microplastics, which are increasingly shown to enter human lungs through breathing [15]. Some producers market their products with the former additional benefits, however, the extent to which plastic products leak various chemicals and the health effects of this is little understood: A study found that sanitary pads have higher phthalate contents than other plastic products and their proximity to the skin leads these to leak into the body of both adults and children [65]. Therefore, substituting plastic in hygiene products may be beneficial to health as well as the general environment.

Health benefits are also quoted by producers in terms of hypoallergenic properties. Here, however, their customers sometimes had preconceptions about wool, allergies, and itchiness. The producer of wool duvets explained that customers referred to wool allergy: This may be connected to the perception of wool as itchy and cutaneous irritation being, confounded with allergic reactions [66]. Down is also thought of as being allergy-inducing and polyester-filled items are presented as allergy-friendly alternatives to these, though in reality, tests show higher levels of dust mite allergens in synthetic bedding [92]. In this case, wool duvets will not only keep one warm and regulate temperature and moisture, but they also represent a plastic-free alternative to down-filled duvets.

One benefit that was mentioned by almost all producers was wool's biodegradability—the ability of the product to avoid becoming waste at the end of life, or even that this was a major part of the product's function. This aspect makes it suitable for single-use products and in particular those that come into contact with organic matter, such as diapers and sanitary towels.

Biodegradability further contributes to the ease of use of wool in garden felt and plant pots, not only through alleviating microplastic pollution issues as they do not need to be removed, but the plant pots can also be planted directly into the soil, and release nutrients to the soil as they decompose. Ease of use was also highlighted by manufacturers of insulation for cars and housing as conventional stone or glass wool requires protective gear during installation, whereas the wool alternative does not.

The producer of wool pellets said their pellets were a 9-0-2 grade fertilizer, containing 9% nitrogen, 0% phosphorus, and 2% potassium. Though wool is not a "full grade fertilizer", as it does not contain phosphorus that is required for plant growth, this can be an advantage as phosphorus pollution has become a serious issue affecting nearly 40% of earth's land areas leading to nutrient runoff into waterways that causes blooming of harmful algae. Low phosphorus content in fertilizers means no nutrient runoff and studies suggest that in places with long histories of overuse, crops can thrive on the stores of phosphorus built up in the ground [93].

A major advantage to using wool compared to plastics is that wool's many properties work together in one product, whereas synthetic products have one main function or are treated chemically to attain other properties. Polypropylene garden felt keeps weeds away and insulates somewhat, but wool felt does this, while it also insulates much better, retains moisture, and becomes a fertilizer instead of microplastics after use. Similarly, when used as a geotextile for erosion control, wool has a sufficiently long decomposition time for plants to take root and start controlling the erosion themselves, and later provides nutrients and retains moisture for these plants [94], again avoiding microplastic pollution and adding plant nutrition.

A less-known additional property is the wool pellets' potential pesticidal effect on slugs and snails. A UK producer makes slug-repelling wool pellets that in addition to working as a fertilizer and water source for plants also keep away slugs and snails. This is due to the felting effect of the wool and its potassium content: As a slug climbs onto the fibers, the cuticle cells, being shaped as scales with small barbs on the tip, irritate the foot while the potassium salts absorb the slime of the slug's foot. This causes the slug to seek easier feeding elsewhere.

An additional highlighted benefit was that replacing fiberglass with wool fibers in products commonly made of fiberglass, such as boats, chairs, and surfboards, created a lighter product with the same strength. The lightness of the wool coffins was highlighted as well, in particular allowing parents who have lost a child to feel closer to their child in the burial process as the coffin weight then was much closer to the weight of their child.

The aesthetic qualities of wool were discussed as added value and a source of uniqueness, both in terms of appearance and tactility: Touching the wool products gives a warm sensation that was put forward in particular by the producers of burial urns and coffins. Here the connection with the deceased was said to be maintained more easily through the burial process. Along with the wool acoustic and sound-absorbing products, these products were highlighted as premium in their product group.

The producer of hand-made burial urns addressed the importance of managing customer expectations: They would not get the exact same product as they would have seen in the picture. In general, using coarser wool for serial production was discussed as difficult or even impossible by some producers. The ability to get standardized colors etc., in Merino wool and synthetic materials does allow for this. Using the natural colors of the coarser wool from sheep will inevitably add another aesthetic dimension to the product. However, this may be advantageous for creating unique products. As an example, the wool plant blanket is branded on its functions and its decorativeness, with the producer saying how much prettier it is than the burlap or other materials that are commonly used.

The producers of acoustic and sound-absorbing products marketed their products using Merino wool as a mark of quality. This points to perceptions of what quality wool is, which is not coarser wool, though the softness of Merino wool is not important in these products. Still, these producers said that using coarser wool would be possible, but it would change the aesthetic of their products.

3.2. Price and Availability

Figure 4 shows the details of the findings related to the price and availability of coarse wool. The two aspects are deeply interconnected. Where fossil materials are produced in large refineries and factories and the materials are easily accessible as they can be produced in any quantities, resulting in goods and prices that are stable and uniform, coarse wool is not uniform and therefore less suited for large-scale production.

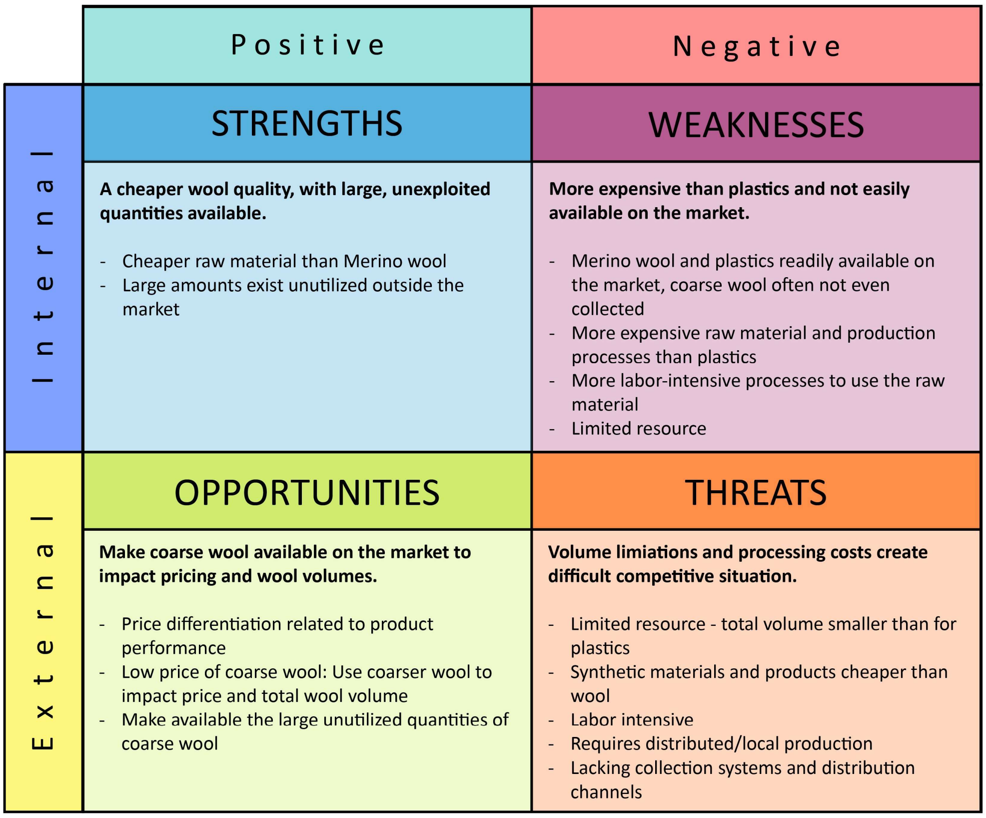

Figure 4. SWOT—Price and availability of coarse wool.

In order to replace more plastic with wool, different types of wool need to be used where they are best suited [4]. Even so, there are still limited quantities available. One interviewee estimated that 220–360 metric tons of wool are discarded in the USA every year. As in the EU, there is no official record and the figure may be too low given that the USA has a sheep population of about 5.2 million sheep [95]. They argued that the amount, following the logic of business growth, is not enough for a company to invest in a larger manufacturing facility.

The easy availability and low prices of synthetic materials make competing with already existing product propositions on price the main challenge for the producers in the interviews. As an example, wool felt constitutes the material from which many acoustic products are made. The fabric comes in many colors and thicknesses and prices vary accordingly. The products are often used in offices to better the acoustics in workplaces and to create private workspaces for employees in open office landscapes. Table 4 shows prices for felt or felt-replacing materials and two series of space dividers. Overall, the wool products were more expensive than the synthetic option. Though these prices are not directly comparable, as the two series differ in terms of design work. The PET screens are a much more simplistic design than the sheep wool screen. It is an indication that products from these materials constitute different product categories for different consumer segments and cannot easily be compared.

Table 4. Price comparison between wool and synthetic sound-absorbing products.

Product	Wool	Polyester	PUR Acoustic Foam
Felt (m^2)	20–97 EUR	6–7 EUR	65–80 EUR
Space dividers	2800–8000 EUR	300–600 EUR	*

* No PUR space dividers were found at the time of the study.

Most acoustic and sound-absorbing products on the market are made of synthetic materials, and a few producers use wool. Though arguably, other wool types have equally good sound-absorbing properties [62], all except one of the informants used Merino wool. The wool products represented a small niche for customers with a specific interest. Due to market dynamics, the producers have little say in choosing the type of wool they use and are dependent on what is easily available. One producer said that they rely on their felt supplier for the choice of wool. A felt supplier explained that they choose wool based on the product for which the felt is intended but that they are also constricted by what is available in the market. Another interviewee explained that their choice to use 100% Merino wool was because of easy availability as well as the color palette they were able to achieve with this type of wool. White wool is easier to dye in standardized colors. When asked, interviewees said that their companies would be open to the use of coarser wool if it became available for purchase either as a raw material or processed.

Wool products go through varying constellations of value chains from raw material to the customer, whereas for synthetic materials, the value chain is much more uniform. This is illustrated in Figure 5 below. Each value chain starts with the raw material and ends with the customer. For wool, the value chain varies between farm and customer. For the examined products, the shortest value chain was when the manufacturers bought the raw materials directly from the farmer and also sold the products directly to the customer, but wool and wool products can also be bought directly from the farmer. The size of the company and the value chain correlate as the smaller companies tend to have a shorter value chain than the larger companies. The smaller companies also more often used coarse, local wool types. For synthetic products, no manufacturer will buy the raw material directly, as it will have to go through a refinery and a producer first. A standardized long global production system is also common for Merino wool.

Informants often referred to “buying what is available on the market” when explaining their material choices. The word “market” meant several different things in this context, from the European or Global trade market where sheep wool is sold and bought, to the market for processed materials like wool and felt. Before even entering the trade market, however, the wool has been collected, sorted, and classified.

Many countries are lacking a collection system for wool, which means the wool never enters a larger market. In Europe, Norway and the UK are among the few countries that have good systems, with a network of wool depots, transport arrangements, national grading standards with trained, professional wool classifiers, education of farmers and shearers, and centralized pricing systems [96,97]. This contributes to both the quantity and the quality of the wool collected; it is estimated that 90% of the Norwegian wool gets collected through the system, including the coarser qualities. From the sample, companies in the USA and Denmark specifically cited collection as an obstacle to using the coarser wool. This mirrors the findings from the WOOLUME project in Poland [40], where farmers report storing years’ worth of wool as they cannot do anything with this wool themselves and have nowhere to bring it. The interviewees explained how smaller producers more often get their wool directly from the farmer. This will more often be the case for coarser and pigmented wool. In such cases, the wool quality received will often be irregular and the producer will need to have the competencies to sort this wool themselves.

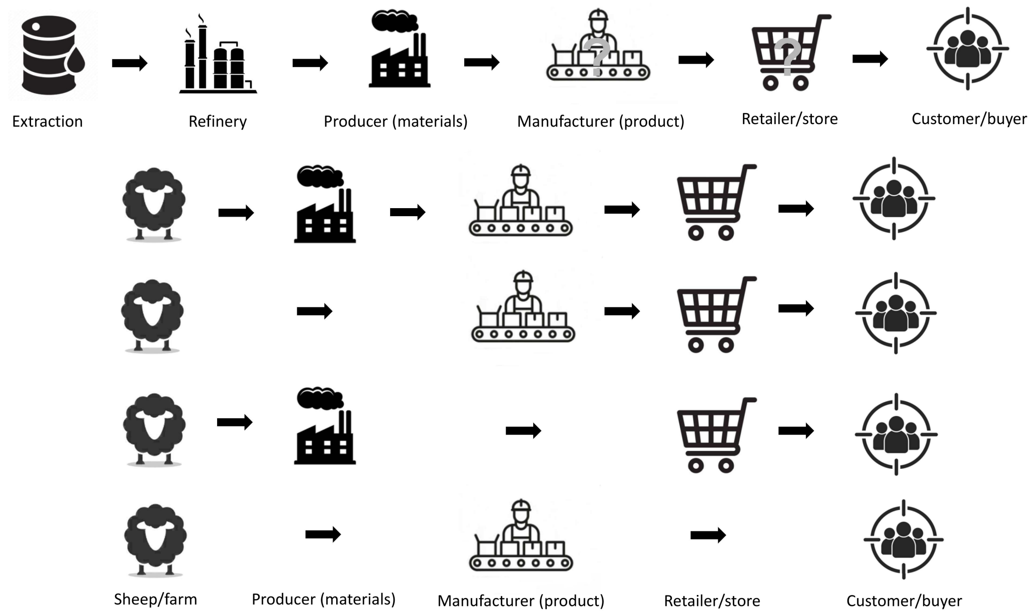

Figure 5. Illustration of value chains for synthetic products and the examined wool products (photos: istockphoto.com).

There were clear differences between the producers of acoustic and sound-absorbing products and the other wool products in their attitude towards using wool and surplus wool in their products (as shown in Table 2). The former was more often larger companies where wool products were only a part of the offering. They saw these as high-end or niche products where the Merino wool was highlighted as a quality attribute. The latter was more often smaller companies, some of which were explicitly using the underutilized wool as a way to improve resource efficiency (see company sizes in Table 3). One producer of coffins had, however, stopped using local wool to simplify their supply chain as only one product within their offering had been made from this wool. This shows how the market favors large scale over small scale and hinders the use of locally based resources, such as coarse wool.

Since other materials generally are cheaper than wool, non-wool products will inevitably be cheaper to produce, making it difficult for wool products to compete. As an example, the funeral services interviewed disclosed that their wool coffins are more expensive than other coffins they offer. Similarly, the producers of wool urns expressed that their urns are more expensive than conventional urns but added that their customers do not mind paying a little extra for a unique handmade product. Here the wool that is currently underutilized may represent an opportunity, as it has a lower raw material price than Merino. Still, costs were highlighted by interviewees as an obstacle to using more of this wool.

The price of transportation was mentioned several times. The sheep farmers are often operating on a small scale and are spread out in different locations, which increases collection costs, especially when no collection system is in place. One interviewee explained that they would be offered wool for free in exchange for collecting it as the farmers did not like seeing it go to waste. This echoes many farmers' experiences of not getting paid enough for their wool in the markets, at the auctions, or at exchanges to warrant the trip.

The necessity of good wool handling adds to the costs of using sheep wool. This is especially challenging in the initial phases before the product and/or company has been established as a brand. Customer demand can be important in such a transition. One producer of insulation attributes much of its success as a small company to the market opportunities created by the segment of buyers who are looking for alternatives to synthetic materials. This is a niche and they do not expect to be able to replace conventional materials such as fiberglass as a standard. This shows that it is easiest to make changes within niche product offerings.

As an exception to this, the producer of wool materials for sanitary products explained that they could produce their materials at the same price points as their synthetic counterparts and still pay the farmers above the 2.20 NZD/kg they are currently receiving at auctions, due to their direct-from-farmer purchasing model. This is important as currently, the cost of shearing exceeds the price received for the wool. They also believe there is further pricing potential for their materials, as the wool provides more functions than their synthetic counterparts, as described above.

This sanitary product company had based its business model on using New Zealand wool, which is according to them, 90% coarse wool, or "strong wool" as they call it. They had set up their supply chain by working directly with local farmers instead of relying on wool auctions or middlemen. The company was one of the few that based its business models on using only local wool. As shown in Table 3, many producers already used coarse wool in their products, and some claimed that their products could potentially be made from coarser wool than what they were currently using, but they supplemented this with Merino wool. Their reasons for using finer wool primarily had to do with supply and access. Hence, establishing own value chains, small-scale production, and local solutions are approaches that work and that can make coarser wool accessible. These solutions create better local resource utilization but are also more labor-intensive.

The issue of volume affects the use of wool in several ways. Where synthetic materials, and also Merino wool, are produced in standardized ways on a global scale, standardized production systems are not adapted to the use of materials that vary in quality and quantity, such as underutilized wool. The way production facilities are set up toward this was described by a producer of acoustic and sound-absorbing products: They had to batch order a specially produced material that contained coarser wool, as the factories do not normally produce this and therefore had to comply with their minimum orders quantities (MOQs) and thus order more than they would have otherwise.

The difficulty in standardizing production methods for scaling production was mentioned by several interviewees. This was due to the irregularity of the wool. Even when a product could be made from any wool, this came up as an issue. The producer of wool fertilizer pellets explained that they often consult on setting up production facilities for the local wool in other countries, but the manual skill of feeding the pelletizer at the appropriate speed according to the wool types requires practice and was not easily transferred. This had led to efforts to set up some new local production sites failing. Exceptions found in this general picture are a producer of materials for hygiene products and a producer of bubble wool for packaging. In these products, coarseness, color, etc. is of little importance and the production could potentially be upscaled and replace a large volume of synthetic materials on the premise that there is wool available for this purpose.

3.3. Sustainability

Sustainability is an important quality for the informants and the marketing of the products discussed in this paper. They also report sustainability inquiries from their customers, who see wool as a sustainable option. This resonates with research findings on consumer fiber preferences [98]. Defining what is sustainable is however not easy, particularly not in the textile industry, where differing views and arguments easily contradict one another. Figure 6 gives an overview of the findings related to this.

Customer perceptions of sustainability differ from the sustainability messaging by the textile industry, where important actors have declared polyester, especially if recycled, the sustainable fiber of the future [99]. Several informants reported that their customers were concerned with finding sustainable alternatives and that this was a factor influencing purchasing decisions toward wool products.

Figure 6. SWOT—Sustainability of coarse wool.

Wool's biodegradability was mentioned by almost all producers and was also put forward by many of the producers when promoting their products. This quality would indeed help alleviate the waste and microplastic problem of synthetic fibers. Many of the new products made of wool were also 100% wool or combined with other natural fibers. A few products did however combine wool with non-biodegradable materials, sometimes because of costs and production constraints, sometimes claiming that this creates the best product. In the work with sustainability, this is an important dilemma because use properties and durability are also so important. One can argue that these mixes are an improvement because they reduce the use of synthetic materials, but equally that they are a disadvantage because natural/synthetic hybrids make the products difficult to recycle or compost.

There were many examples of different combinations with fossil materials. The replacement of glass fiber without considering the biodegradability of the resin used, still creates a non-degradable product. One producer uses a 40% bio-based resin in their products, and another a bio-degradable resin from bio-based polylactic acid (PLA). The felted flowerpots and burial urns come in bright colors. Unfortunately, there has been little research on the biodegradability of synthetic dyes, which completely dominate the market. The producer of wool insulation adding rPET to their products still saw their product as a sustainable material and marketed its biodegradability.

For burials the wool products represent an easily biodegradable option, alleviating concerns about bodies not decomposing. The estimated decomposition time of the burial urns was 5 years, alleviating any concerns about the remains of a loved one being disturbed. It was the environmentally friendly aspect that was highlighted both by the producers and the customers concerning biodegradability.

3.4. Regulation and Policy

Regulation and policy determine the context of and set limits as well as incentives, showing how a problem is understood and what solutions the political authority imagines and is working to develop or implement. Figure 7 gives an overview of the findings from the policy document analysis that is detailed further and discussed in the following.

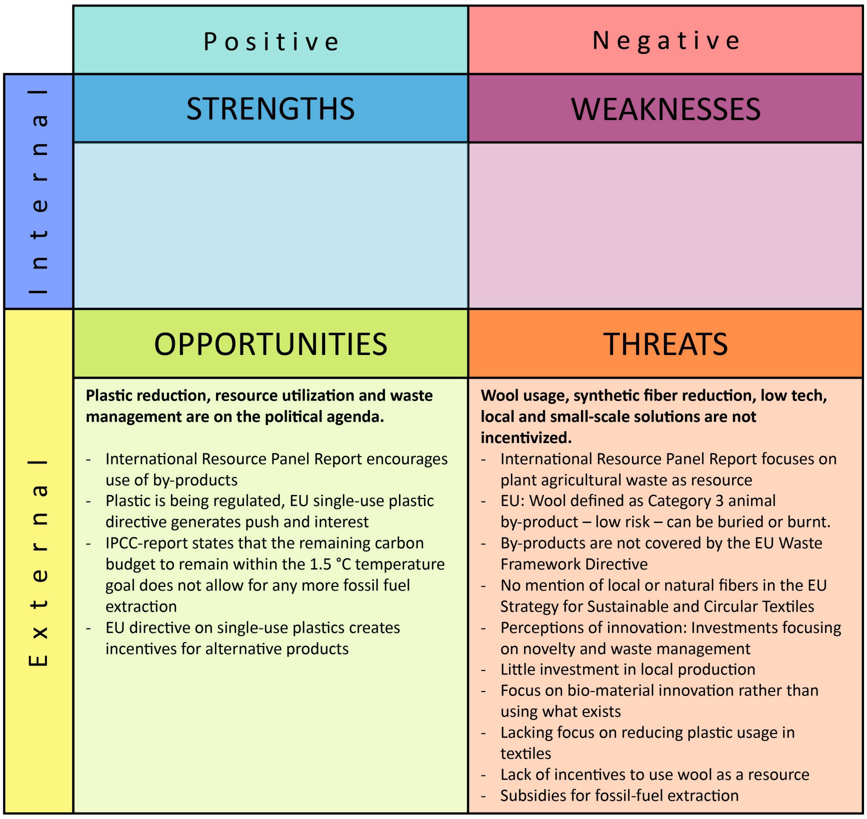

Figure 7. SWOT—Regulations and policy affecting coarse wool.

The main focus of the International Resource Panel Report [82] is resource efficiency, defined as more productive use of resources over their life cycle. The utilization of by-products from industry is mentioned as a way to reduce waste along with the need for extraction of virgin materials. An example mentioned is how food producers may increase their production by utilizing unused or underused resources. However, the report focuses on plant waste and does not mention the use of by-products from animal agriculture.

Following the EU definition, unprocessed wool is classified as an animal by-product: “Animal by-products (ABPs) are materials of animal origin that people do not consume” [100]. A by-product is defined as “a substance or object, resulting from a production process, the primary aim of which is not the production of that item” [83]. Wool falls under “Category 3” APBs, designated as low risk and that therefore can be composted or burnt [84]. This means that wool can be buried or burned at the farm.

Information indicating that APBs can be processed into anything other than animal feed or fertilizers is found as far down as point (j) in Article 14 of the “Regulation (EC) No 1069/2009 concerning animal by-products”: “Category 3 material shall be: [. . .] (j) used for the manufacture of derived products referred to in Articles 33, 34 and 36 and placed on the market in accordance with those Articles” [84]. The previous, and following points refer to various disposal methods of by-products, with the first point being “disposed of as waste by incineration, with or without prior processing.”

At a wool seminar, it was stated that there is a belief that the EU definition of wool as a by-product makes it subject to regulations where farmers must dispose of their wool as hazardous waste, which is costly, but that they burn or bury it on their farms to avoid these costs [101]. As the regulation above states, this is not the case, but the misinformation surrounding the regulations may further hinder good resource utilization. In either case, there is no incentive for the farmer to make use of the wool from the policy side, nor from the market side as previously discussed.

In the EU documents on the circular economy, there is little that goes in the direction of valorizing the underutilized wool. It is not defined as waste and therefore is not included in the circular economy's focus on recycling, nor the waste hierarchy and Waste Framework Directive [83]. As a by-product, the wool to some extent becomes invisible in that the wool is mainly disposed of on the farms directly and therefore does not enter into any formal waste management system. When the EU Strategy for Sustainable and Circular Textiles does not even mention wool—or the possibilities that wool and other local EU fibers hold—but discusses local solutions solely as future potential recycling plants, this is in line with the premises lain herein.

The above EU regulations, therefore, have little to offer in the development of an industry for better utilization of local wool. If, on the other hand, plastic-related strategies are examined, there is more potential support.

In the most recent EU circular economy action plan [86], the reduction of plastic waste, and in particular single-use plastic products, is in focus. From July 3rd, 2021, certain single-use plastic items such as straws, cutlery, cotton bud sticks, and food containers were banned from EU Members States' markets [85]. One interviewee cited increasing interest in their materials from sanitary product manufacturers due to this regulation, the EU Directive on single-use plastics, where sanitary items have been designated as a priority product group [85]. Bio-degradable solutions are particularly pertinent in products such as diapers, that cannot be recycled due to the organic matter they have soaked up during use.

This interviewee also discussed lobbying their government to increase the focus on self-sufficiency and local production. The lack of this had been a large problem for good resource utilization during the COVID-19 pandemic as New Zealand had been closed down and wool could not be transported to production facilities in China. Large quantities had therefore been discarded. At the same time, the supply of many products had been difficult as they have no local production. They explained that they were looking to build pilot facilities for product testing and innovation, however, finding funding for this was difficult. In addition to purely practical obstacles, this situation also highlights a difference in lobbying capacity between smaller producers of natural materials and large producers of synthetic materials connected to a very powerful and also heavily subsidized petroleum industry [102]. These subsidies can also be connected to the above price discussion and contribute to keeping the synthetic materials at a low price.

Products in wool for transportation and packaging can benefit from the incentives for change that policies regarding plastic waste minimization create when listing plastic packaging as the main issue [85,103]. Plastic packaging is receiving this attention because it is often a single-use product that easily goes astray.

The latest EU report related to the proposed directive for micro-plastic had a focus on end-of-pipe solutions, such as capture and filters on washing machines, rather than reducing plastic usage [88]. Microplastics are increasingly a subject of legislation: The EU Strategy for Sustainable and Circular Textiles [87], however, goes a little bit further in emphasizing the need for measures all along the product lifetime, from design to production to use. It does not, however, mention the EU's own, natural fibers as solutions to the plastic problem but instead looks to invigorate the EU textile sector through bio-economy initiatives that make use of waste products from agriculture to create new fibers, e.g., straw from wheat farming.

4. Discussion

While the research points to definite technical and environmental advantages in using wool in both single- and multiple-use products and both in traditional products and in new product groups, there are definite obstacles connected to this. Table 5 gives an overview of these obstacles as well as the opportunities connected with coarse wool usage.

Table 5. Overview of obstacles and opportunities for coarser wool in consumer goods.

Obstacles	Opportunities
	Product performance and innovation
Standardization	Local production
Large-scale production	Local job creation
Focus on quantity and price	Focus on quality
Policy and regulations	Preserving culture and heritage
Missing local infrastructure and production facilities	Sustainability
Consumer habits, perceptions, and knowledge	Resilience
	Good resource utilization

In this section, some common conceptions about wool which may explain why wool products are sometimes perceived as less desirable by consumers will first be discussed. Second, how the price and scale are affected by more local cooperation and better utilization of materials. Third, the issues of sustainability as this consists of several equally important dimensions are connected to the discussion. Fourth, the potential for regulations and policies to improve resource utilization is discussed. Finally, the above themes are discussed from a systemic perspective.

4.1. (Mis-)Conceptions

Wool has many seemingly contradictory properties. When wool products were deemed less satisfactory than their synthetic counterparts, it often came down to customer expectations and habits. Overcommunicating about certain wool properties may have caused misconceptions about others. Its propensity to be labeled as warm and insulating may be why potential customers thought that wool duvets would be too warm, disregarding wool's temperature-regulating properties. Sleep research has, however, confirmed wool's positive impact on sleep quality [104]. This shows that emphasizing one property may be a hindrance to fully taking advantage of another.

As the results above show, standardized practices make it harder to use resources that are variable in a production system. But this also applies to lifestyles and other systems. The producer of materials for sanitary products highlighted consumer habits in connection with product performance. They underlined the importance of the product being single-use and compostable. This would allow them to replace current single-use items that have become essential in people's busy lives and contexts such as day-care centers for children. They deemed it unlikely that a shift back to multiple-use sanitary products would be feasible. They also highlighted the obstacle of waste management systems not being adapted to composting showing the importance of also designing the waste systems for the improved products and processes desired, rather than designing products for the current waste system. During another interview, a producer told of how they have had to give up on an initial idea for production for nursing homes for the same reason—it did not fit with the current laundry practices.

Washing has become synonymous with hygiene and is seen as the main way to care for textiles. Today's washing machines, detergents, and habits are adapted to cotton, which both requires and can endure frequent, mechanically intensive, and high-temperature washing. Wool, on the other hand, does not need this, nor can it withstand the same mechanical treatment. Synthetic textiles also require more frequent washing than wool [105]. These washing habits may have become conflated as cotton and synthetic textiles have grown in market share, and the latter is also being used as a wool replacement. Because of its resistance to smell, wool is often thought to be antibacterial. However, laboratory tests show that bacteria persist longer on wool fabrics than on cotton and polyester which means the reason why wool is odor-resistant remains unknown [48]. Still, its odor-preventing qualities also reduce the need for washing, which, contrary to common perceptions, makes wool products easy-care. The producer of wool duvets explained that some were reluctant to use wool duvets, as the duvets did not conform with their current washing habits and they thought that not washing a wool duvet was unhygienic. Though not needing frequent washing, all wool can be washed with various degrees of care taken. In addition, the producer of wool duvets used Shropshire wool that does not felt. These misconceptions about wool care are in part due to a lack of knowledge about wool and different wool types and being habituated to super-wash wool as well as synthetic materials. The duvet producers said they had mostly positive reactions to their products when people learned about them but that wool duvets were also surprising to some customers.

Some products require education and changes in habits to take full advantage of the different wool properties and the opportunities to develop easy-care products. The above perceptions of wool contrast selling points that the producers put forward. Better and more accurate communication around the different fibers' actual properties seems needed. This resonates with previous research that found that consumer knowledge about textiles is low [104,106,107].

4.2. Price vs. Scale

Price is less of a problem for some products and production set-ups than for others. It is the least problematic for:

- Small-scale, niche products with short and more localized value chains;
- Products with multiple positive properties or that are aesthetically more attractive;
- Marketing toward customers that are willing to pay more to avoid plastic.

These approaches can also be a hindrance to reaching a size where the business becomes financially viable.

If the goal is to scale up and replace plastics on a larger scale with wool, the obstacle would be the limitation in production volumes. This can also be seen through a different lens: Part of the issue with plastics is exactly that production is so easy to scale up and that this has enabled the enormous global over-production with its accompanying environmental issues. Wool products might "replace" plastics also as a material linked to other business models. Utilization of local wool is often done through local cooperation and better utilization of low-volume raw materials [108]. More collaboration and more direct interactions are both premises and results of a transition to using underutilized wool. Therefore, what this wool replaces is more than a material, but also systemic; business models, production methods, and ways of organizing value chains.

For some of the products, scaling up production volumes may be achieved by using other underutilized raw materials such as recycled wool, felted wool, and wool/hair from other animals. This could be the case e.g., for hygiene products which are more processed products that already can use more diverse ranges of wool.

4.3. Environmental, Social, Economic—And Cultural

The pastoral practice of the Polish mountain sheep farmers is deeply rooted in the local culture [1,104] as is other wool production worldwide [109]. Other than the mention of wool duvet making as a tradition upheld by the producer interviewed, cultural aspects of sustainability are lacking in the empirical data. However, for several of the products, wool usage represents traditional ways of doing; rugs and carpets of various types were traditionally made from wool or other natural fibers, but are now predominantly made of synthetic materials. Here synthetic materials have replaced wool, and using wool would be a question of going back to traditional ways and thus evaluating whether the use of synthetic materials was an improvement in these cases. Using traditional materials such as wool for new applications further creates opportunities for local value chains and value creation, and helps preserve cultural heritage and ways of living connected to sheep farming.

An important opportunity for sustainability when using natural fibers is that of decreasing dependency on synthetic materials, which are responsible for the exponential growth in textiles [7], and therefore for a majority of the increase in environmental impacts. At present, 80% of a garment's climate impact stems from the production phase and

92% of the toxicity impact stems from the production phase [110]. The calculation would give similar results for other textile products with equivalent after treatments. Reducing production is therefore the most efficient way of reducing environmental impacts [8].

The limited access to wool puts a natural limit on the growth of business based on these raw materials. This may in certain cases prevent businesses from becoming economically viable, as highlighted by some informants, however, perpetual growth is not necessary to create economic sustainability as long as growth to the point of viability is possible. The use of coarse wool, therefore, requires smaller entities and more locally based production systems. These are less reliant on larger quantities: As long as the number of local sheep stays relatively constant and the business plans its activities based on this, the foundations can be good for long-term, stable activity. This way, using a labor-intensive material, as discussed in Section 4.2, will create local jobs and local economic sustainability. In addition, business growth being limited is a prerequisite for environmental sustainability and staying within planetary boundaries [111].

While biodegradability was mentioned most often in connection with the sustainability of the products, several of the functional benefits highlighted by the interviewees also contribute to wool's environmental sustainability performance. The odor-preventing capacity allows for decreased washing frequency which will decrease the environmental impacts of the use phase of wool products compared to other products [112]. An important, and largely unexploited sustainability possibility exists within the aesthetics of a product. While dyeing and after-treatments are known to be the most polluting part of textile production, there is little discussion about synthetic dyes. The underutilized wool is often pigmented, which allows for colored and patterned textiles without the use of dyes. This is one of the environmental benefits that could be exploited further. Examining the informants' products and marketing reveal that there was overall a lot to gain both in the work to make products more sustainable through the use of wool and in better marketing of this, putting forward more aspects of sustainability, including small-scale and local production.

Like plastic, wool can be recycled mechanically. During this process, wool fibers break and are substantially shortened, which leads to lower strength and luster in the resulting materials. In most cases, one also has to add some new material to create textile materials from recycled wool. Here recycled wool can more easily be reused than rPET and therefore wool can create a truly circular system where the material goes from one product to another, depending on the quality needed, until it ends up biodegrading back into the soil. The producer of bubble wool is setting their business up for such a system where they can also potentially make use of wool no longer suitable for knitted or woven textiles in their products. Similarly, the wool plant pots are made from defective pre-consumer wool hats.

4.4. Resource Utilization in Policy

Given the EU's ambitious focus on the environment, textiles' central position in the planned transformation, and the informants' (and their customers') clear perception of wool as an environmentally friendly fiber, there is surprisingly little support for increased use of EU's wool—or other local fibers—in the examined documents. This is partially connected to the way wool is defined within regulation, and the way sustainability is perceived. The circular economy has been a central part of EU policy since 2014 and important policy documents published around this focus on resource efficiency and waste prevention as essential strategies. Later documents to some extent also include the product and consumer perspectives [113]. The strategies do not, however, address good resource utilization of by-products such as wool but rather focus on recycling as a way to optimize the use of resources.

With the underutilized wool specifically in mind, there is little support to gather from the EU environmental strategies that were examined. Small-scale, local production, pure, biodegradable natural materials, better resource utilization, and by-products are not accorded much attention. The textile strategy is devoid of these themes and gives little hope of support for the transition discussed here. The political strategy that could potentially support a transition from plastic to underutilized wool is therefore not found in the textile strategies, but more likely in the policies directed at plastic. Here, clear statements about reducing the use, especially of virgin plastic and single-use plastic items, are found. One of the product types examined was within a category targeted by the EU Directive on single-use plastics, albeit indirectly, and it is not surprising that the directive increased interest in these products.

The most recent IPCC report states that no more fossil fuel extraction can be allowed to remain within the 1.5 °C temperature goal [114]. This might impact textile regulation in the future, even though measures are currently not taken to stop the increased use of synthetic textiles [8]. Rather, it looks like important regulations, such as the EU Product Environmental Footprint (PEF), will promote plastic [115,116].

4.5. A Systemic View

On a product level, this study highlights the major functional benefits of using wool in consumer goods and opportunities for taking advantage of the many properties of wool. Surplus wool is functionally and/or esthetically a good alternative but requires systemic changes both on a practical, political, and economic level. On a consumer level, it requires re-education about material properties and behavioral change, e.g., in terms of waste management and laundry.

The quantity of wool available would be a major limitation in replacing large quantities of plastic in products. It is, however, possible to increase the wool ratio by using surplus wool, but wool being a natural, limited resource, will never be able to replace all plastic. On the other hand, using the underutilized wool would free up the Merino wool that is currently being used in applications where its fineness is not required. This Merino wool could then be used for clothing and as such the underutilized wool could also indirectly reduce plastic use.

In addition, using coarse wool represents an opportunity to replace particularly problematic plastic products: Several of the examined products are today mainly made of plastic, including sanitary products where the plastic cannot be recycled and represents a waste problem. It is unlikely that all such plastic can be replaced by wool, but it is nevertheless important to develop alternatives and at the same time exploit available natural materials. For this solution to become a reality, however, waste management systems would need to be set up for the resulting biodegradable products.

Political measures in the EU are directed toward new fibers, bioplastics, and innovation of new technology rather than good resource utilization and building local value chains. The focus on bioplastics as a response to the synthetic textile problems ignores the limits in quantity and capacity to replace all existing plastics and the need to make use of all the possible means to reduce the plastic problem.

Furthermore, the current EU regulations do not incentivize taking care of the coarse wool. Labeling wool as an APB, though a Category 3 by-product with low risk for human health, makes disposal easy, rather than encouraging the use of this resource. The use of wool is low despite there being no legal restrictions on it. Farmers themselves could take actions such as selling wool directly from the farm. This highlights the importance of regulations and policy to explicitly encourage favorable practices. The lack of these incentives can explain many of the practical obstacles faced by the informants, such as little access, bad sorting, and lacking local value chains and processing facilities. These practical obstacles are part of a larger systemic issue where large scale is favored over small scale, and homogenous materials, therefore, are preferred for the mass production methods it entails. The situation for much of the EU coarse wool is therefore very different from the situation for the Norwegian wool. Norwegian wool has a high degree of utilization, despite being what the global market would define as coarse wool because it has a local market incentivized by wool subsidies [117]. The findings, therefore, confirm previous research that shows that a mix of small and larger businesses improves resource utilization [39].

The David vs. Goliath structure of the textile industry, where large actors dominate, is also a factor in determining what is sustainable and what is not and how plastics should be weighed against natural materials in sustainability ratings [115]. Here the “Absolute Zero” report chimes in by stating that one should cut out beef and lamb from diets in order to reach climate goals [118], which would imply cutting out leather and wool from fiber diets. Other research on sustainability, however, put forward the beneficial aspects of grazing animals, contributing to biodiversity, carbon sequestering, etc., [119–122]. The discussion around the sustainability of wool production will likely continue for some time. However, wool is beyond doubt biodegradable, and surplus wool is produced whether it is used or not. Using wool in general makes it possible to decrease chemical usage in textile products to achieve many technical properties and using pigmented wool adds the opportunity to decrease dye usage in the textile industry.

The enormous plastic consumption reflects the current economic system that is completely dependent on fossil fuels and fossil materials. For all its benefits, it has also created the ongoing environmental and climate crisis. Instead of considering our way of living, ways to maintain the same habits using different materials are examined in much of the academic research and business approaches. It is important to remember that the extensive use of plastic is relatively new in human history and that a range of solutions existed before these products. There is a need for both starting to use existing resources, but also scale down and find when plastics are both the best solution and under control. To replace it all is neither realistic nor desirable, but a range of products can be made from underutilized, coarser wool.

5. Conclusions

Many products can be made of wool because it has properties suited for a wide range of uses. Still, large volumes of wool are discarded. The research question was: Why is not more coarse wool used in consumer goods? The answer to this is that there are many, diverse reasons for this that are not related to the properties of the wool, but rather that these are not seen and utilized in good products. This highlights the potential for both innovation and sustainability improvements.

This research shows that, with a few exceptions, companies that work with small-scale and local production solutions are the ones that can make the most out of coarse wool, but that practical issues, such as collection systems for the wool, are an obstacle to extending this use. The reason for the low degree of utilization and plastic domination is therefore not a lack of beneficial properties, it is a one-sided emphasis on global mass production and distribution in the textile industry. This is therefore a systemic issue. This focus is also visible in the lack of emphasis on the cultural aspects of local wool usage and the heritage connected to it in both the interview data and examined legislation. The findings however show that policy can incentivize material usage transitions, but that these tools are little employed.

To our knowledge, no systematic review of how wool or other natural materials can be used to replace plastic has been done nor what the obstacles are to replacements. The initiatives identified were all a result of sporadic business innovation rather than systematic efforts. Further research on this topic could include the perspective of producers of plastic products.

The initial studies highlighted the practical obstacles to using coarse wool. The further examination of the context and policy in this paper points to why the necessary infrastructure is not present, why the wool is not available and why its price is a hindrance. In future research on good resource utilization of wool and other natural resources, it is important that not only the technical properties of the material are examined, but also the societal and contextual situation of the resource utilization.

Author Contributions: Conceptualization, A.S.S. and L.L.B.; methodology, L.L.B.; validation, I.G.K., A.S.S. and J.B.; formal analysis, L.L.B.; investigation, A.S.S. and L.L.B.; resources, L.L.B., I.G.K., A.S.S. and J.B.; data curation, L.L.B.; writing—original draft preparation, L.L.B. and I.G.K.; writing—review and editing, L.L.B., I.G.K., A.S.S., J.B., M.R. and K.K.-M.; visualization, A.S.S. and L.L.B.; supervision, I.G.K.; project administration, J.B. and I.G.K.; funding acquisition, J.B., M.R., K.K.-M. and I.G.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by a Norway Grant titled "Polish sheep wool for improved resource utilisation and value creation". NOR/POLNOR/WOOLUME/0007/2019.

Institutional Review Board Statement: Not applicable. The research has been conducted in accordance with the ethical research guidelines of the Norwegian Centre for Research Data.

Informed Consent Statement: All interviewees were informed about the reasons and context of the research as well as the use of the data collected and gave their informed consent for inclusion before participation.

Data Availability Statement: Not applicable.

Acknowledgments: The authors want to thank the interviewees for their participation in these studies. The authors further want to thank Vilde Haugrønning and Ingrid Haugsrud from OsloMet and Tone Skårdal Tobiasson from NICEFashion for commenting on the draft.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Salachna, A.; Kobiela-Mendrek, K.; Kohut, M.; Rom, M.; Broda, J. The Pastoralism in the Silesian Beskids (South Poland): In the Past and Today. In *Sheep Farming—Herds Husbandry, Management System, Reproduction and Improvement of Animal Health*; Ronquillo, M.G., Riocerezo, C.P., Eds.; IntechOpen: London, UK, 2021; pp. 51–68.
2. Haugrønning, V.; Broda, J.; Espelien, I.S.; Klepp, I.G.; Kobiela-Mendrek, K.; Rom, M.; Sigaard, A.S.; Tobiasson, T.S. Upping the WOOLUME: Waste Prevention Based on Optimal Use of Materials. In *Local, Slow and Sustainable Fashion: Wool as a Fabric for Change*; Klepp, I.G., Tobiasson, T., Eds.; Palgrave Macmillan: London, UK, 2022; pp. 61–82.
3. Sigaard, A.S.; Haugrønning, V. *WOOLUME: Mapping the Market for Acoustic and Sound Absorbing Products Made of Wool*; SIFO Report No. 9-2021; OsloMet: Oslo, Norway, 2021.
4. Sigaard, A.S.; Løvbak Berg, L.; Klepp, I.G. *WOOLUME: Potential New Products from Vacant Wool*; SIFO Report No. 18-2021; OsloMet: Oslo, Norway, 2022.
5. Parker, L. *The World's Plastic Pollution Crisis Explained*; National Geographic: Washington, DC, USA, 2022.
6. Conti, I.; Simioni, C.; Varano, G.; Brenna, C.; Costanzi, E.; Neri, L.M. Legislation to limit the environmental plastic and microplastic pollution and their influence on human exposure. *Environ. Pollut.* **2021**, *288*, 117708. [CrossRef] [PubMed]
7. Changing Markets Foundation. *Fossil Fashion: The Hidden Reliance on Fossil Fuels*; Changing Markets Foundation: Utrecht, The Netherlands, 2021; p. 45.
8. Klepp, I.G.; Løvbak Berg, L.; Sigaard, A.S.; Tobiasson, T.S.; Hvass, K.K.; Gleisberg, L. *The Plastic Elephant: Overproduction and Synthetic Fibres in Sustainable Textiles Strategies*; SIFO: Oslo, Norway, 2023.
9. Henry, B.; Laitala, K.; Klepp, I.G. *Microplastic Pollution from Textiles: A Literature Review*; SIFO Project Report No. 1-2018; OsloMet: Oslo, Norway, 2018.
10. Henry, B.; Laitala, K.; Klepp, I.G. Microfibres from apparel and home textiles: Prospects for including microplastics in environmental sustainability assessment. *Sci. Total. Environ.* **2018**, *652*, 483–494. [CrossRef] [PubMed]
11. Klepp, I.G.; Laitala, K. Halver ditt utslipp av mikroplast fra klær. *Aftenposten Vitenskap*, 15 January 2018.
12. Klepp, I.G.; Tobiasson, T.S. Debattinnlegg: Klærne våre Dreper liv i Havet. *Forskning*, 6 February 2017.
13. Browne, M.A.; Crump, P.; Niven, S.J.; Teuten, E.; Tonkin, A.; Galloway, T.; Thompson, R. Accumulation of Microplastic on Shorelines Woldwide: Sources and Sinks. *Environ. Sci. Technol.* **2011**, *45*, 9175–9179. [CrossRef] [PubMed]
14. Ragusa, A.; Svelato, A.; Santacroce, C.; Catalano, P.; Notarstefano, V.; Carnevali, O.; Papa, F.; Rongioletti, M.C.A.; Baiocco, F.; Draghi, S.; et al. Plasticenta: First evidence of microplastics in human placenta. *Environ. Int.* **2020**, *146*, 106274. [CrossRef] [PubMed]
15. Jenner, L.C.; Rotchell, J.M.; Bennett, R.T.; Cowen, M.; Tentzeris, V.; Sadofsky, L.R. Detection of microplastics in human lung tissue using μFTIR spectroscopy. *Sci. Total. Environ.* **2022**, *831*, 154907. [CrossRef] [PubMed]
16. Horvatits, T.; Tamminga, M.; Liu, B.; Sebode, M.; Carambia, A.; Fischer, L.; Püschel, K.; Huber, S.; Fischer, E.K. Microplastics detected in cirrhotic liver tissue. *Ebiomedicine* **2022**, *82*, 104147. [CrossRef]
17. WHO. *Dietary and Inhalation Exposure to Nano- and Microplastic Particles and Potential Implications for Human Health*; WHO: Geneva, Switzerland, 2022.

18. Merkl, A.; Charles, D. *The Price of Plastic Pollution: Social Costs and Corporate Liabilities*; Minderoo Foundation: Nedlands, Australia, 2022.
19. Textile Exchange. *Preferred Fiber & Materials Market Report 2021*; Textile Exchange: Lamesa, TX, USA, 2021.
20. Textile Exchange. *Preferred Fiber & Materials Market Report: October 2022*; Textile Exchange: Lamesa, TX, USA, 2022.
21. IWTO. *Market Information: Statistics for the Global Wool Production and Textile Industry*; International Wool Trade Organisation: Brussels, Belgium, 2021.
22. Petek, B.; Logar, R.M. Management of waste sheep wool as valuable organic substrate in European Union countries. *J. Mater. Cycles Waste Manag.* **2020**, *23*, 44–54. [CrossRef]
23. Zoccola, M.; Montarsolo, A.; Mossotti, R.; Patrucco, A.; Tonin, C. Green Hydrolysis as an Emerging Technology to Turn Wool Waste into Organic Nitrogen Fertilizer. *Waste Biomass Valorizat.* **2015**, *6*, 891–897. [CrossRef]
24. EC. CW—Circular Wool. Available online: https://single-market-economy.ec.europa.eu/sectors/fashion/eliit/learn/partnerships/cw-circular-wool_en (accessed on 13 January 2023).
25. Dey, A.; Dhumal, C.V.; Sengupta, P.; Kumar, A.; Pramanik, N.K.; Alam, T. Challenges and possible solutions to mitigate the problems of single-use plastics used for packaging food items: A review. *J. Food Sci. Technol.* **2020**, *58*, 3251–3269. [CrossRef]
26. Zhang, C.; Xia, L.; Zhang, J.; Liu, X.; Xu, W. Utilization of waste wool fibers for fabrication of wool powders and keratin: A review. *J. Leather Sci. Eng.* **2020**, *2*, 15. [CrossRef]
27. Sun, Y.; Li, B.; Zhang, Y.; Dou, H.; Fan, W.; Wang, S. The progress and prospect for sustainable development of waste wool resources. *Text. Res. J.* **2022**, *93*, 468–485. [CrossRef]
28. Haque, A.N.M.A.; Naebe, M. Waste Wool Powder for Promoting Plant Growth by Moisture Retention. *Sustainability* **2022**, *14*, 12267. [CrossRef]
29. Lebedytė, M.; Sun, D. A review: Can waste wool keratin be regenerated as a novel textile fibre via the reduction method? *J. Text. Inst.* **2021**, *113*, 1750–1766. [CrossRef]
30. Parlato, M.C.M.; Porto, S.M.C.; Valenti, F. Assessment of sheep wool waste as new resource for green building elements. *Build. Environ.* **2022**, *225*, 109596. [CrossRef]
31. Parlato, M.C.M.; Porto, S.M.C. Organized Framework of Main Possible Applications of Sheep Wool Fibers in Building Components. *Sustainability* **2020**, *12*, 761. [CrossRef]
32. Podjava, A.; Zarins, A.; Avotina, L.; Shvirksts, K.; Baumane, L.; Rasmane, D.A.; Grube, M.; Kizane, G. Latvian Sheep Wool Fiber as a Cheap Natural Adsorbent for the Removal of Congo Red Dye from Wastewater. *Water Air Soil Pollut.* **2022**, *233*, 451. [CrossRef]
33. Aluigi, A.; Corbellini, A.; Rombaldoni, F.; Mazzuchetti, G. Wool-derived keratin nanofiber membranes for dynamic adsorption of heavy-metal ions from aqueous solutions. *Text. Res. J.* **2012**, *83*, 1574–1586. [CrossRef]
34. Guna, V.; Ilangovan, M.; Vighnesh, H.R.; Sreehari, B.R.; Abhijith, S.; Sachin, H.E.; Mohan, C.B.; Reddy, N. Engineering Sustainable Waste Wool Biocomposites with High Flame Resistance and Noise Insulation for Green Building and Automotive Applications. *J. Nat. Fibers* **2019**, *18*, 1871–1881. [CrossRef]
35. Khan, F.M.; Shah, A.H.; Wang, S.; Mehmood, S.; Wang, J.; Liu, W.; Xu, X. A Comprehensive Review on Epoxy Biocomposites Based on Natural Fibers and Bio-fillers: Challenges, Recent Developments and Applications. *Adv. Fiber Mater.* **2022**, *4*, 683–704. [CrossRef]
36. Bhavsar, P.; Balan, T.; Fontana, G.D.; Zoccola, M.; Patrucco, A.; Tonin, C. Sustainably Processed Waste Wool Fiber-Reinforced Biocomposites for Agriculture and Packaging Applications. *Fibers* **2021**, *9*, 55. [CrossRef]
37. Memon, H.; Wang, H.; Langat, E.K. Determination and Characterization of the Wool Fiber Yield of Kenyan Sheep Breeds: An Economically Sustainable Practical Approach for Kenya. *Fibers* **2018**, *6*, 55. [CrossRef]
38. Ghermezgoli, Z.M.; Moezzi, M.; Yekrang, J.; Rafat, S.A.; Soltani, P.; Barez, F. Sound absorption and thermal insulation characteristics of fabrics made of pure and crossbred sheep waste wool. *J. Build. Eng.* **2020**, *35*, 102060. [CrossRef]
39. Klepp, I.G.; Tobiasson, T.; Haugrønning, V.; Vittersø, G.; Grøva, L.; Kvingedal, T.; Espelien, I.; Kubberød, E. *KRUS Final Report: Enhancing Local Value Chains in Norway*; SIFO Report No. 8-2019; 8270634948; OsloMet: Oslo, Norway, 2019.
40. OsloMet. WOOLUME: Polish Sheep Wool for Improved Resource Utilisation and Value Creation. Available online: https://www.oslomet.no/en/research/research-projects/woolume (accessed on 30 December 2022).
41. Sousa, A.F.; Patrício, R.; Terzopoulou, Z.; Bikiaris, D.N.; Stern, T.; Wenger, J.; Loos, K.; Lotti, N.; Siracusa, V.; Szymczyk, A.; et al. Recommendations for replacing PET on packaging, fiber, and film materials with biobased counterparts. *Green Chem.* **2021**, *23*, 8795–8820. [CrossRef]
42. Cheng, H.; Chen, L.; McClements, D.J.; Yang, T.; Zhang, Z.; Ren, F.; Miao, M.; Tian, Y.; Jin, Z. Starch-based biodegradable packaging materials: A review of their preparation, characterization and diverse applications in the food industry. *Trends Food Sci. Technol.* **2021**, *114*, 70–82. [CrossRef]
43. Semple, K.E.; Zhou, C.; Rojas, O.J.; Nkeuwa, W.N.; Dai, C. Moulded pulp fibers for disposable food packaging: A state-of-the-art review. *Food Packag. Shelf Life* **2022**, *33*, 100908. [CrossRef]
44. Oliaei, E.; Lindström, T.; Berglund, L.A. Sustainable Development of Hot-Pressed All-Lignocellulose Composites—Comparing Wood Fibers and Nanofibers. *Polymers* **2021**, *13*, 2747. [CrossRef]
45. Kathuria, A.; Zhang, S. Sustainable and Repulpable Barrier Coatings for Fiber-Based Materials for Food Packaging: A Review. *Front. Mater.* **2022**, *9*, 21. [CrossRef]
46. Zhang, Y.; Duan, C.; Bokka, S.K.; He, Z.; Ni, Y. Molded fiber and pulp products as green and sustainable alternatives to plastics: A mini review. *J. Bioresour. Bioprod.* **2022**, *7*, 14–25. [CrossRef]

47. Schmidtchen, L.; Roleda, M.Y.; Majschak, J.-P.; Mayser, M. Processing technologies for solid and flexible packaging materials from macroalgae. *Algal Res.* **2021**, *61*, 102300. [CrossRef]
48. Santos, A.S.; Ferreira, P.J.T.; Maloney, T. Bio-based materials for nonwovens. *Cellulose* **2021**, *28*, 8939–8969. [CrossRef]
49. Jason Mills LLC. Technical Textiles: Industrial Applications & Types of Fabric. Available online: https://www.jasonmills.com/technical-textiles/ (accessed on 2 November 2022).
50. Devold. Natures Super Fiber. Available online: https://www.devold.com/en-nz/our-choices/natural-choices/natural-choices/ (accessed on 2 November 2022).
51. Icebreaker. Merino: Nature's Performance Fibre. Available online: https://www.icebreaker.com/en-au/our-story/natures-performance-fiber.html (accessed on 2 November 2022).
52. NatureWorks LLC. *Fiber and Fabric Properties*; Technical Bulletin 180904; NatureWorks LLC.: Plymouth, MN, USA, 2005.
53. Dénes, O.; Florea, I.; Manea, D.L. Utilization of Sheep Wool as a Building Material. *Procedia Manuf.* **2019**, *32*, 236–241. [CrossRef]
54. Li, Y.; Luo, Z.X. Physical Mechanisms of Moisture Diffusion into Hygroscopic Fabrics during Humidity Transients. *J. Text. Inst.* **2000**, *91*, 302–316. [CrossRef]
55. Tepe, E.S.; Hoover, E.E.; Poppe, S. *The Wool Mulch System of Producing Strawberries: A Manual for Commercial Growers in Minnesota*; University of Minnesota: Minneapolis, MN, USA, 2008.
56. Røsvik, B.L. *Utforming av Skillevegg i Ull*; NTNU: Trondheim, Norway, 2012.
57. Cai, Z.; Faruque, M.A.; Kiziltas, A.; Mielewski, D.; Naebe, M. Sustainable Lightweight Insulation Materials from Textile-Based Waste for the Automobile Industry. *Materials* **2021**, *14*, 1241. [CrossRef]
58. Arnesen, K. Naturlig ull Som Lydabsorbentmateriale. Master's Thesis, NTNU, Trondheim, Norway, October 2015.
59. Ballagh, K.O. Acoustical properties of wool. *Appl. Acoust.* **1996**, *48*, 101–120. [CrossRef]
60. del Rey, R.; Uris, A.; Alba, J.; Candelas, P. Characterization of Sheep Wool as a Sustainable Material for Acoustic Applications. *Materials* **2017**, *10*, 1277. [CrossRef]
61. Allafi, F.; Hossain, M.S.; Lalung, J.; Shaah, M.; Salehabadi, A.; Ahmad, M.I.; Shadi, A. Advancements in Applications of Natural Wool Fiber: Review. *J. Nat. Fibers* **2020**, *19*, 497–512. [CrossRef]
62. Kobiela-Mendrek, K.; Bączek, M.; Broda, J.; Rom, M.; Espelien, I.; Klepp, I. Acoustic Performance of Sound Absorbing Materials Produced from Wool of Local Mountain Sheep. *Materials* **2022**, *15*, 3139. [CrossRef]
63. Kuffner, H.; Popescu, C. 8—Wool fibres. In *Handbook of Natural Fibres*; Kozłowski, R.M., Ed.; Woodhead Publishing: Cambridge, UK, 2012; Volume 1, pp. 171–195.
64. Mansour, E.; Curling, S.; Stéphan, A.; Ormondroyd, G. Absorption of volatile organic compounds by different wool types. *Green Mater.* **2016**, *4*, 1–7. [CrossRef]
65. Park, C.J.; Barakat, R.; Ulanov, A.; Li, Z.; Lin, P.-C.; Chiu, K.; Zhou, S.; Perez, P.; Lee, J.; Flaws, J.; et al. Sanitary pads and diapers contain higher phthalate contents than those in common commercial plastic products. *Reprod. Toxicol.* **2019**, *84*, 114–121. [CrossRef]
66. Zallmann, M.; Smith, P.K.; Tang, M.L.; Spelman, L.J.; Cahill, J.L.; Wortmann, G.; Katelaris, C.H.; Allen, K.J.; Su, J.C. Debunking the Myth of Wool Allergy: Reviewing the Evidence for Immune and Non-immune Cutaneous Reactions. *Acta Derm. Venereol.* **2017**, *97*, 906–915. [CrossRef]
67. McQueen, R.H.; Vaezafshar, S. Odor in textiles: A review of evaluation methods, fabric characteristics, and odor control technologies. *Text. Res. J.* **2019**, *90*, 1157–1173. [CrossRef]
68. Kjeldsberg, M.; Eilertsen, K.; Buck, M.; Klepp, I.G. *Lukten av Svette: Luktutvikling i Ulike Tekstiler [Smell of Sweat: Development of Odour in Different Textiles]*; SIFO: Oslo, Norway, 2012.
69. Broda, J.; Mitka, A.; Gawłowski, A. Greening of road slope reinforced with wool fibres. *Mater. Today Proc.* **2020**, *31*, S280–S285. [CrossRef]
70. Broda, J.; Gawlowski, A. Influence of Sheep Wool on Slope Greening. *J. Nat. Fibers* **2018**, *17*, 820–832. [CrossRef]
71. Ordiales, E.; Gutiérrez, J.I.; Zajara, L.; Gil, J.; Lanzke, M. Assessment of utilization of sheep wool pellets as organic fertilizer and soil amendment in processing tomato and broccoli. *Mod. Agric. Sci. Technol.* **2016**, *2*, 20–35.
72. Parker, L. A Whopping 91 Percent of Plastic Isn't Recycled. *Natl. Geogr.* **2022**. Available online: http://aipack.com.au/a-whopping-91-of-plastic-isnt-recycled/ (accessed on 13 January 2023).
73. Gorecki, R.S.; Gorecki, M.T. Utilization of Waste Wool as Substrate Amendment in Pot Cultivation of Tomato, Sweet Pepper, and Eggplant. *Pol. J. Environ. Stud.* **2010**, *19*, 1083–1087.
74. McKinnon, K. *Bruk av Restull i Jord-og Hagebruk En Delrapport i Prosjektet Ny giv for Pigmentert ull*; Norsøk: Tingvoll, Norway, 2019.
75. Zheljazkov, V.D. Assessment of Wool Waste and Hair Waste as Soil Amendment and Nutrient Source. *J. Environ. Qual.* **2005**, *34*, 2310–2317. [CrossRef] [PubMed]
76. Hoover, E.E. *Bio-Based Weed Control in Strawberries Using Sheep Wool Mulch, Canola Mulch, and Canola Green Manure*; Minnesota Department of Agriculture: St Paul, MN, USA, 2020; p. 4.
77. Cardno, C. Policy Document Analysis: A Practical Educational Leadership Tool and a Qualitative Research Method. *Kuram Ve Uygul. Eğitim Yönetimi/Educ. Adm. Theory Pract.* **2019**, *24*, 623–640. [CrossRef]
78. Atkinson, P.; Coffey, A. Analysing documentary realities. In *Qualitative Research: Theory, Method and Practice*; Silverman, D., Ed.; Sage: London, UK, 2004; Volume 2, pp. 56–75.

79. Thwaites, T.; Davis, L.; Mules, W. *Introducing Cultural and Media Studies: A Semiotic Approach*, 2nd ed.; Palgrave Macmillan: Basingstoke, UK, 2002.
80. Taylor, S. Critical Policy Analysis: Exploring contexts, texts and consequences. *Discourse Stud. Cult. Politi. Educ.* **1997**, *18*, 23–35. [CrossRef]
81. Bowen, G.A. Document Analysis as a Qualitative Research Method. *Qual. Res. J.* **2009**, *9*, 27–40. [CrossRef]
82. UNEP. *Resource Efficiency: Potential and Economic Implications*; International Resource Panel: Nairobi, Kenya, 2017.
83. European Commission (EC). Waste Framework Directive. Available online: https://ec.europa.eu/environment/topics/waste-and-recycling/waste-framework-directive_en#ecl-inpage-631 (accessed on 7 December 2022).
84. European Commission (EC). *Regulation (EC) No 1069/2009: Health Rules as Regards Animal By-Products and Derived Products Not Intended for Human Consumption, 2009*; European Union: Brussels, Belgium, 2009.
85. European Commission (EC). Single-Use Plastics. Available online: https://ec.europa.eu/environment/topics/plastics/single-use-plastics_en (accessed on 13 September 2021).
86. European Commission (EC). *Circular Economy Action Plan for a Cleaner and More Competitive Europe*; European Union: Brussels, Belgium, 2020.
87. European Commission (EC). *EU Strategy for Sustainable and Circular Textiles*; European Union: Brussels, Belgium, 2022.
88. Manshoven, S.; Smeets, A.; Malarciuc, C.; Tenhunen, A.; Mortensen, L.F. *Microplastic Pollution from Textile Consumption in Europe*; European Topic Centre Circular Economy and Resource Use: Mol, Belgium, 2022.
89. Sarsby, A. *SWOT Analysis*; Leadership Library: Oakland, UK, 2016.
90. Speth, C.; Probert, C. *The SWOT Analysis*; Lemaitre Publishing: Namur, Belgium, 2015.
91. McKinnon, K. VerdifULL: How Can We Boost the Value of Lower-Grade Wool and Increase the Share of First-Class Wool? Available online: https://www.norsok.no/en/projects/2021/verdifull-how-can-we-boost-the-value-of-lower-grade-wool-and-increase-the-share-of-first-class-wool (accessed on 9 January 2023).
92. Siebers, R.W.; Crane, J. Does bedding affect the airway and allergy? *Int. J. Occup. Environ. Med.* **2011**, *2*, 65–75.
93. Rosen, J. *Farmers Are Facing a Phosphorus Crisis. The Solution Starts with Soil*; National Geographic: Washington, DC, USA, 2020.
94. Broda, J.; Przybyło, S.; Kobiela-Mendrek, K.; Biniaś, D.; Rom, M.; Grzybowska-Pietras, J.; Laszczak, R. Biodegradation of sheep wool geotextiles. *Int. Biodeterior. Biodegrad.* **2016**, *115*, 31–38. [CrossRef]
95. Shahbandeh, M. *Total Number of Sheep and Lambs in the United States from 2001 to 2022*; Statista: Hamburg, Germany, 2022.
96. Uldal, S.H. Norsk Ullstandard/Norwegian Wool Standard. Available online: https://www.animalia.no/no/Dyr/ull-og-ullklassifisering/norsk-ullstandard/ (accessed on 30 December 2022).
97. British Wool. British Wool Grading System. Available online: https://www.britishwool.org.uk/grading (accessed on 30 December 2022).
98. Sigaard, A.S.; Laitala, K. Natural and Sustainable? Consumers' Textile Fiber Preferences. *Fibers* **2023**, *11*, 12. [CrossRef]
99. Kerr, J.; Landry, J. *Pulse of the Fashion Industry*; Global Fashion Agenda & The Boston Consulting Group: Copenhagen, Denmark, 2017.
100. European commission (EC). Animal By-Products. Available online: https://ec.europa.eu/food/safety/animal-products_en (accessed on 16 March 2022).
101. SheMakes. *Wool Mondays: Rethinking Wool Together in May Wool Ecosystems*; TCBL: Le Mans, France, 2022.
102. OECD. *Update on Recent Progress in Reform of Inefficient Fossil-Fuel Subsidies that Encourages Wasteful Consumption 2021*; OECD: Naples, Italy, 2021.
103. WRAP. *European Plastics Pact: Roadmap*; WRAP: London, UK, 2020.
104. Klepp, I.G.; Laitala, K.; Tobiasson, T.S. *Woolbed—Sweet Dreams in Merino*; Project report No. 2-2016; SIFO: Oslo, Norway, 2016.
105. Laitala, K.; Klepp, I.G.; Haugrønning, V. Textile Cleaning and Odour Removal. In *Odour in Textiles: Generation and Control*, 1st ed.; Thilagavathi, G., Rathinamoorthy, R., Eds.; CRC Press: Boca Raton, FL, USA, 2022.
106. Laitala, K.; Klepp, I.G. Environmental and ethical perceptions related to clothing labels among Norwegian consumers. *Res. J. Text. Appar.* **2013**, *17*, 50–58. [CrossRef]
107. Heidenstrøm, N.; Haugsrud, 1.; Hebrok, M.; Throne-Holst, H. *"Hvorfor kan Ikke bare alle Produkter være Bærekraftige?" Hvordan 905 Forbrukere Oppfatter og Påvirkes av Markedsføring med Bærekraftpåstander*; SIFO Report 16-2021; OsloMet: Oslo, Norway, 2021.
108. Smith, T.; Ehrnström-Fuentes, M.; Hagolani-Albov, S.E.; Klepp, I.G.; Tobiasson, T.S. Rethinking the (Wool) Economy. In *Local, Slow and Sustainable Fashion Fibres: Wool as a Fabric for Change*; Klepp, I.G., Tobiasson, T.S., Eds.; Palgrave MacMillan: London, UK, 2022; pp. 133–170.
109. Miller, L.; Isaksen, K.; Burgess, R.; Klepp, I.G.; Tobiasson, T.S. Slow and Indigenous Approaches to Textiles Arts. In *Local, Slow and Sustainable Fashion: Wool as a Fabric for Change*; Klepp, I.G., Tobiasson, T., Eds.; Palgrave MacMillan: London, UK, 2022; pp. 83–131.
110. Wennberg, M.V.; Östlund, Å. *The Outlook Report 2011–2019: Mistra Future Fashion Final Program Report*; Mistra Future Fashion: Stockholm, Sweden, 2019.
111. Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; De Vries, W.; De Wit, C.A.; et al. Planetary boundaries: Guiding human development on a changing planet. *Science* **2015**, *347*, 1259855. [CrossRef]
112. Laitala, K.; Klepp, I.G.; Kettlewell, R.; Wiedemann, S. Laundry Care Regimes: Do the Practices of Keeping Clothes Clean Have Different Environmental Impacts Based on the Fibre Content? *Sustainability* **2020**, *12*, 7537. [CrossRef]

113. Heidenstrøm, N.; Strandbakken, P.; Haugrønning, V.; Laitala, K. *Product Lifetime in European and Norwegian Policies*; SIFO Report No. 11-2021; OsloMet: Oslo, Norway, 2021.
114. IPCC. *Climate Change 2022: Mitigation of Climate Change*; IPCC: Geneva, Switzerland, 2022; p. 2913.
115. Klepp, I.G.; Laitala, K.; Haugrønning, V.; Sigaard, A.S.; Tobiasson, T.S. The Fate of Natural Fibres in Environmental Evaluations: A Question of Volume. In *Local, Slow and Sustainable Fashion Fibres: Wool as a Fabric for Change*; Klepp, I.G., Tobiasson, T., Eds.; Palgrave Macmillan: London, UK, 2022.
116. Make the Label Count. *Delivering EU Environmental Policy through Fair Comparisons of Natural and Synthetic Fibre Textiles in PEF*; IWTO: Brussels, Belgium, 2022.
117. Landbruksdirektoratet (Norwegian Directorate of Agriculture). *Pristilskudd for ull og Skinn [Price Subsidies for Wool and Leather]*; Landbruksdirektoratet: Oslo, Norway, 2021.
118. Allwood, J.M.; Dunant, C.F.; Lupton, R.C.; Cleaver, C.J.; Serrenho, A.C.H.; Azevedo, J.M.C.; Horton, P.M.; Clare, C.; Low, H.; Horrocks, I.; et al. *Absolute Zero: Delivering the UK's Climate Change Commitment with Incremental Changes to Today's Technologies*; University of Cambridge: Cambridge, MA, USA, 2019.
119. Salachna, A.; Marcol, K.; Broda, J.; Chmura, D. The Contribution of Environmental and Cultural Aspects of Pastoralism in the Provision of Ecosystem Services: The Case of the Silesian Beskid Mts (Southern Poland). *Sustainability* **2022**, *14*, 10020. [CrossRef]
120. Sørensen, M.V.; Graae, B.J.; Hagen, D.; Enquist, B.J.; Nystuen, K.O.; Strimbeck, R. Experimental herbivore exclusion, shrub introduction, and carbon sequestration in alpine plant communities. *BMC Ecol.* **2018**, *18*, 29. [CrossRef]
121. Whitehead, D. Management of Grazed Landscapes to Increase Soil Carbon Stocks in Temperate, Dryland Grasslands. *Front. Sustain. Food Syst.* **2020**, 1–7. [CrossRef]
122. Lazcano, C.; Gonzalez-Maldonado, N.; Yao, E.H.; Wong, C.T.; Merrilees, J.J.; Falcone, M.; Peterson, J.D.; Casassa, L.F.; Decock, C. Sheep grazing as a strategy to manage cover crops in Mediterranean vineyards: Short-term effects on soil C, N and greenhouse gas (N_2O, CH_4, CO_2) emissions. *Agric. Ecosyst. Environ.* **2022**, *327*, 107825. [CrossRef]