



DEPARTMENT OF AGRICULTURE, FOOD AND THE MARINE; REVIEW OF MARKET OPPORTUNITIES FOR IRISH-GROWN WOOL- BASED PRODUCTS



Background and Introduction	2
Executive Summary.....	3
Information on Market Opportunities.....	8
Identification of Potential Research Projects	44
Mechanisms to Support a Commercially Sustainable Wool Sector.....	69
Perspective on Economic Feasibility	79
Conclusions & Recommendations	100
Appendix 1 Funding Opportunities.....	103
Appendix 2: Stakeholder List	120
Appendix 3. Table of Market Sizing Number	122
Appendix 4. Summary of Research Projects	125
References	129

Background and Introduction

This study was conducted in line with the tender requirements and terms of reference outlined in the Request for Tender (dated 08/07/2021 for the provision of a review of the potential demand in domestic and international markets for wool based products such as insulation and fertilisers) issued by the Department of Agriculture, Food and the Marine (DAFM). It took the form of a review of the potential demand in domestic and international markets for wool-based products such as insulation and fertiliser.

There were a number of phases to the study, namely:

1. The identification of market opportunities domestically and internationally for wool-based products;
2. The identification of potential research projects applicable to supporting the identified market opportunities;
3. Determining mechanisms that could be used to support industry initiatives;
4. Carrying out economic feasibility and cost benefit analysis on proposed market opportunities.

All submissions to the prior public consultation carried out by DAFM were reviewed as part of this study. This report is intended to form the basis for the development of a robust policy roadmap for the Irish Wool Industry by DAFM.

Whilst the investigation of on island scouring was deemed out of scope, we have identified that most added value product applications other than composting and pelleting of fertiliser need some scouring to be conducted. There is no facility for any significant scale scouring of wool in Ireland at present. To this end we suggest that DAFM engage in further studies to consider:

- Developing a long-term roadmap towards on-island scouring and processing capability.
- Provide funding for research into modern methods of scouring which may be more suited to the volume of wool, suitable applications, and environmental constraints for establishing scouring capability in Ireland within the constraints of the 2030 environmental targets.

This review was carried out by a consortium led by The Agile Executive. The consortium team members and affiliations are as follows:

- Pat Byrne – The Agile Executive
- Matthew Carroll – Suck Valley Farm/ The Galway Wool Co-op
- Dr Tim Yeomans – Shannon ABC
- Catriona Power – Munster Technological University
- Liz Gavin – Eur Digital Village
- Chris Weiniger – Donegal Yarns
- Will Hogan – Kennedy Insights
- Nick Bennett – The Agile Executive
- Sean Griffin – Th Agile Executive

Executive Summary

This review seeks to identify and assess market opportunities for Irish Grown Wool. Several market sectors were assessed with some encouraging prospects identified. It was, however, found that there are many barriers and obstacles to Irish Grown Wool in successfully accessing these opportunities. It became obvious that solutions are required to overcome these hurdles in restoring value to the Irish Grown Wool industry. The solutions discussed in this review include proposed research projects and recommended mechanisms to support the industry along the entire value chain, from producer to end user.

An “Irish Grown” Wool Brand is Needed

Virtually all of our interviewees were adamant that the creation of an Irish Grown Wool Brand is an essential pre-requisite to growing the value-added sector and successfully scaling the production of new wool-based products.

Our international research has confirmed that the successful promotion of value-added products is very much driven by the story behind the product and its provenance, strong branding is therefore an essential starting point to achieving sustainable commercial gains.

The best-known sector of value-added wool products in Ireland is in textiles but unfortunately the vast majority of wool consumed by the textile sector is imported merino wool. This reflects modern consumer preference for soft textured textiles and Irish Grown Wool tends to be strong wool more suited for use in hard wearing carpets and other non-garment uses. To this end, a new Irish Grown Wool brand is needed.

We recommend the following:

- Establish an All-Island “Irish Grown” **Wool Council**:
 - An industry led steering group to champion an Irish Grown Wool Brand;
 - Tasked to develop and promote this brand both domestically and internationally;
 - Empowered to create and oversee structures designed to bring disparate groups together for collaboration, innovation and scaling activities
- Ensure a broadly based membership of this Council to include a range of direct and indirect stakeholders, all participating on a voluntary basis. Membership should include a mix of primary producer farmers and stakeholders/supporters, including successful commercial enterprises who should be willing to fund research and promotions and to advise on scaling of micro businesses involved in the wool sector;
- Some funding would be generated by annual membership subscription for the Council and affiliate membership. In addition, corporate members may sponsor some of the research activities;
- Support the commercial scaling of micro-enterprises via collaboration and mentoring.;
- Marketing activities should be focused on new product categories listed in the body of this report with a focus on higher value add products such as mattresses and filled products such as duvets and pillows;
- We also recommend an awareness campaign to be run in schools and elsewhere, along the lines of the “Wool in School” initiative, promoting awareness of Irish Grown Wool products and their green Circular Bio Economy led credentials;

- A key enabler for success will be the creation of a **Wool Hub** where various academic researchers and commercial entities may:
 - Collaborate on research projects such as those proposed in this report;
 - Promote innovation through complimentary research projects and optimum cross-fertilisation of ideas;
 - Incorporate an independent Wool Testing facility – to set standards and substantiate all promotional claims made about Irish Grown Wool products;
 - Develop a system of traceability for wool that is sent abroad for scouring and further processing so that provenance is protected at all stages in the value chain;
- The Wool Council should sponsor high impact, quick delivery projects and high impact projects developed in the Wool Hub and elsewhere to highlight the value and appeal of innovative Irish Grown Wool products.

The Wool Value Chain is Heavily Concentrated in the Hands of Wool Merchants

Wool is a highly commoditised product and the decline in the selling price of raw wool over recent decades means that wool value is minimal as percentage of typical income from the sale of related lamb meat. The wool sector is highly fragmented with individual farmers mainly selling raw wool directly to domestic and large UK based wool merchants with Irish operations. Merchants collect the wool for aggregation at depots, grading, sale at auction and/or export for scouring and processing.

This situation presents challenges for the underlying objective set by DAFM, to get a higher proportion of the value created by wool production into the hands of the primary producer farmer. It is clear from our research that a key stage of value creation is when the wool is professionally graded. We believe that if the wool were to remain in the ownership of the farmer or a related entity such as a Wool Co-Op, until it reaches the graded stage there would be significantly more value in the wool for the farmer.

The proposed Wool Council could investigate the possibility of:

- Retaining ownership of the wool until it has been graded and significant value added;
- Entering into contract wool grading arrangements with wool handlers on the Island of Ireland. Currently those include various regional merchants, Comharchumann Uan Chiarraí Teo (Established by Udarás na Gaeltachta for Kerry and West Cork Gaeltacht areas), The Galway Wool (rare breed) Co-Op and Ulster Wool (part of the British Wool Board that operates on a Co-Op basis);
- Overall, we believe that there is significant merit in the Co-Op model as it creates some commercial scaling capacity that individual farmers can't achieve. A Co-Op model also allows discussion between the farmer and the Co-Op around early-stage processes of dagging and skirting to extract the low quality (waste wool) so that only reasonable quality wool is bagged and collected for transportation to the nearest grading depot;
- There are sufficient players in the marketplace to facilitate a regionally based wool collection and grading process that should minimise the transportation costs that are currently high, relative to the low value wool being collected;

- An alternative collection model was adopted in Norway (see EU Success Stories later in this report) in similar circumstances where they engaged an independent entity to collect all wool for grading centres - this should be considered for the Island of Ireland;
- At this stage, this appropriately graded wool, with Irish Grown Wool designation, could either be sold directly, or via auction, to wool merchants or buyers (Irish or foreign) similar to the British Wool Marketing Board process;
- Under this Co-Op model the sales proceeds less the costs of collection and contract grading would be paid to the farmers in proportion to the volume and grade of wool that each farmer supplied to the Co-Op system.

Need for Better Awareness and Training on Wool Handling and Presentation

Our interviews confirmed that wool is being presented in a very poor state to merchants and buyers; some report up to 10% being unsaleable. This is not an unexpected outcome of the long-term low prices that have been received by farmers where they pay over €2 to have a sheep shorn and only get paid (in some cases) 5 cents per Kg for Scotch Mountain Wool and 20 cents per Kg for lowland wool. With a fleece weighing 2-2.5 Kg on average, this is a significant loss. This generates farmer apathy with wool being presented badly, including dags and poor wool. This circumstance, unfortunately, plays against any hope of a buyer considering paying more for the intrinsic value of the good wool included in the bags.

We believe that there are significant opportunities to change the presentation standards via:

- A programme of education and training on wool handling organised by Wool Co-Ops with shearers and collection agents/merchants being encouraged to sponsor wool handling training for the primary producer farmers at the start of the value chain;
- Create an apprenticeship in wool handling and grading along the lines of the British Wool Board Scheme – potentially under the tutelage of existing grading operations;
- Encourage the certification and accreditation of shearing contractors with an emphasis on animal welfare standards and them taking a role in encouraging good presentation of fleeces.
- Incentivise pricing to farmers for only presenting properly dagged/skirted wool to collectors. This may involve two tier pricing for skirted or un-skirted wool, giving the farmer an option to earn more by skirting and sorting the waste wool;
- Alternatively, the local Co-Op or wool collector may do the dagging and skirting for a fee so as to avoid transporting waste wool to grading centres and having them use expert grading staff to do basic skirting of fleeces;
- In line with our recommendations on the possibility of establishing localised fertiliser composting or pelleting facilities, the waste extracted at the on-farm skirting stage can be transported in trailers to local composting facilities;
- A change in classification of wool away from Category 3 Animal By Product status could help perceptions of the value of the wool, although this change may impact the overall LCA of wool.

General Findings Involving Tactical Solutions

There is a dearth of usable data on the wool sector in general and particularly on sheep breeds and grades of wool produced across the island.

- The Wool Council and related entities should identify relevant data points for future data collection in animal censuses etc and steps should be taken to ensure full compliance with census completion.
- The proposed wool testing facility and establishment of wool grading standards for Irish Wool will help in this regard.

The percentage of the annual clip that is suitable for use in the high value and high-profile textiles industry is very low.

- Support small scale breeding programs for dual purpose breeds and industry collaborations to produce quantities of medium fibre diameter for use by textile producers and crafters in authentically Irish products.

Fertiliser and Insulation

Both fertiliser and insulation applications for wool have challenges associated with the business model for farmers, but they are also both well-established uses to which wool could be applied (although not currently in Ireland at scale). As such these are proposed as initial applications to focus on to begin to establish the use of wool as a feedstock for new products or, more broadly, for scaling the volume of some existing products that are only produced in minor volumes by micro enterprises. Both these applications will require intervention to encourage farmers to follow this route. Gate fees for composting facilities with licences to manage Class 3 animal by-products are higher than other facilities, and material for insulation must be scoured in the first instance. Both these approaches require farmers to take on additional cost, in either gate fees or scouring costs. Value may at some stage start to come to the farmer if a market pull is established for sheep's wool fertiliser or insulation, but advantages to its use must be determined and communicated. In this circumstance, certainty of demand is a driver for product innovation as illustrated by the model adopted by the Galway Wool Co-op and Donegal Yarns.

Market demand and willingness to pay for bio fertiliser and growing media needs to be stimulated but a number of factors are coming together at this time to support that shift in awareness and mindset among potential customers, including:

- EU Directives promoting a shift from chemical to bio fertilisers will encourage greater appreciation of merits of wool-based fertiliser;
- The current record high cost of chemical fertilisers is being dramatically compounded by the Ukraine conflict and related trading sanctions on Russia, as Russia is a major supplier of chemical fertiliser to world markets;
- Substitute sources need to be found and bio fertiliser is an attractive alternative.

This report focuses on enhancing the overall value chain while delivering meaningful returns to the primary producer. It is clear that there is space and an openness to address fragmentation in the sector as set out in this report. The opportunity created through a circular bioeconomy approach can be a catalyst for change, taking advantage of enhanced collaboration and innovation from within this sector. The wool sector in Ireland has the potential to turn itself into a significant success story bringing

new income sources and positive imagery and reputation for the island of Ireland if well supported by all stakeholders. A well framed policy roadmap can support and encourage a new era for Irish Grown Wool.

Information on Market Opportunities

Introduction to Market Research

Across the world, natural fibres are receiving attention for their sustainability and unique natural properties. Sheep's wool is no exception and is one of the natural and renewable resources widely used in a range of applications. Wool has a unique composition that makes it applicable to many markets including Horticulture, Packaging, Insulation, Textiles, Cosmetics, Filled Products and Composites.

During the market research process, we engaged with companies large and small who sell wool products on the market, either directly to consumers or to businesses within their value chain. From our discussions, we identified key insights and macro-economic trends that will shape the future of Irish Grown Wool in the global marketplace.

KEY MARKETS FOR WOOL PRODUCTS



Figure1. Illustration of key markets for wool applications.

To complete the market research, our approach consisted of:

- Collating information on market opportunities;
- Identifying top markets for wool and corroborating this with a market sizing for each sector;
- Identifying key players in the sectors that could be potential customers of wool. This is composed of a mixture of those who already use wool in their products and those with the potential to do so;
- Conducting 18 interviews across 6 sectors with potential industrial users of wool to understand interest in the uptake of wool as an ingredient in their product;
- Conducting an analysis of competitive international landscape and key players through a mix of meetings and reviewing literature.

Market Outlook

Overall, we found very positive feedback for the potential of Irish Grown Wool. On the island of Ireland, we are seeing innovative approaches to market development for added value Irish Grown Wool products start to come together. As a result, there is a market shift with increasing demand for wool from consumers over the last 2 years evidenced by a marked increase in sales of wool-based products from the textiles, insulation, and filled product sectors.

The sales increase was driven by several factors including:

- The Business to Consumer model is taking off due to increased online sales. The Covid Pivot meant more businesses are selling directly online and opening a new market avenue;
- Natural fibers are increasingly appealing for several reasons – health, sustainability and provenance (more of which is discussed in the Market Drivers section);
- Government and Business Policy – the pivot to zero carbon and sustainability across sectors is driving demand for environmentally friendly and bio-based products.

Examples of businesses working in these areas are Galway Wool Co-op, Donegal Yarns, Baavet, Woolow, The Sheepish Dog and Sheep Wool Insulation. In addition, we found in our market research that all the target markets for wool applications are predicting increased growth over the coming years.

To scale this level of activity up, we need targeted interventions based on market research and economic feasibility. Outlined in this section below are:

- SWOT analysis of Irish Grown Wool;
- Detailed information on market trends and outlook;
- Information on market opportunities, wool product pricing and market size.

SWOT Analysis of Irish Wool



Figure 2. SWOT analysis of wool sector in Ireland.

Strengths

Provenance - "The Story"



Wool is part of Irish heritage. Sheep and the Aran Sweater are inextricably linked with Ireland. Ireland's family farm model and relatively small average flock sizes lends something romantic to Irish Grown Wool in the minds of consumers. Wool production was a mainstay of the Irish rural economy for large parts of our history. Native Irish breeds such as the Galway and the Roscommon breeds were developed in the 19th century

as dual-purpose meat and wool producing animals. The Aran Sweater was a construct devised to provide gainful employment to women in the west of Ireland in the wake of the Great Famine. It flourished as an icon of the Irish cultural craft industry, providing much needed exposure to Ireland's fledgling economy following independence. A large proportion of the Irish population are only one or two generations removed from farming and as such tend to have an affinity with the story of farm produce.

Traceability (due to small scale)

Ireland produces in the region of 7m kilogrammes of wool from around 35,000 flocks. Thorough record keeping and traceability of individual sheep is already in place through the National Sheep Identification Scheme with electronic ear tags used on all breeding sheep over 12 months of age. This coupled with advances in technological traceability solutions offers an excellent opportunity for Irish Grown Wool to be 100% traceable from farm to yarn.

***"Traceability
opportunity...farm
to yarn"***

Perceived Sustainability

Irish Grown Wool is widely perceived to be a sustainable, renewable bio-fibre. Irish sheep tend to be reared outdoors on a mainly grass based diet giving the image of wool being a green product. Though there is a lack of data to validate this, consumers inevitably take wool to be more sustainable than other natural fibres such as cotton and most certainly more sustainable than any synthetics.

Perceived Low Carbon

There is a strong perception and narrative around the carbon sequestration of grasslands. The oversimplistic narrative of sheep's wool being a low carbon product is as follows:

- Grass absorbs CO₂ from the atmosphere
- Sheep convert grass into meat and wool
- Wool is shorn from the sheep
- Wool contains carbon which is stored for the lifetime of the wool product until it degrades at the end of use.

These perceptions are not widely validated, and it is unclear what effects rumination and meat harvesting have on this carbon budget when sheep production is assessed holistically.

Resilient Strong Fibre

Irish Grown Wool is mostly classified as “Strong Wool” and as such has traditionally been more suited to carpets, filled products and rugs. While it is not as fine as wool produced in drier climates, it is a very strong and resilient fibre which lends itself to other applications such as hard wearing and high traffic carpet.

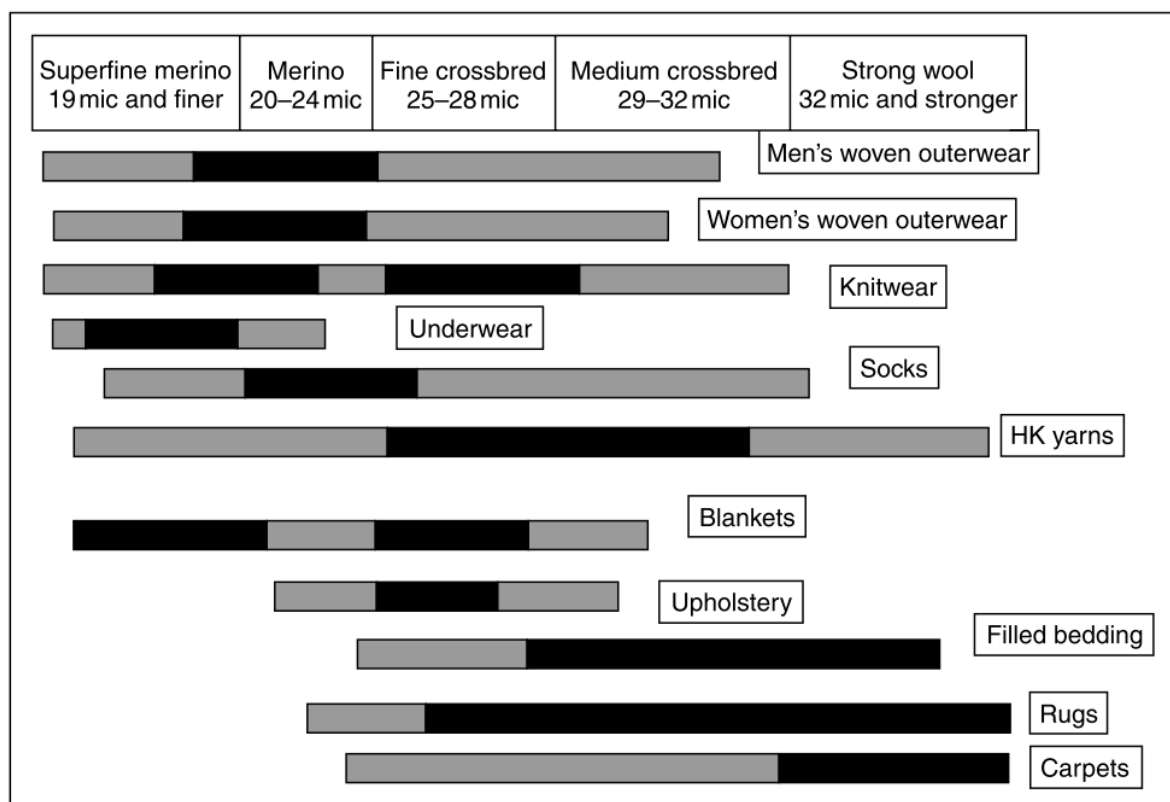


Figure 3. Wool fibre diameter and applications.

Perceived Health Benefits

Wool is perceived to be suitable for those suffering from respiratory illnesses such as asthma. It is reported as not harbouring dust mites and often claimed to be anti-microbial. Wool has been shown to absorb VOCs such as formaldehyde which are commonly used in construction materials. Wool is also said to be a natural temperature regulator due to its unique hygroscopic properties. This has led to claims of better sleep when using wool-based bedding products.

Consistent Supply

Ireland has had a consistent number of breeding ewes since 2010, following a gradual decline between 1990 and 2010 ([Teagasc 2015](#)). All projections point to steady numbers of sheep in Ireland for the medium term and hence a consistent supply of wool. Changes in breeding and genetics have been remarkably slow in Ireland, so it is reasonable to assume that there will be consistency in the type of wool produced also. That said, there are initiatives mooted to improve genetics in a small number of flocks to achieve more desirable wool traits.

Recyclable/Compostable at End of Life

A key advantage that wool has over most synthetic fibres is that it is biodegradable and compostable. Wool does not pose a risk to health or the environment at the end of its useable life and is easily disposed of.

Naturally Fire Retardant

Many of the stakeholders interviewed claimed that wool is naturally fire retardant without any amendment. This may give it an advantage in applications such as insulation, bedding, and composites, but would require technical validation. The fire performance of insulation is one of the key parameters influencing the selection of materials and is the subject of intense regulatory scrutiny in the wake of high-profile building fire events.

Weaknesses

Fragmented Suppliers

There are in the region of 45,000 wool producers on the island of Ireland. Very few of these have formed collective bargaining groups with the notable exception of Ulster Wool which is supplied by around 5,000 farmers.

Consolidated Buyers

There are only forty-one registered wool stores in Ireland and more still are merely collection agents for larger buyers. While it is difficult to ascertain exactly, it is estimated that there are less than ten competitive wool buying operations in the country. The two largest wool merchants in the UK have acquired wool merchants in Ireland. There is a clear risk of further acquisitions leading to large players squeezing indigenous merchants out of the market. In some areas there are long distances between producers and merchants leaving very limited options for growers. From the perspective of the remaining independent merchants, they are reluctant to refuse poorly presented wool for fear of losing suppliers to the larger players who may have more resources for grading.

Lack of Data on Carbon Footprint

There is a lack of data on the sustainability and carbon footprint of sheep's wool. Irish sheep farming is diverse in terms of hill/lowland flocks and is vastly different from sheep production in other parts of the world. Little resources appear to have been put into research on the sustainability of wool. This makes it difficult for business-to-business manufacturers of wool products to give their clients comfort on the green credentials of the products.

Strong Wool

Most Irish Grown wool is greater than 30 microns in fibre diameter, making it unsuitable for most textile applications. It has traditionally been used in carpet and other more industrial applications. With the general downward trend in prices and move to synthetics it is now more difficult to find a market for this wool. A small percentage (estimated at 1%) is below 30 microns or has other desirable properties such as lustre, handle, or colour. This may be suitable for textiles and is sufficient to supply the domestic crafts sector. The remainder of Irish Grown Wool, especially wool from the hill flock, is not suited to wearable textiles and requires development of other value streams. In the days when the Aran Sweater was developed, most consumers had no experience of softer fibres and were glad of the warmth given by strong wool. In today's globalised world of fast fashion, consumers are well accustomed to softer synthetics quite different to the itchy feeling of strong wool garments.

Poor Wool Handling

The quality of wool presentation has decreased significantly over the last decade according to wool buyers. Merchants have reported an increase in faecal and vegetative matter, moisture and other contaminants which create difficulty in grading and sorting wool. This adds to the labour costs for processors, eroding opportunities for better farm gate prices. Wool producers tend to

“Wool producers tend to blame the low prices for the lack of attention to wool handling”

blame the low prices for the lack of attention to wool handling, but merchants maintain that it has been a longer running gradual decline. If wool growers are to achieve a more favourable farm gate price, then presentation will need to improve. It is the subject of debate whether farmers should be financially incentivised to improve wool presentation, or if market forces should be allowed to dictate.

Farmer Reliance on Direct Subsidies

Irish agriculture in general is reliant on direct supports through the Common Agricultural Policy. This dependence on direct payments tends to stifle innovation and discourages entrepreneurial spirit at farm level. There is little appetite among the sheep farming community for producer led co-operatives or groupings due to the perception that the revenue gained would be insignificant when compared with the value of subsidies and hence not worth the effort.

Incumbent Supply Chain

The existing supply chain for wool has not significantly changed for generations, except for an increase in greasy wool exports to the far east. Wool is generally bought by merchants and their agents across Ireland and traded with buyers in the UK for scouring in Bradford and onward sale across the world. Buyers of scoured wool tend to be concentrated in the manufacturing strongholds in Asia and elsewhere. This incumbent supply chain works for those already taking part, but inevitably leaves little of the value in the hands of the primary producer. It is difficult to disrupt due to long standing supply relationships and as such, initiatives such as farmer co-ops and other collective bargaining arrangements have never been widespread.

High Cost of Value Adding in Ireland - Lack of Processing Facilities

As is the case in many developed economies, labour intensive manufacturing is extremely expensive in contrast to developing nations. Shearing, skirting, grading, sorting, and packing of wool are all manual operations which are costly in relation to the price achieved for wool. Scouring is water and energy intensive and presents challenging wastewater issues. The trend of offshoring manufacturing capability means local skills are lost and difficult to reinstate. Potential enterprises do not have the benefit of the cluster effect and must incur extra expenses in developing manufacturing capability. Planning and social buy-in are barriers for heavy manufacturing as is nimbyism.

Perception and Classification as a Waste Product

Sheep's wool is classified as a Category 3 Animal By-product in the EU. It is generally perceived as being a waste product and this perception is deepened by the fact that wool production is a loss-making exercise for farmers when taken in isolation. While this categorisation can have benefits in terms of waste to value applications, it also presents regulatory difficulties with transport and processing. Wool is an animal by-product which

can present threats to the biosecurity of both animals and humans and as such needs to be treated with care. All details on the regulations are available on the DAFM webpage.

“Sheep’s wool is classified as a category 3 animal by-product in the EU”

Opportunities

Farmer Co-operation

There have been examples on a small scale of farmer co-operation and collective bargaining. Wool producers pooling their produce and negotiating as a group with the benefit of scale, presents a good opportunity to achieve better returns. There is also scope for these co-operatives to take on the tasks of skirting, grading, sorting and baling of wool depending on the resources available.

Education of Consumers

Education of consumers through promotional awareness campaigns has scope to improve the perception of Irish Grown Wool. This education could address the fact that many wearable woollen textiles offered for sale by Irish retailers is Merino wool which is not of Irish origin. Information on various validated benefits of wool in general could also be disseminated through these campaigns to give wool-based products an advantage over synthetic and other fibres.

Collaborative Opportunities

Operators within the wool ecosystem could benefit from collaboration with other operators who have compatible goals. This could be in the form of collaboration with producers of other types of biofibres such as hemp and flax among others. It could also take the form of collaboration with other promotional bodies such as the Campaign for Wool, Woolmark, IWTO, British Wool Marketing Board and Ulster Wool. There are also opportunities for Irish wool producers to collaborate with existing commercial operators within the existing wool supply chain to capture more of the value of their wool.

Improved Traceability

Irish Grown Wool-based products could benefit greatly from improved traceability which would allow the use of provenance as a marketing tool. It has been shown in food and other markets that authentic Irish products are in great demand worldwide, due to the trust and perceived green credentials of our farming systems. There are advances in technology available which could be applied to Irish Grown Wool to create a traceable value chain from producer to end-user. This gives an opportunity to highlight good social and environmental practices within these value chains and to market products to more discerning customers.

Improved Marketing and Brand Promotion

Other jurisdictions have well established marketing and lobby organisations to champion their wool-based products. This approach could be applied in Ireland in several ways. It could be led by industry, producers, state bodies, or a blend of all three. The creation of a brand or trademark for “Irish Wool Inc.” would give a platform to build on the provenance and traceability mentioned, to administer any promotional or awareness campaigns. A National Wool Group could be formed by producers, merchants, manufacturers, and retailers to promote Irish Grown Wool.

Government Support of Bio-based Materials (Green Premiums)

In the context of committing to promoting the Circular Bio-Economy, natural fibres could be formally promoted by the State. There is huge potential for wool-based products, such as insulation, to be given an advantage or Green Premium as part of the national retrofit program or new-build housing. Given that wool is bio-degradable it can form part of the circular economy, with less impacts at end of life when compared to synthetic materials. Natural fibre-based products tend to be in the premium price range and as such find it hard to compete with incumbent synthetic products. If the State were to consider mechanisms to give natural fibre-based products a comparative advantage, their use may become more mainstream and price point may become more competitive with economies of scale.

Labelling Transparency Regulations

Introduction of regulation on labelling of woollen goods could be beneficial for Irish Grown Wool. Most woollen apparel sold in Ireland is made from overseas Merino wool and much of it is also manufactured overseas. Almost all this apparel is marketed using an Irish theme. It is difficult for any authentically Irish grown products to compete on a level playing field. If items were labelled transparently with country of origin of the fibre and place of manufacture clearly displayed, this would strengthen any demand for Irish Grown Wool and allow products derived from Irish Grown Wool to compete on a level playing field.

New Technology for Scouring

Traditional aqueous scouring may not be feasible in Ireland due to environmental and economic constraints. New technologies may be developed making it feasible to carry this out in Ireland, thus retaining more of the added value in the country. These technologies include dry scouring, hydrolysis, ultrasonic and many others at an early stage of development.

By-product Valorisation

An opportunity that would arise from any on-island scouring operation would be by-product valorisation. While Irish Grown Wool does not contain the same levels of lanolin that Merino wool does, it does still have a certain amount and this along with grease and suint contain many minerals

and compounds which could be valorised in cosmetics, aquaculture and lubricants. Further details of opportunities to further develop these products are outlined in the research section of this report.

Natural Fibre Blending

There is an opportunity for wool to be blended with other natural fibres such as hemp, linen, cotton, alpaca fibre and others for a wide range of applications. The benefit to creating a fully natural blended products is their renewable and biodegradable nature. This also helps certain products overcome scale barriers.

Genetics/Breeding Programs

There is scope for breeding programs to improve wool quality on a small scale. These programs can be delivered in collaboration with speciality or heritage breed societies with a view to creating premium authentically Irish textile or upholstery products. Collaboration between breeders and manufacturers could help with initiating these programs. These programs and products could be used as pilot projects to investigate the feasibility of breeding for wool traits on a larger scale. Ideally the breeding programs would not adversely affect meat production or other traditional traits.

Threats

Commodity Price Fluctuation

Wool is a commodity traded on world markets and subject to fluctuation in demand and price. If Irish Grown Wool is not marketed as a premium product, then it will continue to be sold in a price-taking fashion with little value returned to primary producer.

Shedding Sheep

Sheep breeders may choose to introduce wool-shedding breeds such as the Easy Care instead of producing wool. This negates the need for shearing and other welfare actions. Since wool is very much a by-product of sheep meat production in Ireland it is not inconceivable to see farmers moving towards an animal which does not have this burden. It should be noted that this is a long-term threat due to the slow-moving nature of breeding.

Closure of Local Merchants

There has been a consolidation of Irish wool merchants in the past number of decades, to the extent that there are now only a handful of truly independent merchants. The two main British wool scouring operations now have controlling interests in several Irish merchant businesses. There are geographical areas of Ireland in which merchant closure makes it extremely difficult to sell wool. If this trend were to continue, there is a threat of British operations taking full control of the Irish clip. Haworth Scouring (Curtis Wool) and Thomas Chadwick's (Standard Wool) are significant scouring operations for which Irish Wool provides volume to achieve greater efficiencies of scale.

Farmer Apathy/Waste Perceptions

Farmers have not seen wool as a valuable output for some time now. It is perceived and treated as a burdensome waste product which needs to be dealt with for animal welfare reasons. This apathy from farmers presents a threat of wool being forever undervalued and underutilised. Waste is a resource in the right hands and wool needs to be seen as an important bioresource if its farm gate value is going to recover. The buy-in of farmers to the potential value of wool is essential as without it, every other

player along the value chain will be happy to exploit this resource without rewarding the primary producers.

Lamb Price Fluctuation

Lamb price fluctuation affects wool production in many ways. If the relatively high prices of 2021-22 continue, then the income gained from wool will be a very small portion of the total output. If lamb prices become poorer, then there may be a decrease in sheep numbers. Both scenarios present threats and opportunities for Irish Grown Wool.

Mislabelling

The practice of marketing faux Irish wool apparel to tourists in a misleading fashion presents a threat to the credibility of authentically Irish Grown Wool products. Much of the wearable textiles sold by gift-shop type retailers is made from Merino wool and sometimes manufactured elsewhere. The issue is that consumers are led to believe that the products are Irish Grown through clever marketing themes and lack of transparent labelling.

Customs/Tariffs Post Brexit

Much of the Irish Grown Wool clip ends up transiting through the UK either for scouring or sales. While there are currently no tariffs or customs barriers to this movement, it is quite possible that they could be introduced at short notice. This would present a massive threat to Irish Grown Wool, leaving very little alternative routes to market.

Continued Rise of Synthetics

The decline in the use of wool over the course of the 20th century can largely be attributed to the rise of synthetic materials such as nylon and polyester. Should this trend continue, Irish Grown Wool would be of little value on the world commodity markets. A similar threat could be a move away from animal-based fibres to plant-based cotton or hemp.

Skills Shortage

There is a risk that key skills are being lost in wool related tasks such as shearing, handling, skirting, sorting and grading with the latter already almost non-existent. Without an improvement in attitudes to wool and better returns, this is a threat to the sector. Without these skills it is very difficult to see value to be retained on the island of Ireland in future.

Irish Wool Ecosystem Map

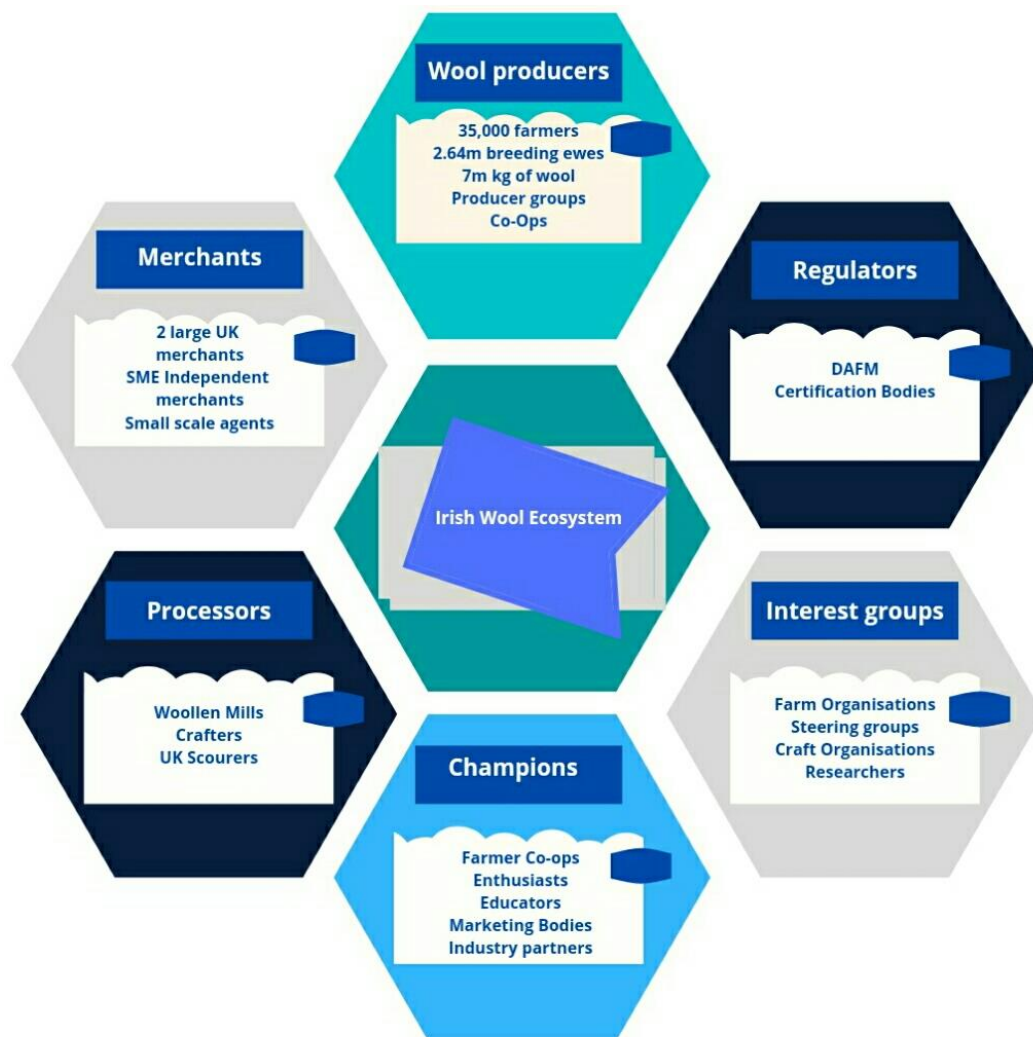


Figure 4. Illustration of wool ecosystem in Ireland.

Market Drivers

Consumer Lifestyle Trends

A number of Lifestyle Trends are shaping the market, driving demand for natural and sustainable products. These are Health & Wellbeing; Responsible Living; Community and Identity; and Engaging Experiences that will advance this market further.

Health and Wellbeing

Businesses that develop consumer filled bedding products are reporting a 50% increase in turnover. This is due to consumer concerns around sleep quality, allergies to synthetic products and the need for temperature control. Wool has been reported to offer a 'hypo-allergenic' alternative (with ongoing studies being conducted in this area to validate claims) as well as regulating temperature; this is a growing market specifically for certain demographics and sectors like healthcare.

Responsible Living: Sustainability and GHG Emissions

Consumers are becoming more aware of their individual carbon footprint, and in parallel are seeking products that align with their sustainability values. For example, over the past two years, insulation-based businesses reported an increase in the number of sales of sheep's wool thermal insulation for homes. This is a sustainable alternative as it can lower the carbon footprint of a home as an energy efficiency measure, contains no petrochemicals, safer to handle compared to fibreglass products and overall using wool helps with a positive assessment of embodied carbon of the construction process aligning with Net Zero Buildings goals.



Greenhouse gas emissions are categorised into three groups or 'Scopes' by the most widely used international accounting tool, the Greenhouse Gas (GHG) Protocol. Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain[1]. As a result of Scope 3 emissions and sustainability commitments made by large corporations, we are seeing a cascading demand for proven environmentally friendly products throughout corporate value chains. For example, Jaguar Land Rover are seeking bio-based composite materials from their suppliers for components of the vehicle, Irish companies such as Kingspan are conducting research at their IKON Research centre on biobased materials in panelling and insulation and Kerry Group purchase wool-based packaging for their products as a sustainable alternative to plastic.

Interest in natural fibres is escalating because of increased knowledge among consumers, particularly younger demographics, about 'fast fashion' and how damaging it is socially and environmentally. In textiles and other industries, we are seeing the blending of wool with other natural fibres that are appealing visually and soft to touch. Coupled with a growing emphasis on quality and provenance, these are the qualities that are increasingly appealing.

Community and Identity

Traceability of natural resource commodities is an ongoing trend driven by the need for transparency in supply chains by government and consumers. In addition, buyers and customers of wool product like to know where their product is from. For example, the British Wool Board have undertaken a significant effort on traceability by investing in ICT infrastructure to have a digital record of the wool all the way back to lot number and the farmer. According to Andrew Hogley, CEO of the British Wool Board, this is driven by their customer's needs and as a result, has created a value-add opportunity by creating a premium product and customers are willing to pay more, at an additional 25 cents per kilogram of wool sold.

According to the Irish companies we have spoken with who have products on the market, there is an opportunity to tell the provenance story of Irish wool and its application in various products and supports its international branding. It will also prevent the misinformation about alternatives on the market that are labelled as Irish product but do not contain Irish wool.

There is potential to create socio-economic benefits by investing in educational and training programmes about wool ranging from local handling, to processing to manufacturing Irish Grown Wool craft products. In the tourism sector, we are seeing increasing demand for engaging and activity-based tourism opportunities. Providing facilities and activities for overseas visitors to visit, engage and buy Irish Grown Wool would be an added advantage unlocking socio-economic benefits in many parts of rural Ireland. This will create stronger authentic tourism and heritage linkages and benefits.

Data and Digitalisation

In addition to Consumer Lifestyle trends shaping the market of wool-based products, there is also a cross cutting trend around Data and Digitalisation.

In the information era, data is essential to prove a product is traceable, low carbon, delivers on named benefits and is supporting sustainability across the value chain. Whether this data comes in the form of tracking data points in a traceable supply chain to prove its provenance or conducting Life Cycle Analysis of wool products to prove their green credentials, or information on animal welfare, this is a trend that is here to stay and will be very important to sustain an added value Irish Grown Wool industry.

Life Cycle Assessment (LCA) is an increasingly common process required by buyers of products to meet environmental standards. LCA is a method that quantifies the environmental impacts of a process so as to provide meaningful data that can be compared against other processes Life Cycle Assessment is looked favourably upon by corporates and larger SMEs who are engaging with suppliers in the supply chain.

In addition, digitalisation has helped several businesses pivot their sales, marketing and customer engagement processes during Covid. This made enterprises more resilient, and in the case of sheep's wool products, it was an enabler for increased sales overseas.

Safety

Wool is reportedly a natural fire retardant, and this makes it appealing in insulation and acoustic panelling for the construction industry. Increasingly, we are seeing that those manufacturers of insulation materials are conducting R&D on materials such as wool and hemp and testing these in environments to address health and safety challenges in the industry.

Markets for Irish Wool



Irish Grown Wool can be broadly categorised as mountain/hill type, crossbred and lowland. Mountain/Hill wool comes predominantly from breeds such as the Blackface and Cheviot. Crossbred wool mainly comes from mule ewes and lowland wool is shorn from breeds such as Suffolk, Texel, Charolais, among others. Mountain type wool tends to be coarser and generally achieves a lower commodity market price than crossbred or lowland wools, with some limited exceptions.

The finest of the Irish Grown Wool currently being produced is measuring 26-28 micron fibre diameter and comes from Bluefaced Leicester sheep. Most of the Lowland and Crossbred wool is in the low to mid 30 microns while Mountain/Hill type wool often ranges from 36-38 microns fibre diameter and above. Certain breeds contain a portion of brittle hair-like kemp fibres which are undesirable in many applications. There is currently little or no focus on improving wool quality within the Irish sheep farming community because of the low prices achieved over a long period of time and increased focus on meat production.

Compared to famous merino type wools from Australia and New Zealand, which can achieve much finer fibre diameters, the Irish wool is more limited in its range of applications. Fine and superfine merino wool is much more suited to wearable textiles, with Irish Grown Wool being traditionally used in carpets due to its superior fibre strength.

Horticulture

HORTICULTURE	
Application Areas	Fertilizer; Compost; Mulch Mats; Slug Repellents
Potential	Use low grade wool as a biobased fertilizer, compost, mulch mats, slug repellent
Highest Potential	Compost, Mulch Mats
Value	Low Value Product
Import Substitution	Peat replacement
Market Size	<p>€1.2 billion amenity horticulture market in Ireland[2]</p> <p>Peat imports. In 2021 to date, 42,800 tonnes of peat valued at €7.3m has been imported into Ireland. The vast majority came in from Northern Ireland, followed by the Netherlands, Great Britain, Germany, Lithuania, Ukraine, and Belarus.[2]</p> <p>The global fertilizer market amounted to more than 171 billion U.S. dollars in 2020. It is forecast that the fertilizer market will surpass 210 billion U.S. dollars by 2027[3]</p>
Supporting Policy	New regulation introduced in Europe to include biobased material in Fertilizing Product Regulation 2019 / 1009
Considerations	When combined with other materials in composting etc processes the modest tonnage of Irish Grown Wool can generate a substantial volume of natural fertiliser and growing media.

The properties of sheep's wool may make it a highly effective growing media for the horticulture sector. Horticulture in Ireland has two sub-sectors: food and amenity produce. The key crops in the sector are mushrooms, potatoes, field vegetables, fruit, nursery stock, cut foliage, Christmas trees and bulbs, primarily for the domestic market. Ireland also has around 100 nursery stock producers, who produce plants for the domestic and export markets[2]. Given that sheep's wool is an animal by-product, the priority application as a fertiliser is in the amenity horticulture (non-food chain) market. In 2020, the gardening market at consumer level was valued at €1.2bn, of this total plants and flower segment was €385 million[2].

Fertiliser

New European regulation to be introduced later in 2022 offers a market opportunity for biobased materials in products like fertiliser, compost etc. This is specifically called Fertilizing Product Regulation 2019 / 1009. It is creating a market for Secondary Raw Materials, including animal-based by-products. The new EU (European Union) Fertilizer Regulation (Fertilizer product regulation 2019/1009) replaces one which focused on mineral sources. All new biofertilisers arising from this Regulation will have to undergo a 'conformity assessment' provided by a national assessment body. A set of technical documentation will need to be prepared by manufacturers (and feedstock suppliers) to meet the assessment criteria. The technical documentation shall specify the applicable requirements and cover, as far as relevant for the assessment, the design, manufacture and intended use of the EU fertilising product.

There are cost pressures on farmers in the agricultural industry due to rising price of chemical-based fertilizers. The chemical fertilisers are fossil-based, and use of chemical nitrogen in Ireland was 408,000t in 2018[4].

According to sheep's wool stakeholders, the total wool clip in Ireland is in the region of 7,000t per annum. Given that the lowest value wool (skirt wool and dags that is not sent for scouring) should be used as fertilising agent, this would result in a small portion of the total clip available for this application. This imbalance in volumes means that wool-based fertiliser may be more suited to lower volume markets such as organics, domestic gardens, or small-scale horticulture.

This was confirmed via an interview with an Irish fertiliser company who sell broadcast grass fertiliser. They were interested in supporting the sheep farmers and they are looking to include biological materials in their fertiliser mixes, however the volume in their opinion was "not near what they require". They would usually price a product based on per unit price per value and no conclusion could be drawn on how to price the low value wool for this application or an appropriate business model, given the potential small volume available. Compo, a German based company, has pioneered bio gardening products, including peat substitutes, helping to position the company at the forefront of the sustainability agenda. They have a fertilising product for garden and horticulture comprising of 50% sheep's wool[5].

***"Total
wool clip
in Ireland
is 7,000
tonnes
pa"***

Conclusion

Fertiliser would represent a reasonably straightforward, if low value, application for sheep's wool. The biggest challenge for this may be in the scale of wool available to provide security of supply chain if an enterprise or producer did commit to this. As with any biological raw material, security of supply chain can become challenging, particularly when being produced as a by-product of another sector. The concentration at which wool may be used in a fertiliser would need to be considered and this may contribute easing some of the supply chain issues.

Compost

Utilising organic bio-resources and novel technologies to develop specifically designed and sustainable peat replacements is necessary for professional horticultural crop production. Peat has become an essential component in the production of plants and mushrooms in professional horticulture, due to its favourable physical, chemical, and biological characteristics. However, there is a pressing need to evaluate and develop alternatives which have a favourable environmental profile while also maintaining crop yield and quality.

Peat replacement has become a pressing issue in Ireland for the horticulture industry, particularly since the decline in peat harvesting in Ireland. Sheep's wool may offer benefits when used in a mixture as compost or mulch: as a source of slow-release nitrogen and other trace elements, in weed and pest control, moisture retention and temperature regulation. In this case, it may be used as a sustainable, renewable, and environmentally friendly alternative to peat and peat compost. Producers and merchants may be looking for alternative ways to make use of their fleeces, particularly dags and dirty

***"Peat
replacement"***

or low-quality wool. A company in the UK already commercially produce several ‘wool and bracken’ composts, a sustainable, environmentally friendly, peat-free alternative.

Sheep’s wool replaces the peat element of other composts by increasing water retention and acting as a source of slow-release nitrogen[5].

Conclusion

In today’s compost market in Ireland, to be profitable, composters are dependent on gate fees. Composters that hold a licence to manage Class 3 Animal By-Products generally charge higher gate fees to take account of increased regulation. For this reason, composting wool would require a unique selling point to enable it to generate a viable sales price. The UK company was advertising wool compost at over €1 (equivalent of GBP) per litre which according to a compost producer in Ireland, ‘*is a good price, as compost in Ireland is very low value*’. With effective marketing and wider awareness, there is potential for Irish Grown Wool compost using the skirt and dags to create a value-add produce that appeals to horticulturalists and market gardening in the amenity horticulture sector.

Mulch Mats

Mulch mats are materials placed on the surface of soil to prevent weeds and protect the soil when growing plants, vegetables, and trees. This is an alternative to products like herbicides and plastic mulch sheeting. Wool based mats have the additional advantage of retaining water within the mat. In the UK, a company (Chimney Sheep) has created a 100% natural sheep’s wool garden felt. It comprises of a dense layer of wool and a layer of jute carrier materials. This product is used to inhibit weed growth and retain water; it will also biodegrade over the course of the year releasing the nutrients into the soil. In 2007, the Council for Forest Research and Development funded research to examine the technical feasibility of using a range of mulch mats, as an alternative to herbicide use to establish forest and other tree crops on both afforestation and reforestation sites. They found that mulch mats are at least as effective as conventional herbicides in controlling weeds but can cost more.

Conclusion

The garden wool felt advertised by the UK company was £7.99 GBP per 1.4 linear metre. The assumption is that low priced wool is used for a product like this. Compared to conventional herbicide products this may be an expensive option for gardeners and horticulturalists, depending on the application.

Slug Repellent Pellets

Wool helps to prevent slugs and pests from harming plant growth. In the UK, Vitax produces slug repellent wool pellets for the horticulture sector. The product is certified organic by the Soil Association and in additions meets EC 1069/2009 animal by product standards. Creating pellets is a new process that requires equipment and in addition it is unclear as to the exact ingredients in the pellet and the casing of it to ensure it breaks down. This is discussed in further detail in the Research Projects section.

Conclusion

Similarly to Horticulture applications overall, they may be potentially require the lowest level of development to get product to market. That said, pelleting equipment would be required for this

application, with a capital investment that would only be made where a clear market opportunity can be identified.

Horticulture Overall Conclusion

The highest potential application for sheep's wool is for composting and mulch mats for the amenity horticulture market, and market gardening. A business model needs to be outlined across the value chain to understand how the farmer can benefit from an added value price for supplying sheep's wool.

Textiles, Furnishing and Carpets

Textiles, Furnishing and Upholstery	
Application Areas	Textiles; Upholstery; Carpets; Home interiors & Composite furniture
Potential	Wool's potential health benefits can be used to market indoor furnishings. Irish Grown Wool has properties which lend it to these applications, being coarse but strong.
Highest Potential	The global market for Automotive Upholstery, estimated at US\$3.6 Billion in the year 2020, is projected to reach a revised size of US\$5.2 Billion by 2026, growing at a CAGR of 6.6% over the analysis period[6].
Value	Medium – High
Import Substitution	Cotton, Feathers, Synthetics
Market Size	<ul style="list-style-type: none"> The global textile market size was valued at USD 993.6 billion in 2021[7] The global market for Automotive Upholstery, estimated at US\$3.6 Billion in the year 2020[6] The European carpet market size was valued at USD 51.7 billion in 2018[8]
Supporting Policy	National Policy Statement on the Bioeconomy, February 2018.
Considerations	<ul style="list-style-type: none"> Blending of fibres with Irish wool represents an opportunity Strengths of Irish grown wool are sustainability, provenance and traceability

While Irish wool may be at a disadvantage to Merino wool and other fibres for skin contact wearable fabrics, it does still have a market for outer garments, upholstery, home interiors, carpets, and furniture. Traditionally, most of the Irish wool is used in carpet manufacture. Due to the high costs of production in Ireland, most of the manufacture takes place outside of the state. This has led to the loss of control of the supply chain and therefore poorer prices for Irish merchants and hence primary producers. Upholstery and home interior pieces could be an avenue for well-presented Irish Grown Wool since the fibre diameter is not as much of an issue. There may be a small portion of the best quality Irish wool (28-32µm) which is suitable for clothing applications. In both the clothing and home interior markets, the strengths that Irish Grown Wool can lean on are sustainability, provenance, and traceability.

Textiles and Upholstery

For wool to be used in textiles, it needs to be less than 28 microns. Much of the Irish wool clip is over 32 microns, it is a coarse fibre and therefore coarse to touch compared with other softer fibres and has the perceived 'itch factor' associated with it.

One of the leading suppliers of spun Irish wool yarn for use in textiles is Donegal Yarns, and they supply to the mills and textiles manufacturers across Ireland and globally. These manufacturers all use different types of fibres (cashmere, lambswool, merino, British wool) in their products (blankets, scarves etc.) and some of them have bespoke wool product or blended products. For example, an eco-blanket using British wool that is undyed. The textile is rougher to handle but the selling point is that it is a natural yarn and not dyed.

A challenge for the industry is that there is not enough demand for Irish wool textile products, and it is an expensive yarn to use in textiles compared the softer fabrics, overall coming across as more expensive and less functional. Given that other parts of the textile manufacturing process are capital intensive (dyeing and finishing), using Irish wool may not create a competitive product. However, there is opportunity to turn this around. The Campaign for Wool[9] is changing the perception of wool in textiles and other consumer products, highlighting the story and the provenance in a positive light, working with brands like John Lewis, Marks and Spencer, Jaeger and many more. This is creating increased demand for wool-based textile products and opening up an opportunity for creating softer blends with Irish grown wool.

Conclusion

Most of the brands we spoke with are interested in using Irish wool if the quality and quantity was available. Given the demand for natural fibres in textiles, there is an opportunity for blending fibres with Irish wool to make it a softer fabric. One of the companies referenced that using 100% Irish wool in a textile is a challenge, and more likely it would be a 70-80% wool product. This is already underway, for example a leading yarn spinner is creating blends of hemp with Irish wool and an Irish heritage brand have a blend of 60% Irish wool and 40% New Zealand wool in their garments.

Creating an authentic Irish brand for wool products, even if blended, would support the marketing of Irish Grown Wool products in the global marketplace, tying in with the Campaign for Wool. With greater demand, there will be a greater need for volume of product produced which means that it may become more capital efficient and more competitive to produce wool-based textiles. Supports will be required for businesses to manage this scale – perhaps through dedicated micro wool processing facilities on site or technologies that process coarse wool to give it a softer handle.

Carpets

Traditionally the coarser wools are used for the mass carpet industry. According to Andrew Hogley, CEO of British Wool, 8% of their target market is the carpet industry.

The carpets manufactured with coarse wool are typically used for cruise ships and hotels, the hardy fibres make it a long-lasting product. One manufacturer in Ireland produces a large volume, 40,000 m² of carpet per week, with a typical blend of 80% wool and 20% synthetics using 2 million kg a year of wool. Two types of carpet are produced, woven, and tufted. During Covid-19, the sales of carpet decreased due to lack of demand, however sales are rising again. This one of the few industries where

wool product sales decreased during Covid-19, however, since the bulk of Irish Grown Wool is aimed at this sector it had an impact on global trade.

The high-volume manufacturers of wool-based carpets stress that wool is known for increasing the quality of carpet, and this is the premium unique selling point above all else. In terms of environmental and sustainability concerns, the interior design contractors who fit out hotels and buildings, would typically seek carpet specification around sustainability goals.

In comparison, specialist boutique bespoke rug manufacturers in Ireland use about half a tonne per year of wool in their products. High quality wool is of importance given their high-end market and customers. In one recent rug design, they used the Galway Wool breed amongst others as they found the fibres from coarse mountain wool are too short and lends itself to a shorter wear and tear lifespan.

Small-scale bespoke manufacturers would like to use more Irish wool in their products, but they face some challenges: 1) they do not always have a consistent supply of quality wool; 2) The price point for processing, spinning and dyeing the wool can be too high to justify using it in a bespoke rug compared to Spanish wool or Alpaca products; and 3) the Irish wool e.g. Galway wool is a creamy colour and requires bleaching and chemicals.

For the small-scale bespoke industry to reduce the cost of manufacturing rugs and other textiles and crafts on the island of Ireland, a mini processing plant would be required for textile and craft industries. This could potentially unlock a new business model for integrating wool into consumer craft and textile products.

Conclusion

Companies agreed that the branding and story of Irish Grown Wool in their products (whether mass market or bespoke) would support the marketing of their products and help command a premium price that can be shared across the value chain.

Textiles, Furniture and Upholstery Overall Conclusion

Availability of sufficient wool and branding were two key considerations in this section. An Irish Grown Wool brand would provide significant support to use of Irish wool in textile products. The availability of sufficient scoured wool, while providing a potential bottle neck initially can have positive impacts. It may increase the value of the scoured wool as it is in lower supply, and as this value increases it may encourage greater production of wool to take advantage of increasing prices.

Construction

CONSTRUCTION	
Application Areas	Acoustic and Thermal Insulation
Potential	Use wool as an insulator in housing. Wool is a low embodied carbon and user-friendly material for construction insulation. Wool is naturally fire retardant but may need assessment for insect resistance.
Highest Potential	Wall Insulation, Acoustic and Air Filtering Panels
Value	Medium
Import Substitution	Insulation -Rockwool, fiberglass, Icynene (foam), polystyrene, Phenolic insulation boards (Kingspan Panels).
Market Size	Domestic market circa is estimated at around €120m by assuming 70,000 homes per annum between new build and retrofit, 140m ² average insulated area, average cost of insulation €12/m ² . The global market for thermal insulation was \$29.85 billion in 2021 and expected to be a \$40.34 billion in 2028, CAGR of 4.4% during this period[10].
Supporting Policy	Home Performance Index awards credits for embodied carbon calculation and LCA. The international certification schemes for non-residential buildings, LEED and BREEAM, also award credits for the calculation of LCA and embodied carbon. This is driving interest amongst professionals in calculation. EN15978 sets out how the full life cycle carbon and other environmental impacts should be calculated setting out the modules relevant to each part of the building lifecycle.
Considerations	Health benefits of building insulation, Filtering of VOCs, processing needs to be addressed for insect attack (moths).

Insulation

Sheep's wool insulation has an opportunity to replace synthetic alternatives in domestic and industrial buildings[11]. The performance of sheep's wool insulation in domestic building applications is comparable to that of synthetics and it may outperform synthetics in thermal and acoustic insulation applications. The potential benefits of using sheep's wool are:

- It has been claimed that sheep's wool insulation can provide health benefits for those with respiratory issues as it is said to harbour less dust mites;
- It has been claimed to adsorb volatile organic compounds. See research section for further detail;
- Utilisation of wool supports low carbon embodied wool in buildings. Research needs to be carried out into the kgCO₂e of sheep's wool to verify the embodied carbon potential in buildings;
- End of Life, using sheep's wool in products increases its recyclability in the longer term and therefore the product does not require landfilling.

Sheep's wool insulation is available on the market today. Companies have different offerings from 100% wool to wool mixed with synthetic fibre, and each have different thermal and insulation values based on Lambda, R Value and U Value (as defined below and by Kingspan[12]) to determine how effective it's insulative properties are.

- **Lambda Value:** The lambda value, also portrayed as 'K-value' or ' λ -value', measures a product's thermal conductivity in units of W/m·K. A good insulation will have as low a lambda value as possible to reduce heat loss;
- **R-Value:** A product's R-value measures its thermal resistance in units of m²·K/W. By dividing a material's thickness (in metres) by its lambda value, you can discover how well it resists heat transfer at a specific thickness. The best insulation will have a high R-value at a low thickness, indicating that it is just as good at reducing heat loss as its thicker counterparts;
- **U-Value:** A U-value is a sum of the thermal resistances of the layers that make up an entire building element – for example, a roof, wall or floor. It also includes adjustments for any fixings or air gaps. A U-value value shows, in units of W/m²·K, the ability of an element to transmit heat from a warm space to a cold space in a building, and vice versa. The lower the U-value, the better insulated the building element.

In our research, we spoke to two companies who have thermal and acoustic insulation products ranging in size and specifications available on the market today. Both companies are reporting an increase in their sales, and they shared that certifications (such as Environment Product Declaration or NaturePlus) are very important to their position in the market. (See more detail in Industry Initiatives - Certification section).

One of the significant challenges to overcome in manufacturing insulation is addressing moth protection. One of the companies is using chemical borax application at low concentrations and the other has a partnership with a market leader who has a patented process for moth-proofing solutions for wool. In the table below we selected two of their products to undertake a comparison of availability in terms of production, specification, price range and certification.

Company	Product	Specification	Price range	Certification
Company 1	75% British sheep wool	Lambda Value: 0.035 W/mK	£129.86 – £152.34 distributor website	Environment Production Declaration
Company 2	100% sheep wool	U-Value: 0.0339 – 0.042 W/mK	€99 - 133.33 on website	NaturePlus

Following discussion with the Irish Green Building Council regarding green and low carbon credentials of insulation materials for low carbon buildings, it is important to note that the Environment Production Declaration (EPD) is certification that the Irish Green Building Council would expect to see for any wool insulation product that comes to market. In an interview with the Sustainable Energy Authority of Ireland, they highlighted that the incorporation of LCA into building regulations is not expected to be complete for a number of years. This does not impact the sale of sheep's wool insulation in the market today, but it does highlight there will be a future opportunity to quantify the carbon benefit to consumers to meet energy efficiency and embodied carbon codes and regulations.

Several actions need to be undertaken over the coming years by national government working on the Energy Performance of Building Directives (EPBD) including:

- The methodology for LCA calculation and thresholds, needs to be set for insulation materials;
- A harmonised product register needs to be developed across Europe and integrated into the Building Energy Rating (BER) formal platform.

In line with future regulations, many companies are waiting on the side-lines for the low embodied carbon insulation market to open. We found that large companies are conducting research and development on biobased materials in panelling and insulation to reduce the embodied carbon in buildings over the long-term.

Today, the market opportunity for this type of wool insulation is tangible and would solve some unique challenges. For example, in Ireland alone, houses built pre-1950 require major retrofits and energy efficiency measures, and a low carbon source insulation is a solution. This housing segment represents about 16% of the Irish market. Experts have indicated that these types of homes would benefit greatly from the use of breathable insulation made from natural fibres such as wool.

In terms of manufacturing wool insulation, it is important to note that the wool used in insulation is scoured, low quality wool. Most of the cost for producing insulation is in labour and manufacturing. For this reason, it is not competitive for the farmer to sell their wool to the merchants or insulation manufacturers. Companies are buying wool at low price either at auction or from farmers via the merchants, then sending for scouring to Bradford and later integrating the fibre into their insulation product. This product retails at a higher price compared to the standard fibreglass product on the market today at £1.50 per square metre; comparable to wool products at £9 per square meter and £12.50 per square metre. However, wool products may become more competitive due to rising costs of conventional materials. An insulation retailer highlighted that there are two current trends in the market regarding insulation, the first is that the existing price of glass wool is rising and secondly the energy costs to produce it are also rising. This would allow for a wool product to become more competitive on the market.

***“majority of
cost for
producing
insulation is
in labour and
manufacture”***

Construction Overall Conclusion

Many of the companies we spoke with would be interested in advancing the branding of Irish wool in their products, however, a new business model is required to determine how to bring value back to the Irish primary producers who are selling the wool for insulation manufacturing.

Packaging

PACKAGING	
Application Areas	Filler Material for Thermal Packaging
Potential	Insulation packaging for cold-chain transport.
Highest Potential	Cold chain transport in pharmaceuticals, food industry
Value	Medium
Import Substitution	Polystyrene
Market Size	\$20 billion. The Cold Chain Packaging Market was valued at USD 20.08 billion in 2020, and it is projected to be worth USD 36.65 billion by 2026, registering a CAGR of approximately 10.36% during the forecast period (2021-2026)[11].
Supporting Policy	Corporate Sustainability targets outlining using less plastics
Considerations	Replacing non-recyclable material, could be used as thermal insulation

Due to its temperature regulation and thermal properties, sheep's wool has proven to be an effective filler for packaging in the cold chain industry. It is an ideal replacement to the polystyrene filler that companies and consumers often receive as part of deliveries. In addition, polystyrene is hard to recycle and takes up considerable space in warehouses. As part of corporate sustainability targets to reduce plastics overall, there is an uptake in demand for biobased packaging alternatives for transportation of temperature-controlled goods like fresh foods.

There are companies in the market today from the UK and Australia offering sustainable packaging solutions made from 100% wool and covered with biodegradable lining. Interviews with companies from the UK highlighted the growing demand for these types of packaging products from food, pharmaceutical and associated industries where cold chain transport is required. These packaging companies have patents for how they process the wool once they receive it from a scouring plant. Typically, coarse mountain wool mixes are used in the products, which are not a high value feedstock. The manufacturing process is performed to a high standard, (ISO14001) as it meets their customer's expectations. For example, in their sustainability report, Kerry Group highlight their use of this type of packaging as a solution for cold chain transport.

Overcoming the use of plastic in packaging is a known challenge faced by companies across the world. To prevent misinformation and to fill the data gaps that exist around the environmental benefits of wool, one of the companies (Woolcool) is working with a Keele University (UK) on an LCA of wool-based packaging.

Packaging Overall Conclusion

While the market outlook for both biobased packaging and for cold chain packaging markets is on the rise, this industry is new and growing. In terms of competitiveness, companies are mindful of the sensitivities in their supply chain. For example, in terms of the price point for purchasing wool, end customers compare the product with cheaper polystyrene options, and shipment costs are rising. The companies expressed their interest in creating a packaging product created entirely out of Irish wool and sell it back to the Irish market, as an Irish grown branded product. This is an opportunity to be explored along with a business model to bring benefit to the farmers.

Filled Products

FILLED PRODUCTS	
Application Areas	Mattresses; Pillows and Duvets; Pet Bedding
Potential	Health benefits for those with respiratory problems could be used to market wool bedding. The wool is normally used as the filler with cotton or linen used as the liner. Wool's hygroscopic properties are said to regulate temperature better than other materials keeping you naturally cool in summer and warm in winter. There is also emerging evidence of sleep quality benefits arising from use of natural wool products in the bedroom. If those benefits can be validated it would add a further premium to the product pricing.
Highest Potential	High end bedding emphasising health and sleep benefits
Value	Medium – High
Import Substitution	Cotton, Feathers, Synthetics
Market Size	<ul style="list-style-type: none"> The global mattress market is \$30.93 billion in 2021[13] The global home bedding market size was valued at USD 73.88 billion in 2020[13]. In 2019, the pillow market was valued at about 15.6 billion U.S. dollars worldwide[14]. The pet furniture market size was valued at \$3,443.4 million in 2019[15].
Supporting Policy	Corporate Sustainability Scope 3 Emissions
Considerations	Consumers willing to pay premium price for validated sleep enhancement, health benefits and warm in winter, cool in summer attributes of wool bedding materials.

Mattresses

Wool is used as a filler in mattress production, typically in the quilting process or lower down near the springs of the mattress. It is reported to have health and temperature control properties.

Offerings from British bed manufacturers, Harrison Spinks, highlight that wool is attractive as it is a fibre with unique hygroscopic properties, which attracts, absorbs, and releases water molecules, while retaining its thermal efficiency. In this way, it helps to regulate body temperature. On the Woolroom website, they describe their wool mattresses as “traceably British, chemical-free and naturally comfortable handmade wool mattresses”. All their mattresses contain natural fillings, no synthetics and are naturally flame retardant. In the UK, there is a tradition of creating tufted mattresses, they produce 20,000 of these per month and 1 mattress typically requires 40 – 50 sheep's wool fleeces. The scouring process is critical for mattress production to prevent odors.

In Ireland, there are twelve manufacturers of bedding, one of the companies has 12 – 15 styles of bedding that incorporate wool. According to one of the bed manufacturers in Ireland, it's important to prevent the wool from protruding through the fabric, so it is best used in lower layers of the mattress and not on the topper layer. However, if the Irish coarse wool were treated or blended to be softer with material like hemp, it would not be as much of a challenge.

Many companies in the bedding and mattress industry are under pressure to use more sustainable materials due to issues with petroleum-based chemicals in foam bedding and impact of volatile organic compounds (VOC's) on people's health, as well becoming low carbon through their supply chain and Scope 3 (supply chain) GHG emissions. The National Bed Federation members are all conducting a carbon rating and taking a lifecycle approach to their mattress production. Mattresses are complex to recycle given the varied materials used and their weight. One company in Ireland, called Cirtex, is looking to upcycle mattresses.

Conclusion

There is potential for:

- i. More Irish wool to be included in mattress manufacturing;
- ii. Branding potential of using 'Irish Grown Wool' in product;
- iii. Potential for blending natural fibres for mattresses.

Pillow, Mattress Toppers, and Duvets

Pillows, mattress toppers and duvets are an excellent product for scoured Irish wool since the coarse fibre diameter is not as important as the products are normally covered in different fabrics such as cotton or linen.

Interviews with companies who are selling bedding products directly to consumers have reported an increase in sales over the past few years, with some doubling their revenue. They reported that sales on the European continent are increasing due to the duty and delivery delays with doing business in the UK as well as the US market. These companies are using Irish wool that is scoured in the UK, and they market their products as using Irish wool, to help increase brand recognition.

Educating the public and farmers through agricultural shows about the potential of Irish wool in these products has led to an increase in sales but also helped the broader industry understand the opportunity at hand – and take further pride in the wool product.

Products currently on the market use health benefits and sleep quality as the main selling point. There is also ongoing work to develop a pipeline of products for the healthcare industry particularly to help prevent Hospital Acquired Infections (HAI). Certification can be carried out by independent bodies to ascertain the respiratory health benefits.

Companies agreed that there is potential for:

- Targeted marketing media campaign to educate the Irish public about the potential for these products and the health and other benefits of their use;
- An agreed NSAI standard to bring wool in line with synthetic products in terms of consistency.

The price point of the products at retail are medium to high compared to conventional products. Current prices range across the products include:

- Pillow range €30 – €70;
- Mattress Topper, range €124 – 200;
- Duvets range €135 - €265.

Conclusion

The market for these types of products is expected to grow. The boom in the housing sector and growing consumer spending on home furnishings have expanded the growth scenario for the market[16].

In terms of cascading benefits across the value chain; the farmers are supplying their wool to merchants for the market price, this is then sent to Bradford for scouring and then to manufacturing partners for production. There is scope for business model development in this chain to support the farmer.

Pet Bedding

The pet furniture market size was valued at \$3,443.4 million in 2019, and is projected to reach \$5,139.4 million by 2027, growing at a CAGR of 6.5% from 2021 to 2027[17]. Pet furniture is noticeably popular and expanding with significant pace in developed regions of the Americas and Europe, where manufacturers are developing new product innovations considering pets' health and comfort.

In discussions with a small-scale pet bed manufacturer based in Ireland, they highlighted trends in the market that are driving the increase of sales of their products in their business to consumer strategy.

- Wool is a fire-retardant product and given that pet beds are regularly in sitting rooms sleeping near a fire / stove, this is an added advantage;
- The quality of their products is extremely high. The cover of the dog bed uses woven materials from a woollen mill that is expertly sewn in their sewing studio;
- It is a 100% made in Ireland product which is appealing to international markets like USA and mainland Europe.

The operating business model is a very interesting entrepreneurial case study in the context of rural development, as the company:

- Pays the farmer a more than fair market price for presentable clean wool. The company has a pool of 40 sheep farmers they regularly source wool from each year, and a trust has built up that the wool presented is clean and with no dags. This model helps to grade and skirt the wool efficiently;
- Scours their own wool;
- Employs women who are socially disadvantaged (and wouldn't otherwise have a job) in their sewing studio and preserves the sewing expertise from this region.

Customers are very appreciative of the fact that it is an Irish product. To help their marketing, the company signed up to the 100% Guaranteed Irish brand however, a company needs to only have a part of their manufacturing in Ireland to achieve this standard. An Irish wool brand would really be valuable for this type of consumer and lifestyle products to demonstrate 100% Irish and traceability.

Conclusion

This is a growing market opportunity, particularly in the USA where the pet market is the largest. A recognised Irish wool branded product would support further internationalisation and scale.

Filled products Overall Conclusion

The filled products market is one that has not been targeted sufficiently by wool producers. Wool's natural characteristics make it an ideal fill material for a range of bedding products, for both humans and animals. This application does require scouring, thus adding cost, however with a premium branding this may be a potential medium value opportunity for the wool sector.

Composites

Composites	
Application Areas	Furniture; Car Manufacturing
Potential	Replacement of resin
Highest Potential	High end aesthetic automotive and aerospace applications
Value	High
Import Substitution	Resin, Glass fibre, Carbon fibre
Market Size	The European composites market size was worth USD 16.6 billion in 2018[18]
Supporting Policy	Corporate Sustainability Scope 3 Emissions; National Policy Statement on the Bioeconomy, February 2018.
Considerations	Need for validation of kgCO ₂ e of wool

Composites are typically made from a polymer matrix that is reinforced with an engineered, synthetic, or natural fibre (like glass, carbon, or aramid) or other reinforcing material. Composites are used in a range of markets including aerospace, architecture, automotive, energy, infrastructure, marine, military, and sports and recreation[19].

Composites manufacturers are trialling natural fibres like wool in composites with resins. This is driven by the automotive industry who are pushing for more sustainable materials to be used in automobile manufacturing. For example, Ford Motor Company is using biobased and renewable materials in their manufacturing process. Cellulose tree fibres are used in the armrests of some cars where it is used to replace glass-filled plastic. This industry-first material weighs 10 percent less, is produced 30 percent faster, and reduces carbon emissions[20]. The primary motivation for using natural fibres is to reduce the kg CO₂ equivalent of composite materials, driven by client and consumer values.

For wool to be integrated into high value applications requires a Technical Data Sheet with information to highlight the kg CO₂ equivalent to compare with other materials, the strength of the wool fibre and weight of materials. This key information is currently missing in the marketplace. Work is ongoing with universities and companies to fill this gap; however further support is required in research and development and is highlighted in the Research Projects section.

Composites Overall Conclusion

Biosubstitution is a focus for the EU in terms of driving the bioeconomy, sheep's wool can potentially play a significant role here given the characteristics that have been widely discussed in this report. Corporate social responsibility, in addition to advances in composite technologies can provide a roadmap for incorporation of sheep's wool into a wide range of solid materials.

Environmental

Environmental	
Application Areas	Oil sorbent; Heavy metal sorbent
Potential	Contamination remediation
Highest Potential	Both have equal opportunities
Value	Low to Medium
Import Substitution	Synthetic materials
Market Size	<p>The global oil spill management market was worth \$131.16 billion in 2015. A report in 2017 predicted this to grow for the coming decade[23].</p> <p>The global drinking water adsorbents market was estimated as \$459 billion in 2018 and is predicted to rise at a CAGR of 4.0% from 2019-2025[24].</p>
Supporting Policy	National Maritime Oil/HNS Spill Contingency Plan 2020; S.I. No. 122/2014 - European Union (Drinking Water) Regulations 2014
Considerations	Volume of material may not be sufficient to satisfy potential users of its supply chain security.

Increasing safety concerns, together with rising figures of oil spill incidents have contributed to a significant market for solutions for oil spillages. Other natural materials such as feathers[25] have been considered previously for oil sorbency, security of supply chain for naturally based materials can be choke-point; including wool based sorbents in this context may contribute to the use of natural materials for remediation of oil spillages.

Growing concerns regarding health hazards associated with drinking water contamination have driven the size of this market. Within the market report, a demand for organic (natural) materials with adsorbency activity is increasing with the likes of coconut shells, coal and wood. In addition, heavy metal contamination of surface water in industrial plants also requires sustainable treatment. Sheep's wool could potentially play a role here.

Environmental Overall Conclusion

In all aspects of modern society there is a move away from fossil fuel-based materials to more sustainable materials, where possible. In the context of environmental remediation significant quantities of material may be required, given the nature of environmental damage from oil spills and heavy metal contamination. Wool may be able to play a role here, but its absolute impact would need to be calculated per Kg wool to determine the security of the supply chain for this type of development. Consideration should also be given to incorporating other types of natural materials to increase the potential of biomaterials to provide genuine solutions for environmental remediation.

Medical Device/Biotechnology

Medical Device/Biotechnology	
Application Areas	Medical Devices; Bioplastics; Enzymes
Potential	Use as wound healing and support structures in medical device and healthcare products, production of bioplastics, production of enzymes.
Highest Potential	Medical devices
Value	High
Import Substitution	Synthetic materials, security of supply chains
Market Size	The global wound care market was valued at \$17.49 billion in 2021 and is expected to grow at a CAGR of 6.2% to 2029[26]. The global bioplastics market was valued at \$5.8 billion in 2020 and is predicted to reach \$16.8 billion by 2030[27]. The global enzymes market was worth \$8.6 billion in 2019 and is projected to reach \$14.5 billion by 2027[28].
Supporting Policy	HSE National Wound Management Guidelines 2018; Waste Action Plan for a Circular Economy Ireland's National Waste Policy 2020-2025.
Considerations	Access to high value market, funding the cost of wool scouring process and possibly making it feasible to scour wool on Island of Ireland

This section summarises a range of low TRL technologies, based on biotechnological treatment of wool as a feedstock. The primary application of keratin in healthcare/medical devices is in the wound care setting. Treatment of chronic wounds, incorporation into wound dressings and challenges associated with delayed diagnoses provide a role for keratin in terms of patient health. Keratin-based dressings have a number of advantages in wound care, including a superior cosmetic effect when it comes to scar formation. For moderate to heavily exuding wounds, multilayer keratin dressings and keratin matrix dressings are employed. The benefits of keratin-based dressings are expected to drive the global keratin market to grow during the forecast period. Keraplast Technologies, LLC, San Antonio, Texas, USA, has employed keratin protein derived from New Zealand sheep wool to produce wound dressings. The European Union regulatory authorities has authorized Replicine Functional Keratin advanced wound dressings[29].

Bioplastics are different to biocomposites and utilise keratin as smaller building blocks to produce plastic materials, in conjunction with plasticizer chemicals such as glycerol (Keratin based bioplastic film from chicken feathers and its characterization; tough and functional cross-linked Bioplastics from Sheep Wool Keratin). Based on the latest studies, around 80% of the wool can be converted to keratin material for making bioplastic. This rate for advanced application in healthcare is around 30% according to latest research from AMBER Research Centre and Trinity College Dublin submission.

Finally, enzymes can find application across a range of sectors, increasing rate of reaction, converting substrates and degrading unwanted proteins. Enzymes produced as outlined in this report will have niche applications, but may nonetheless attract strong value.

Medical Device/Biotechnology Overall Conclusion

Keratin is potentially a significant resource in wool, once a sustainable and economical extraction can be implemented. It can provide a feedstock for a range of applications, including medical device and bioplastics (in addition to cosmetic outlined below). The extraction process could therefore achieve greater economies of scale as it becomes a process to feed into a number of sectors. Enzymes applications are likely to be more in more niche areas, however progress through third level research should provide mechanisms to de-risk this application.

Cosmetics

Cosmetics	
Application Areas	Lanolin; Keratin
Potential	Ingredient for cosmetic (natural) preparation – Lanolin Ingredient for pharmaceuticals and medical applications – Keratin
Highest Potential	Early stage
Value	High
Import Substitution	Synthetic materials
Market Size	The global lanolin market size was valued at USD 222.0 million in 2018 and is projected to expand at a CAGR of 6.0% from 2019 to 2025.
Supporting Policy	
Considerations	Access to high value market, funding the cost of wool scouring process and possibly making it feasible to scour wool on Island of Ireland

Note: Access to lanolin is dependent on processing facilities which are not developed in Ireland.

Lanolin

The global lanolin market size was valued at USD 222.0 million in 2018 and is projected to expand at a CAGR of 6.0% from 2019 to 2025. Growth in end-use industries, such as pharmaceuticals, personal care & cosmetics, and baby care products, is the key factor driving the market.

Manufacturers are also focusing on new ingredient development, private label introduction, and professional product launches to attract more consumer base. These factors are further expected to positively influence the demand for lanolin derivatives in cosmetic products over the forecast period. Major personal care and cosmetics companies are increasingly utilizing lanolin waxes and oils to improve the sensory appeal and overall product value. These oils help cleanse, even the skin tone, promote elasticity, and impart moisture to skin that is frequently exposed to harsh elements, such as pollution and air-conditioning.

The market has been segmented into personal care & cosmetics, baby care products, pharmaceuticals, industrial, and others, such as sports goods and humectants. In terms of revenue, the personal care & cosmetics segment accounted for 44.63% of the global market share in 2018. The product has high moisturizing properties, thus has tremendous demand in a variety of cosmetics, as well as baby care products[21].

Conclusion

Lanolin is a well-established co-product from the scouring process, in the absence of a scouring facility in Ireland, this is unlikely to be able to provide any value to Irish producers of wool. This coupled with the lower levels of lanolin in coarser wool means that lanolin-based products from Irish wool have a lower potential for success.

Keratin

Keratin is a type of molecule present in glands and internal organs that is required for skin, nail, and hair growth. The industry was estimated to be over 3,500 tons in 2014 and was projected to grow at a CAGR of above 7.0% from 2015 to 2022[22]. It is utilized in the production of personal care products as well as the treatment of wounds, tissues, and other conditions. Consumers frequently utilize keratin products for personal grooming and care. Cosmetics, hair care shampoos, conditioners, skin creams, and nail care treatments are among these items. Keratin products are typically utilized on the outside of the skin as a protective layer, to preserve flexibility & compactness, to control cell proliferation through skin regeneration and softening, and to reduce wrinkles.

Conclusion

Keratin is the predominant protein in sheep's wool and as such provides for a potential substantial resource. Use of wool in this manner is at an early stage of development and so risk is reasonably high from this approach, however the applications from use of keratin in this manner are high value and so may give solid returns.

Cosmetics Overall Conclusion

The supply chain with regards to lanolin is not established that will give any returns to Irish growers of wool. Even with an Irish scouring plant the process is such that it is likely that all lanolin would be harvested in combination, rather than being returned in individual growers of Irish Wool. Where it is pursued it will be in small niche operations. The control of the keratin extraction process can be in the control of Irish growers, and while at reasonably early stages, does provide significant opportunity.

Public Consultation Submissions

The Department of Agriculture, Food and the Marine opened its public consultation process on the 11th of March 2021, inviting stakeholders to submit (a) Comments on the proposed Terms of Reference and/or (b) Submissions on the potential market opportunities for wool products on the domestic and international market. The consultation process was closed on 2nd of April 2021, though late submissions were accepted. A total of 45 submissions were received at the time of tender, with several more submissions arriving during the project delivery phase.

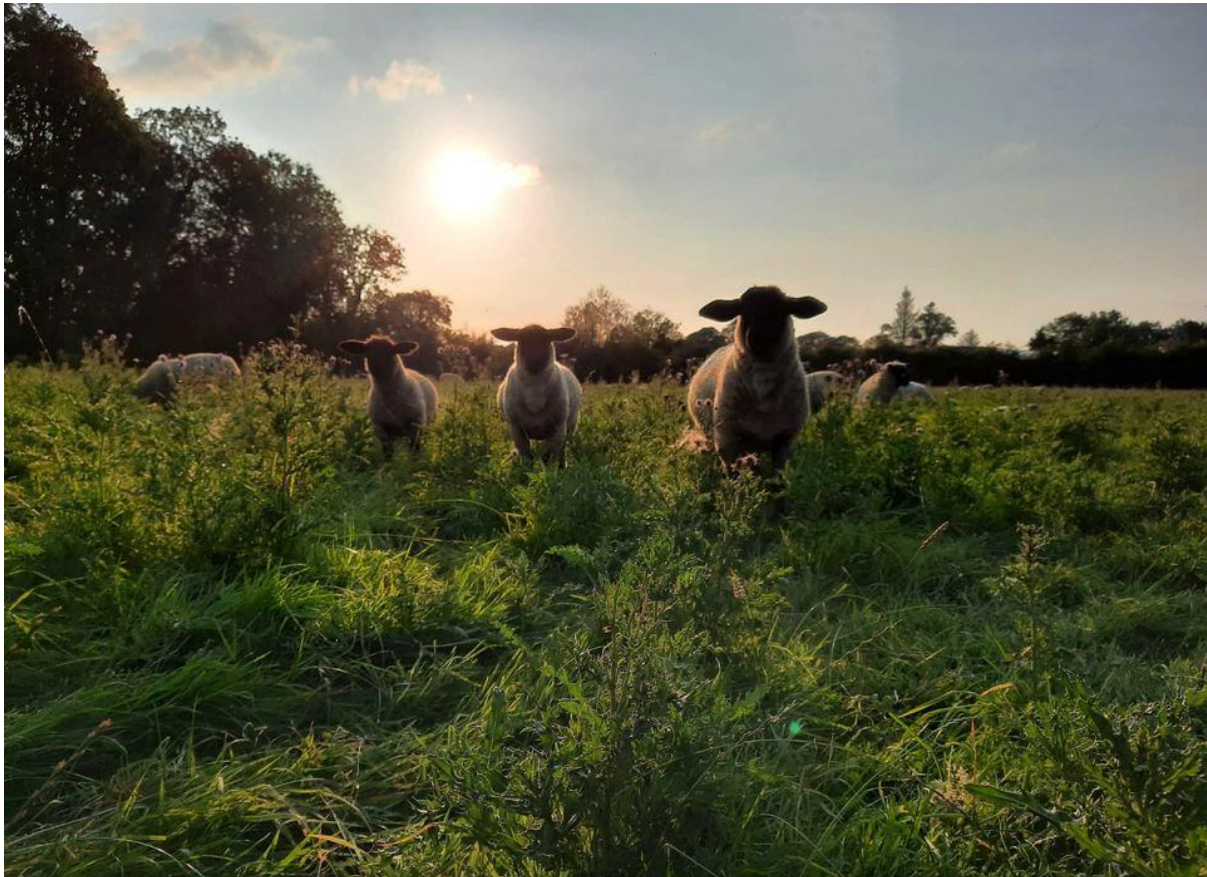
Submissions were received from various stakeholders including farm organisations, co-operatives, entrepreneurs, industry representatives, designers, research groups, wool merchants, state agencies, academics, wool producers, and concerned individuals.

The following is a list of key themes and recommendations from the submissions:

- **Establishment of a branding entity for Irish grown wool**
 - Creation of a brand/mark/logo for Irish grown wool
 - Formation of a voluntary wool board with broad farmer and commercial membership
 - Promotion of the Irish Wool crafts industry
 - Increased development of export markets
 - Improved traceability of Irish Grown Wool Products including blockchain solutions
 - Mechanisms to certify Irish Grown Organic Wool
 - Development of breeding indexes for wool traits in sheep
 - Genetic breeding programs to improve wool traits or develop shedding sheep
 - Addition of a shearing or wool handling action as part of the Sheep Improvement Scheme
 - Wool as part of the circular bioeconomy – waste is a resource in the right hands
 - European collaboration on wool
 - Health benefits of wool
 - Benefits of woollen bedding towards sleep quality
- **Increased support for farmer co-operatives**
 - Educational and awareness programmes
 - Direct subsidies to farmers for improved wool presentation
 - Incentives for wool producers to present wool in a saleable manner to licensed wool stores.
 - Training programs for shearing and wool handling
- **Value added chains from waste wool**
 - Use of wool in natural fertiliser products – address EU Nitrates Directive
 - Use of wool in horticultural growing media - peat replacement
 - Use of wool as slug pellets and fertiliser pellets
 - Repurposing of Bord Na Mona facilities for wool processing/composting
 - Processing of sheepskins
 - Use of felted wool weed mats around trees
 - Use of wool as a growing medium for hydroponics
- **Suggested innovative uses for wool**
 - Development of scouring facilities
 - Use of wool as a sound absorbent and air purification panel
 - Use of wool for building insulation
 - Development of Keratin extraction from sheep's wool
 - Lanolin extraction
 - Extraction of vitamins from wool
 - Use of wool as filter material for face masks
 - Use of wool in mattress manufacturing
 - Use of Irish grown wool in filled bedding products
 - Use of wool in composites
 - Use of wool in orthopaedic support casts

- **Provide funding mechanisms to support craft and textile industry - Irish Grown Wool**
 - Sourcing of local wool for the crafts industry
 - Wool tourism experiences
 - Establishment of felt mongering facilities to process wool

Most of the submissions involved suggestions for novel uses of wool. A significant portion were involved with research and development, while a significant number could be described as concerned individuals with a passion for wool.



Identification of Potential Research Projects

The purpose of this section is to identify research projects that are required to advance opportunities for wool by-products in Ireland. There are a number of considerations in this context which include:

- Source of funding – national or EU;
- Type of research – strategic or product focussed;
- Length of research – short, medium or long term;
- Maturity of research area – the Technology Readiness Level (TRL) of current research.

While each of these should be considered individually, they all very much affect each other. EU funded projects are generally longer and so may be more strategic; projects at a higher TRL level will require less time to bring to market and require less funding, often more targeted at national funding calls. A wide range of funding options are included in Appendix 1 covering national and EU funding calls.

The research proposed is divided into sections; (1) research required to drive the sector (strategic research) as a whole and put in place structures to support advancement of wool as a valued raw material and (2) research required at a practical level to de-risk, validate and commercialise application of wool in a range of sectors (product focussed research). Wool is quite a unique material, and Ireland does not have an established significant research capability for wool as for other biomaterials such as seaweed and cannot really draw parallels from other similar materials such as has been done for hemp.

Strategic Research

The strategic research proposed is by its nature more medium to long term. It is not intended that this strategic research should take place prior to practical research proposed in section 2 below; they should happen in parallel.

1. Establish Research Capability

Research capability for a range of natural raw materials is at an advanced and world class stage in Ireland for a range of materials including seaweed, dairy and meat. There are well established research groups, Technology Centres, Technology Gateways and SFI Research Centres in these areas. The same is not the case for wool; in countries where innovative advances are being made with wool, these tend to be supported by established research activities in the third level sector. Riskier research activities can be undertaken in this environment and as the technology becomes more mature it can be licensed to enterprises or be the focus of spin-out activities (in addition to enterprise collaborative research). It is recommended that through a mechanism (such as Department of Agriculture, Food and the Marine Research Call Instrument) that a consortium of researchers with expertise in wool R&D is established to include those with expertise in targeted development areas for wool (i.e., Bio composites, horticulture, etc). This group will provide a defined point of contact for all stakeholders along the supply chain, from farmers to co-ops and enterprise.

2. Life Cycle Assessment of Wool

There is insufficient evidence and information for a defined sustainability story in terms of wool and its subsequent uses. Due to its classification as a waste material, there is the need for a better understanding of the inputs that need to be considered in terms of sustainability. We are in a unique

position with wool in terms of determining how it can be used; all aspects that will affect this, including sustainability, need to be clearly understood in order to future-proof wool as a sustainable feedstock into the future. The determination of the LCA of wool production and its divergence into a range of sectors should be delivered in the context of Department of Agriculture, Food and the Marine Research Call Instrument.

3. Protected Geographical Indicator



It has been referred to throughout this report that the provenance of Irish Grown Wool can potentially have a premium. This is not currently possible with a low market potential for this product, disengaged farmer cohort and most importantly consumer products that are marketed as Irish without this actually being the case. In this context we propose that a study should be commissioned to determine the potential to attain PGI for Irish Grown Wool; this may extend to products perceived to be Irish (e.g., Aran sweater). The commercial implications for this, and potential for beneficial outcome for Irish Wool Growers needs to be determined before proceeding.

4. Data Collection

The use of wool for value-add applications is ultimately dependent on the quality and physical characteristics of this wool. While there is a general perception of the type of wool produced (i.e., greater than 30 micrometers) this is not based on hard data. In addition, the breed of sheep in Ireland is also undocumented in terms of numbers per breed. Hard data is essential in order to be able to plan for the future of Irish Grown Wool. It is proposed that a database is created of all flocks in Ireland to include breed, number of sheep and analysis of fleece, to include at a minimum average fibre diameter, and ideally staple length, colour, fibre strength and lustre.

It is recommended that while this data is being collected, farmer demographics also be recorded, in addition to determining how this data may impact on the proposed changes in the wool sector. It is the intention that this report supports a roadmap for significant change in the wool sector; it is essential to understand farmer demographics to determine whether these demographics can deliver this change. This could be delivered either through a dedicated, funded Teagasc based initiative, or through Department of Agriculture, Food and the Marine Research Call Instrument.

In addition to the national funded mechanisms recommended above, EU applications should be considered to address a number of these strategic goals, in addition to some of the more long-term research projects. As part of an EU application, regions that are at somewhat of a more advanced stage than Ireland in terms of wool valorisation (Wales, Finland) could be included and a roadmap for European wool valorisation as a whole could be developed. The benefits from this would be very much focussed on rural benefit and would align very well with both national and European priorities.

Product Focussed Research

The research proposed may be more appropriate for industry to deliver, or a Research Providing Organisation (RPO), or a combination of both. This section will identify the opportunities for wool, the technologies required to realise these opportunities, general technology readiness level of these technologies and propose the types of research required to address this.

The TRL describes the maturity of a technology and is ranked on a score of 1-9; TRL 1 is at the very start of research with basic principles observed, TRL 9 describes technology that has been demonstrated in an operational environment. A table summarising proposed research projects, along with approximate TRL, scale of research required to commercialise, funding options that may be appropriate for advancement and research and industry ecosystem to enable this is included in Appendix 5. The organisations listed in this table are not exhaustive and should not be deemed as recommendations.

TECHNOLOGY READINESS LEVEL (TRL)		
RESEARCH DEVELOPMENT DEPLOYMENT	9	ACTUAL SYSTEM PROVEN IN OPERATIONAL ENVIRONMENT
	8	SYSTEM COMPLETE AND QUALIFIED
	7	SYSTEM PROTOTYPE DEMONSTRATION IN OPERATIONAL ENVIRONMENT
	6	TECHNOLOGY DEMONSTRATED IN RELEVANT ENVIRONMENT
	5	TECHNOLOGY VALIDATED IN RELEVANT ENVIRONMENT
	4	TECHNOLOGY VALIDATED IN LAB
	3	EXPERIMENTAL PROOF OF CONCEPT
	2	TECHNOLOGY CONCEPT FORMULATED
	1	BASIC PRINCIPLES OBSERVED

Figure 5. TRL scale (adapted from TWI Global).

This section is divided into

1. Horticulture
2. Textiles, Furnishing, and Upholstery
3. Construction
4. Packaging
5. Filled Products
6. Environmental
7. Medical Devices/Biotechnology
8. Cosmetics

1. Horticulture

The Horticulture sector covers a wide range of plant focussed products, from fertiliser and soil conditioners to hydroponics and weed control products. To date, sheep's wool is most associated with fertiliser applications within this sector. In Ireland, wool is categorised as a Category 3 waste. This is the lower risk category, however in this context it is not legal to use raw wool in the soil; it must be treated in the first instance.

According to Department of Agriculture, Environment and Rural Affairs (UK); "Factory-washed wool and wool which has been treated by another method which ensures that no unacceptable risks remain, may be placed on the market without restrictions" [32]. Regulation (EC) No 1069/2009 identifies that wool (along with other types of Category 3 animal by-products) may be subsequently used, following being "processed by a specific method in an approved processing, technical, biogas or composting plant" [33].

In order to provide for larger scale of use of wool as a fertiliser or soil conditioner, it needs to be treated in some format.

Potential horticultural uses of wool are as follows:

- a. Fertiliser;
- b. Peat replacement;
- c. Support structure for hydroponics;
- d. Moisture and weed control mats.

Fertiliser

Sheep's wool has been used as a fertilizer product from unprocessed fleece all the way through to recycling of wool textiles. The elemental profile of wool is that it is highest in Nitrogen and Sulphur, followed by Calcium, Potassium, Zinc, Phosphorous, Iron and Copper [34]. While there is very little in the scientific literature regarding length of time for sheep's wool to degrade, a number of sources refer to 3-4 months under ideal conditions to as long as two years [35]– [41]. The length of time taken to degrade depends upon soil conditions such as moisture, microbial content and temperature. Even without regulations to consider, the use of large quantities of raw fleeces in the soil would be detrimental due to the long time that they would take to degrade and release their nutrients (in addition to the waste categorisation of unprocessed wool).

A number of treatment processes have been proposed in order to make wool more readily biodegradable and thus have a more rapid impact on the soil into which it is introduced.

i. Composting

Composting is a method to transform organic waste into soil amendment or conditioner products. The process, which utilises a thermophilic phase produces an end product that is free of phytotoxic and pathogenic agents. Fats, cellulose and lignin and other materials are degraded during the composting process and organic matter is mineralised [38]. A study reported in 2016 outlined options regarding composting of wool at large scale and determined a composition of 25% waste wool, 25% horse stall mixture and 50% grass clippings to deliver an acceptable quality compost [39].

ii. Hydrolysis

A number of methods have been reported or hydrolysis of wool, which could be used instead of composting. These include:

- a. Alkaline hydrolysis (sodium hydroxide, potassium hydroxide or calcium oxide), heated to 80°C and filtered, followed by enzymatic treatment with alcalase [40]. Sample was degreased first with detergent;
- b. Superheated water – water was heated to temperatures of 140°C and 170°C, with a material to liquor ratio of 1:3 for 1 hour [41], [42]. Bhavsar et al reported that while both alkaline and superheated water hydrolysis both hydrolysed the wool, the superheated water is a more environmentally friendly and less expensive process [42].

Pelleting of sheep's wool has also been carried out to provide a nutritional source to the soil, as well as having added impacts of slug repellence. Pelleting applies a high pressure to the wool in order to deliver formed pellets, where organic matter remains on the wool, this may improve the conformity of the pellet. Pelleting does not break down the wool to the same extent as composting and hydrolysis. Bohme et al reported on the beneficial impact of sheep's wool pellets on iceberg lettuce, tomatoes and poinsettia. The dilution of sheep's wool and additives differed between each plant, and when used on kohlrabi actually performed 50% less than mineral or other organic fertiliser [43]. A study by Ordiales et al on the impact of a commercially produced wool pellet (FloraPell®) agreed with this previous study identifying positive impact on both tomato and broccoli growth, although the composition of the pellets was not detailed [44].

Peat Replacement

The use of peat for a range of commercial applications is widely recognised as being damaging to environment. Peat bogs are significant habitats for biodiversity and play a substantial role as a carbon sink. Peatlands in the UK are believed to store more carbon than all the forests in the UK and France combined. Peat bogs develop at approximately 1mm per year, and so the damage caused over the last number of decades will take centuries to restore [45].

In particular, peat use in fertiliser products has been significantly reduced and substitutes for peat are required across a range of sectors, one of these being the mushroom sector. The use of peat in mushroom cultivation is in the casing layer. The casing layer is placed on top of the nutritional composted layer, which contains the mycelium. Some key physical parameters for this casing layer include high water retention (for growth of the mycelium and spores), porosity for mycelial respiration and ability to resist structural breakdown following repeated waterings [46]. Microbial composition of

the peat is likely to have an impact on mycelial development [47], however identifying a substitute with the correct physical parameters is the first step in this process.

A number of studies have suggested potential alternatives to replace or reduce the use of peat. These include:

- Peat diluted with spent mushroom compost (18%) and spent sugar beet lime [48].
- Composted wastepaper with nitrogen added [49].
- Vermicompost (12.5%), perlite (12.5%) and peat (75%) [50].
- Composted bark fines, coir, fine particle dewatered coal tailings [46].

A white paper published by the Agriculture and Horticulture Development Board (UK) [51] however has identified a range of challenges associated with some substitutes suggested to date:

- Insufficient water holding capacity; Wood fibre, Lump chalk, Lignite;
- Excessive soluble nutrients, Spent mushroom compost (SMC);
- Digestates Conduciveness to Trichoderma and other moulds; Recycled coir, Paper wastes
- Prohibitive cost; Coir, Vermiculite;
- Insufficient supplies in the UK; Sugarcane bagasse, Tea and coffee wastes.

No reference could be found in the literature for the specific use of sheep's wool for use as a peat substitute in mushroom casing. Work has been carried out previously to determine the potential for rockwool as a replacement, however it was only effective at a concentration of 25% and it may not be suitable due to its synthetic origins; the mushroom mycelium will preferentially grow into a natural substrate that it can feed on [52], [51]. The use of carpet wool has been referred to in a white paper [53], however no references to unrefined sheep's wool have been identified.

Sheep's wool possesses many of the physical characteristics required from mushroom casing, and when un-scoured may possess a bacterial population supportive of mushroom growth. It is similar to rockwool (as will be discussed later), and carpet wool has already been considered.

Support Structure for Hydroponics



Hydroponics is the growth of plants under controlled conditions without the use of soil. A defined liquid nutrient medium is made available to the plants. Plants may be further supported in this growth through a structure being available to their roots. Types of support structure include perlite, coir, vermiculite rockwool and sheep's wool. In a study by Bohm et al (2012), they studied the use of sheep wool slabs for growing cucumber in a hydroponics system. The sheep wool slabs (in comparison to coconut fibre slabs, peat slabs, perlite and rockwool) delivered the highest yield as measured by biomass. The air capacity of the wool slabs was higher than the other substrates, the water capacity was lower than the other substrates but increased significantly following use (increasing from 23% to 44% [54]). However, in a study by Dennehl et al in 2015, they reported that sheep wool was not suitable for hydroponic growth of tomatoes, due predominantly to a greater development of blossom end rot fruit in sheep wool grown tomatoes [55].

Mulch Mats

Mulch mats (for moisture and weed control) are used to control delivery of moisture to seedlings over a longer period of time and to prevent over watering of plants in particularly wet regions. Weed control mats help to suppress the growth of weeds around the roots of plants, they can be composed of plastic or biological components such as coir, polylactic acid and paper. Wool has been used previously as a moisture and weed control substrate. A study in 2000 determined the effectiveness of wool mulch to control weeds in strawberry production, they reported a positive impact from the wool mulch for weed control [56]. In 2004, Duppong et al evaluated a range of weed control mats including those produced from flax straw and wool. All mats effectively suppressed weed growth below economic threshold levels [57]. A review by Sharma et al (2019) also reported on the effectiveness of wool mats for weed control, referring specifically to eggplant and sweet potato. They also confirmed the benefits of wool mats for moisture control in soil management [58].

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Fertiliser:

Fertiliser	
Technology Readiness Level	9
Level of Research required	Minor
Recommended support mechanism	Innovation Voucher/LEO/ Contract research
Research Ecosystem	Teagasc, Shannon ABC (TUS/MTU), IT Sligo
Industry Ecosystem	Cremin's Compost, Larkfield Pellet Products, Cre.

- Determination of a range of “recipes” for composting of sheep’s wool fertiliser. To produce an effective compost, the correct ingredients have to be included. This will also have an impact on where the compost is optimally applied. The method to produce the composts should be defined along with growth trials to validate their effectiveness;
- Comparison of hydrolysis methods identified to determine which is most cost effective and efficient in an Irish context. Validate its use in terms of regulations and determine application method, mixture and efficacy on appropriate crops/plants;
- Determination of compliance of wool pelleting with relevant regulations. Validation trials to produce data to support use of sheep’s wool pellets as slow-release soil amendment products, in addition to their insect repellence activity.

The validation of these areas is essential to provide the confidence for enterprises and sole traders to follow through in terms of commercialisation of these approaches. While the majority of these applications have been shown, they are within other jurisdictions and not using Irish wool. Until these activities are shown in an Irish context, uptake of these opportunities may be low.

Peat Replacement:

Peat replacement	
Technology Readiness Level	5
Level of Research required	Medium
Recommended support mechanism	Innovation voucher/Innovation Partnership/Agile Innovation Fund
Research Ecosystem	Teagasc, Shannon ABC (TUS)
Industry Ecosystem	Monaghan Mushrooms, CMP, Garryhinch Exotic Mushrooms, Cre.

Utilisation of a range of wool available in Ireland, scoured and unscoured, to determine their effectiveness to be used as mushroom casing. Wool samples would be compared to peat and other products to determine their potential to be used in this sector. While the use of unscoured wool may prove challenging in the first instance, due to the regulation of wool as a waste product, it is worth determining this potential, if only to remove it from the list of options. Where unscoured wool does not improve the functionality of mushroom casing in terms of microbial content, scoured wool could be artificially seeded with appropriate microbial population to support mushroom development.

Support Structure for Hydroponics:

Hydroponics	
Technology Readiness Level	9
Level of Research required	Minor
Recommended support mechanism	Innovation Voucher/LEO/ Contract research
Research Ecosystem	UCD, Shannon ABC (TUS)
Industry Ecosystem	Emerald Greens Farm, Killarney Urban Farm, Farmony

Rockwool is already used as a support structure for hydroponics and so this approach of using sheep's wool has structural precedence. Research would be required to determine the best approach for composition of the sheep's wool support structure and subsequent growth trials. Sheep's wool as a support structure would be compared against rock wool and other materials to determine their impact on the growth of a range of representative plants species.



Figure 6. Wool insulation used as a growing support medium for Basil; photograph taken after 5 days. Photograph courtesy of CELLS Research Group, TUS.

Mulch Mats:

Mulch Mats	
Technology Readiness Level	9
Level of Research required	Minor
Recommended support mechanism	Innovation Voucher/LEO/ Contract research
Research Ecosystem	Teagasc
Industry Ecosystem	Fruit Hill Farm, Keelings

Similarly to compost research, due to the acceptance of sheep's wool in the area of moisture and weed control, limited research may be required in this space to provide support for this approach. Incentives may be provided for companies already in this space to incorporate sheep's wool and to carry out industry trials to determine its efficacy.

2. Textiles, Furniture and Upholstery

Textiles and clothing are well established target sectors for wool, however wool produced in Ireland is predominantly coarse wool and so is not as suited for standard textile applications as, for example, merino wool. Wool produced in Ireland may be used in smaller percentages in textile products, or it can be used in application such as carpets. There are potential opportunities to improve the structure of Irish wool, in the context of clothing applications.

Coarse wool fibres generally have diameters of 25-70 μ m, with fine wools being in the range of 17-25 μ m [59]. Coarse wool fibres are stiffer than fine fibres and this is important at the end of the fibre where contact can be made with the skin, leading to irritation [60]. While the diameter of the wool is important in terms of its workability, the stiffness of coarse wool is the most significant obstacle to its use in clothing. Both coarse and fine wool have scales, these scales are responsible for shrinkage of the textile; when the wool fibres are subject to mechanical action in the presence of moisture, the individual fibres start to move. Due to the presence of scales on the fibre, they can only move in one direction. During washing these fibres may lock into another fibre and therefore cannot return to their original position [61].

Some treatments of wool have been identified that can address the stiffness of wool fibres, as well as other technical characteristics. These are:

- a. Enzyme treatment
- b. Plasma treatment

Enzyme Treatment

Enzymes can be produced by bacteria and fungi and have been used for a range of industrial applications. Pooja et al reported on the use of protease enzymes to improve a number of characteristics of wool. The predominant one of these was to smooth the scales of the wool fibres, reducing the potential for felting to occur during washing [62]. Hassan et al also studied the effect of a protease enzyme on wool characteristics. They reported smoother fibres following treatment, as well as increased water uptake [63]. Finally, a study by Mojsov in 2016, also using protease enzymes confirmed the findings of Pooja et al and Hassan et al, and also reported on improved softness of the fibres that had been treated with the enzyme [64].

While these studies reported on the use of purified enzymes for the treatment of wool fibres, it is also possible to treat the wool through solid state fermentation (SSF). SSF refers to the growth of a micro-organisms on a solid substrate, as opposed to liquid medium. Fungi naturally produce protease enzymes and are well suited to solid state fermentations. It would be possible to grow fungi on unscoured sheep's wool, avoiding the expense associated with scouring, while improving the characteristics of the coarse wool through already established protease enzyme activity; the fungi would in essence scour the wool.

Plasma treatment

Plasma is formed when a gas is ionized, this gas can be oxygen or air (as well as argon or ammonia for example) [65]. Plasma treatment can alter the surface of a range of materials, without altering their bulk properties. Plasma treatment of textiles is well established and has been used to increase wettability, as well as to coat fabrics with specialized layers for additional functionality [66]. Plasma has been applied successfully to wool fibres and has been used to descale the fibres [67], which can result in increased sorption of humidity and dye, as well as improved wettability [68].

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Enzyme Treatment of Wool Pre-scour

Enzyme treatment of wool pre and post scour	
Technology Readiness Level	4/5
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	TUD, IT Sligo, Shannon ABC (TUS), BiOrbic
Industry Ecosystem	Niskus Biotec, Cushendale Woollen Mills, Donegal Yarn, Magee Weaving, Irish Bioeconomy Foundation (IBF)

Solid state fermentation of wool	
Technology Readiness Level	3
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	Teagasc, TUD, IT Sligo, Shannon ABC (TUS)
Industry Ecosystem	Niskus Biotec, Cushendale Woollen Mills, Donegal Yarn, Magee Weaving, IBF

Fungi can grow on solid materials in a solid-state fermentation system. As they grow, they produce enzymes to enable them to grow on the substrate. Dependent on the substrate and the fungal species, protease enzymes can be produced. Unscoured wool could be used in such a system where the fungal species produce proteases to treat the wool to make it softer and more suited for textile applications. The advantage of this approach would be to remove the necessity to scour the wool in the first instance. The contaminants that remain on the wool would actually support the growth of the fungi. Testing would need to be carried out to determine the appropriate fungi to use, and the growth

conditions to produce proteases. At the end of this process the fibres would be analysed to determine the impact of the solid-state fermentation on the wool fibres.

Enzyme Treatment of Coarse Wool Fibres Post-scour

This project would be similar to the previous one, but with the direct addition of the enzyme, rather than using a fungus as a deliver system. Similarly, the treatment conditions would need to be optimised to ensure effective treatment of the wool fibres. At the conclusion of this process, fibres would need to be analysed to determine the effectiveness of the treatment.

Plasma Treatment of Coarse Wool Fibres Post-scour

Plasma treatment of wool	
Technology Readiness Level	9
Level of Research required	Medium
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund
Research Ecosystem	IT Sligo
Industry Ecosystem	Cushendale Woollen Mills, Donegal Yarn, Magee Weaving

This project would be similar to the previous one, but with use of plasma treatment rather than enzyme treatment. Similarly, the treatment conditions (plasma energy, length of time, etc) would need to be optimised to ensure effective treatment of the wool fibres. At the conclusion of this process, fibres would need to be analysed to determine the effectiveness of the treatment.

3. Construction

Wool can potentially play a role in a range of product areas in the Construction sector. These include:

- a. Insulation
- b. Green roofs
- c. Concrete

Insulation

As a material, wool is strong, has good thermal performance, is fire resistant and has both hydrophobic and hydrophilic properties. These characteristics make wool an excellent candidate for insulation material. Current options for insulation material can require personal protective equipment to install and are often not ideal for the homeowner to spend significant amounts of time with. Wool does not have these disadvantages, and has advantages over some synthetic insulation products. A challenge associated with wool as an insulation material is its susceptibility to moth infestation and damage. Permethrin has been widely used for a range of insecticidal products, however it is a dangerous chemical and there is in general a move away from its use, where possible. Nazari et al (2014) have investigated the use of nano titanium dioxide to coat the wool fibres to protect them from moth and insect damage and observed strong protective capabilities from this approach [69]. Nazari et al also reported in 2017 on the use of walnut hull and henna dye as eco-friendly options. They pre-treated the wool with aluminium sulphate and reported high protection from *Deremestes maculatus* [70]. A report by Schafer et al in 2007 identified Mystox®MP as a biocide-registered chemical suitable for moth proofing of wool insulation, with better toxicological properties than the pyrethroids [71].

Sustainability is a consideration that needs to be incorporated at all levels of consumption, and this includes the construction sector. Programs such as Leading Energy and Environmental Design (LEED) certification have been established and implemented in North America. LEED certification is awarded to products and processes that achieve their certification. When consumers are purchasing products or services, they can then be informed as to the impact of their choices on sustainability. This certification also provides for a regulatory 'push' towards sustainability as governments can weight state procurement policy towards products and services with certification such as LEED. A similar weighted approach was proposed by the IFA in article in the Irish Examiner in Aug 2021: "It [IFA] also wants the use of Irish wool as insulation in all social housing projects and public buildings to be made mandatory" [72].

The production of insulation follows the standard wool processing steps of scouring, picking and carding, followed by wet felting. Wet felting uses moisture and friction to mat the wool fibres together to create a denser material. A study by Corscadden et al in 2014 on the economics of producing sheep's wool insulation suggested that its production could be achieved in a commercially competitive manner to standard insulation products [73].

Sheep's wool is the only natural fibre used in the indoor environment that is predominantly composed of protein; the majority are composed of cellulose. In studies in 2009[74] and 2014[75], the inherent sorption ability of keratin from sheep's wool towards aqueous formaldehyde was demonstrated, sheep's wool has also been shown to sorb formaldehyde in gaseous form [76]. Other gases have also been reported to be absorbed by wool, including toluene [77], sulphur dioxide and nitrous oxide. In this context, sheep's wool can potentially be an added value insulation material by providing passive absorption of harmful VOCs. A study by Mansour in 2017 confirmed these studies, comparing a range of coarse wool material, and including mineral wool for comparison. The mineral wool absorbed minimal amounts of formaldehyde, up to 25 times less than the best sheep's wool product. In terms of toluene, dodecane and limonene, all scoured wools reduced limonene and toluene, however they did not have much of an impact on dodecane, whereas mineral wool did reduce dodecane, limonene and toluene levels [78].

Green Roofs

Green roofs are at a very early stage of adoption, and are almost non-existent in Ireland. For this reason, a market assessment was not compiled. They are however an innovative way to make use of roof areas, particularly in urban regions. The roof of a building is partially or completely covered with vegetation and a growing medium. The growing medium is fundamental as there is no existing medium for the vegetation to take root in, to any great extent. The material chosen is very important, from a vegetation growth perspective, but also for its physical characteristics, such as weight. Plastics are often introduced, due to their low weight. Green roof systems are normally composed (from the roof up) of a root barrier layer (to protect the roof from plant roots), drainage layer (to allow excess water to be removed), filter layer (to prevent particles blocking the drainage layer), water retention layer (to retain water for runoff control and to keep growing medium layer moist) and growing medium (supply of nutrients to the vegetation)[79].

A range of materials have been used for these layers and they include polyethylene, polypropylene, crushed brick, crushed tile, mineral wool and composted green waste [79]– [82]. We could not identify any reference in the scientific literature or other media for use of sheep's wool as a compositional

element of a green roof. Given its characteristics of water retention and thermal regulation, as well as its alignment with mineral wool in terms of functionality, this may be a viable option.

Concrete

A range of different fibres can be used in concrete in order to improve its functional properties. These include steel fibres, glass fibres, basalt fibres, polyester, bamboo, hemp, banana, human hair and animal wool fibre. Naturally based fibres are gaining attention to address sustainability, particularly with respect to the construction sector. Cost savings can be generated through the use of natural fibres, in addition to improvements in compressive strength [83]. Fiore et al reported that fibres of length less than 1mm could be used in concrete but would not improve its characteristics; sheep's wool fibres of greater than 6mm however can reinforce the mortar and deliver improved compressive strength. The length and number of wool fibres added must be controlled as excess of either leads to greater water requirement and reduced strength cement [84]. A study in Ethiopia in 2019 also identified the percentage of sheep's wool as important; they identified an optimum incorporation rate as 1.5%. At this concentration, while workability did increase somewhat, there was also an increase in compressive strength, flexural strength and split tensile strength property [85]. In addition to improvement of strength characteristics, inclusion of wool fibres has also been shown to improve the sound absorption ability of concrete [86], [87].

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Determination of Materials Approach to Wool Insulation Development

Insulation	
Technology Readiness Level	9
Level of Research required	Medium
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund
Research Ecosystem	Teagasc, IT Sligo, CirculEire
Industry Ecosystem	Pierce Insulation, Bi-Eco, Thermafleece*, Kingspan

There are a number of areas for research that need to be addressed in terms of insulation development. These include:

- How best to treat wool fibres for application to insulation, i.e., felting;
- Whether to include other fibres to deliver a composite material to optimise insulation effectiveness;
- Following development, testing of insulation characteristics such as thermal properties (R value), acoustic properties, dust production;
- Determination of treatments that may be required for insulation material, such as moth repellence.

VOC Filtration Ability, Based on Proposed Materials Approach

VOC Filtration	
Technology Readiness Level	6/7
Level of Research required	Medium
Recommended support mechanism	Innovation Voucher/ Innovation Partnership/Agile Innovation Fund
Research Ecosystem	IT Sligo, Shannon ABC (TUS), AMBER
Industry Ecosystem	Ulster Carpets

It has been identified that wool insulation may provide a way to remove VOCs from the home. This may be in terms of general air circulation or from formaldehyde emitting structure. It is assumed that the wool insulation would either be placed in the attic or in wall cavities. In terms of air circulation, for this to be a value-add characteristic of wool, the air circulation would need to be such that the air would be driven into the attic from the house (the main repository of accessible wool), and back to the main indoor air environment. Where it is intended to absorb formaldehyde or VOCs from structures already in place, the wool could be installed as insulation to these structures. The functionality of the wool fibre as a filter is based on the keratin binding to the VOC.

Over time the wool may become saturated with VOCs and stop absorbing any additional VOCs and could start releasing VOCs that had previously been bound. For wool to be effective as a filter, as for any filter, it may have to be replaced from time to time. Some studies have suggested that the wool degrades or alters the structure of the VOC [88], this would need to be established, in addition to what these breakdown products are. Research would need to be carried out to determine at what point the wool filter becomes saturated, and based on normal to high levels of VOCs, how long it would take before this saturation point is reached. In addition, the potential for the wool to release the VOCs following binding would also have to be determined.

Development of Wool-Based Mats for Green Roof Development

Wool mats for green roofs	
Technology Readiness Level	9
Level of Research required	Minor
Recommended support mechanism	Innovation Voucher/LEO/Contract research
Research Ecosystem	UCD, BiOrbic
Industry Ecosystem	Soprema, Cork Rooftop Farm

A review of material that can be incorporated in green roof mats would need to be established. This would include treatment of wool fibre prior to use in this type of product. This information would be used to inform construction of prototype products with a variety of materials. The incorporation method would have to be addressed and growth trials would then be carried out to determine which types of plant material are supported best by this approach. End points such as germination rate, shoot height, etc would be measured.

Leveraging From Work Already Completed on Wool Amendment of Concrete Blocks, Identify Benefits and Impacts of Addition of Sheep's Wool to Concrete

Concrete blocks	
Technology Readiness Level	9
Level of Research required	Minor
Recommended support mechanism	Innovation Voucher/LEO/Contract research
Research Ecosystem	CREST, Teagasc
Industry Ecosystem	Ecocem

A number of considerations have been identified for the inclusion of wool in concrete blocks, including fibre length and addition rate. This information would be utilised to determine the effects of inclusion of Irish wool in concrete blocks. A range of approaches to this should be considered, and following prototype development, testing would be performed to determine the impact of inclusion of the wool on, for example, compressive strength, flexural strength and sound absorption ability.

4. Packaging

Wool has gained attention in the past decade for its properties as they may be applied to packaging and protection of materials during transport. In addition to its physical characteristics, wool can also help control humidity and reduce condensation [89]. Bhavsar et al (2021) treated greasy wool with superheated water to hydrolyse the wool, this was mixed with kraft pulp (digested wood chips) to produce a bio composite material suitable for packaging as a rigid material [90]. Woolcool®, have significantly benefited from wool's physical characteristics. They have developed a wool packaging material suitable for a range of applications from food to pharma. They state that they are the only company that is using a "range of sheep's wool insulated packaging available on a commercial scale". They also refer to patented technology behind their product. According to their website, their product is scoured using a natural process, is then felted and sealed within recyclable industry grade micro-perforated polyethylene wrap. Their product maintains chill temperatures for at least 24 hours.

There are six patents held by the Wool Company in this area:

EP2727727A1 – Packaging laminates; A laminated packaging sheet for forming into a generally rigid insulated package, the sheet comprising a relatively stiff layer of board, such as corrugated card-board, and a pliable liner secured to one side of the board, the liner being comprised of fibrous strands, such as felted wool, the strands being compressed from their natural condition and retained in that compressed condition, such as by needle stitching, to thereby trap air between the strands and act as a heat insulant, the strands also acting to, in use, absorb moisture therewithin or there-upon.

GB2490539A – Laminated packaging sheet comprising stiff and hygroscopic fibre layers; The laminated packaging sheet comprises a stiff (rigid) layer of board, preferably cardboard, and a pliable liner secured to one side of the board. The liner comprises hygroscopic strands, preferably felted wool. The strands are compressed from their natural condition and retained in that compressed condition, preferably by needle stitching, to thereby trap air between them. Preferably the wool felt liner is fixed to the corrugated cardboard by a soluble adhesive, especially starch.

EP3190361A1 - Temperature controlled packaging and transportation method; a thermally insulated product delivery container (PDC), including therewith in a rigid shell defining a hollow tube containing

wool, first and second tube-end closure boxes containing wool to thereby collectively define an inner void for receiving at least one phase change material container for providing a temperature-controlled condition within the void in the presence of a phase change material (PCM).

WO2014/068290A1 – Multi-layered non-woven insulating textile material; A multi-layered non-woven hygroscopic fibrous textile material and method of making said material is disclosed. The fibres of the material extend across the thickness of the material and respectively opposite outer layers of fibres are fixed in a matted state relative to the inner fibres. The extent of matting is sufficient to increase thermal insulation per unit thickness relative to the inner fibres, whilst still permitting the outer layer fibres to allow air circulation between and through the outer fibres, to thereby permit moisture retention or release.

GB2537894A – Constructional sandwich board comprising non-woven between corrugated cards; Composite constructional board comprises outer sheets 3, 4 sandwiching needle-felted fibrous material 2. The outer sheets 3, 4 comprise corrugated cardboard attached to the fibres 2 by means of an adhesive. The corrugated cards 3, 4 and fibrous batt 2 are supplied from rolls. The fibres 2 are preferably wool and cut to the same dimensions as the cards 3, 4. The sandwich laminate is used as thermal insulation, packaging carton.

GB2549777A – Composite constructional board; A fibrous textile material 3 including or adjacent discrete storage containers 4, each container storing a Phase Change Material (PCM). The textile material may be sheep's wool. The PCM containers may be spherical or elongate. The material may be applied to the inside of a carton 1 or a blank thereof. The outer membrane of the storage container may be waterproof and compostable. The PCM containers may be arranged in a discrete row between a wall of corrugated cardboard 2 and a wall of woollen fibres. The woollen fibres may be detachable from the row of PCM containers. The material is intended to keep the contents of the carton within a given temperature range. The carton may be used for the transport of vaccines.

While the use of wool as a packaging material has been identified for some time (and is recognised within the patents above), it may be challenging to enter this sector given the patents that already exist in this area, regarding improvement to the use of sheep's wool in packaging and cold chain transport.

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Determination of Freedom to Operate and Produce Competitive Product

Packaging	
Technology Readiness Level	9
Level of Research required	Medium
Recommended support mechanism	Innovation Voucher/LEO/Contract research
Research Ecosystem	CREST, APT, CirculEire, AMBER
Industry Ecosystem	Woolcool*

Development of a wool insulation product will only be successful if it is competitive with that already on the market. In this context a desk-based study should be carried out on the patents that already exist in this area to determine freedom to operate, and where the opportunities may exist for development.

5. Filled Products

Sheep's wool has been used for centuries in, essentially, filled products. These products have a broad range and the application of sheep's wool to a particular application within these products is predominantly based on its physical qualities such as fibre length, diameter, coarseness, etc.

Bedding

Sheep's wool is used for a range of bedding applications including duvets, pillows, mattress protectors and mattresses. In general, for products that are coming in contact with skin, finer wool is preferred. For a mattress fill, for example, the thicker wool fibres from more robust wools are preferred. A number of websites report on the benefits of wool bedding for those with asthma and allergies [91], [92]; they cite its breathability and temperature regulating characteristic as providing an inhospitable environment for dust mites and fungi to proliferate. A range of previous studies had actually identified wool bedding as being a risk factor those with asthma and allergies [93]– [96]. More recently, a certification standards company based in Dublin, has recently published the first test standard to test merino wool as asthma & allergy friendly®. ASL operates this certification program globally and has significant presence particularly in North America. It is noted that previous reports of allergies to wool may predominantly be due to the presence of lanolin and chemicals for cleaning and finishing of the wool. The certification of merino wool is based on specific criteria which include chemical testing, as well as measuring the mean fibre diameter and residual grease content [97]. Of interest, merino is the only wool eligible to be certified at present and each wool would be considered on its own merits; angora wool has been designated as an asthmagen by the Association of Environmental and Occupations, albeit due to occupational exposure.

Furniture

In addition to being used as upholstery, wool has begun to be researched and developed to determine its potential for inclusion in composite material for applications as robust as use in furniture products. A company called Solidwool has developed furniture by blending oils reclaimed from paper processing (as a resin) with wool by-product [98]. Work by Donegal Tweed has also explored the opportunities

around development of furniture from wool, as well as other natural materials such as hemp (personal communication).

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Validation of Irish Wool for Health Claims

Wool Health Claims	
Technology Readiness Level	7
Level of Research required	Medium
Recommended support mechanism	Innovation Voucher/LEO/Contract research/Innovation Partnership
Research Ecosystem	IT Sligo, Shannon ABC (MTU)
Industry Ecosystem	Allergy Standards Ltd, Woolow

Different wool types may have different considerations in the context of their suitability for use for those with asthma and allergies. Where it is intended to market Irish wool as suitable for this use, it should be based on scientific evidence, rather than anecdotal evidence. A desk-based study determining the factors that will impact on wool's suitability for those with asthma and allergies should be carried out, in addition to provisional testing to determine whether Irish wool aligns with this use.

Development of Wool Composites for Production of Furniture

Furniture/Biomaterials	
Technology Readiness Level	9
Level of Research required	Medium
Recommended support mechanism	Innovation Voucher/LEO/Contract research
Research Ecosystem	APT, UCC, CirculEire
Industry Ecosystem	Donegal Yarns

In order to progress this opportunity, the materials required to combine with wool to produce bio composites should be compiled and assessed across a matrix. This assessment would be based on structural, aesthetic and sustainable characteristics. This will identify which materials are most appropriate, and the processing conditions to deliver functional and sturdy furniture products.

6. Environmental

Wool has been proposed for a number of environmental applications, these include

- Sorbent for oil spill clean-up;
- Sorbent for treating water pollution with heavy metals.

Sorbent for Oil Spill Clean Up

The physical characteristics of wool - irregular scaly and rough surface, crimp and presence of waxy matter – make it a suitable material for adsorbing oil. Wool based woven mats (78% wool/22% polyester) have been demonstrated to have excellent sorption affinity for crude oil, diesel and base oil. The mats were shown to be able to retain more than 10-fold their weight in oil [99], [100].

Sorbent for Treating Water Pollution with Heavy Metals

Natural materials, such as spent grain and feathers have been used with some success for the adsorption of heavy metals from wastewater. For both feather and wool, the key compound is keratin and its charge and pH. Physical and/or chemical treatment is required to activate the wool for successful adsorption of heavy metals; this is the case also for use of spent grain in this manner. Treated wool has been shown to be successful in the adsorption of copper, chromium, lead, cobalt, aluminium, and magnesium [100]. Treatments for wool include:

- Cleaned and cut into short pieces;
- Wool powder from raw and chemically modified wool;
- Keratin colloidal solution from reduced wool;
- Nanofiber membrane from S-sulfokeratine;
- Chemically modified by graft copolymerization of ethyl acrylate (EA);
- Chemically modified by grafting of maleic anhydride;
- Wool keratose / silk fibroin blend.

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Utilisation of Existing Research to Validate use of Wool and Wool Composites for Oil Absorbency

Sorbent for Oil Spill	
Technology Readiness Level	9
Level of Research required	Minor
Recommended support mechanism	Innovation Voucher/LEO/Contract research
Research Ecosystem	Shannon ABC (MTU), CirculEire
Industry Ecosystem	AES-Marconi, Spilltech Environmental.

- Defining optimum treatment process of wool prior to its use for oil absorbency, potential for incorporation of additional biological or synthetic materials;
- Measurement of ability of prototypes to absorb a range of waste oils;
- Identification of uses for wool post use, importance of circular process, rather than linear.

Utilisation of Existing Research to Validate use of Wool, Wool Composites and Wool Treatments for Heavy Metal Absorbency

Sorbent for Heavy Metals	
Technology Readiness Level	6
Level of Research required	Medium
Recommended support mechanism	Innovation Voucher/LEO/Contract research/Innovation Partnership
Research Ecosystem	NUIG, Shannon ABC (MTU), CirculEire
Industry Ecosystem	Galco Steel, Verde.

- Defining optimum treatment process of wool prior to its use for heavy metal absorbency, potential for incorporation of additional biological or synthetic materials (for example spent grain has been used in commercial settings for removal of some heavy metals);
- Measurement of ability of prototypes to absorb a variety of heavy metals;
- Identification of uses for spent bio-filter so that it does not become another waste.

7. Medical Devices/Biotechnology

More advanced applications for wool have been identified which include sectors such as medical device, healthcare and biotechnology. These applications are predominantly based on the keratin content of the wool. Keratin is abundant in wool and has a high proportion of the amino acid cysteine. It has been researched for applications in biomaterials due to its low toxicity, biocompatibility, polymerisation ability and biodegradability [101]. Mahoney et al reported on its use in orthopaedics research, used in conjunction with hydroxyapatite for bone regeneration [102] and Dias et al reported on its use in an ovine model as a bone graft substitute [103]. Keratin from sheep's wool has also been investigated for its wound healing ability.

Sharma et al reported on the use of keratin extracted from sheep's wool for its ability to aid wound repair in a rat model of dental pulp tissue [104]. Ramirez et al developed a dual scaffold model for the support of skin regeneration during wound healing. The lower layer utilised keratin extracted from wool in conjunction with PVA (polyvinyl alcohol) fibres. The authors noted that the wool keratin improved the swelling properties of PVA fibres and supported an efficient interface with the human cells [108]. A review by Konop et al in 2021 also identified applications for sheep's wool keratin in resorbable implant materials, supporting cellular attachment and wound dressings [106].

Keratin has also been proposed for use as a bioplastic, most work on this has been carried out on keratin from chicken feathers [107]– [109], however in 2019 Fernandez-d'Arlas published a paper on the development of cross-linked bioplastics from sheep's wool keratin. At laboratory scale, the keratin was extracted and combined with plasticizers; they reported on its robustness and that it provided a UV barrier.

Wool has also been used to induce bacteria to produce keratinases; keratinases are enzymes that degrade keratin. They can find excellent use in the leather industry to degrade wool in order to improve processing and can also be used to degrade keratinaceous wastes to use them for animal fodder for example [110]. Fang et al demonstrated how wool could be used as a substrate to induce *Stenotrophomonas maltophilia* to produce keratinase [111] and Slaveva et al demonstrated the use of *Streptomyces flavis* and *Microbispora aerate* to produce keratinases in the same manner [112].

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Development of Cost Efficient, Effective Extraction of Keratin from Wool

Keratin extraction from wool	
Technology Readiness Level	4/5
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	Shannon ABC (TUS), BiOrbic, AMBER
Industry Ecosystem	IBF, Resolve Partners

- Review of literature for methods to extract keratin from wool;
- Identification of effective, sustainable, cost-efficient method;
- Characterisation of keratin from selected methods.

Utilisation of Keratin Across a Spectrum of Medical Device and Healthcare Settings to Validate and Determine Opportunities for Commercialisation

Medical device applications	
Technology Readiness Level	4/5
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	Shannon ABC (MTU), RCSI, AMBER, UCD
Industry Ecosystem	Resolve Partners, PBC Biomed

- Screening for utilisation of keratin for medical device and healthcare products;
- Screening could include wound healing ability, use in collagen structures;
- Incorporation of keratin extracted above into appropriate prototype medical device and healthcare products.

Development of Bioplastic from Sheep Wool Keratin

Bioplastics	
Technology Readiness Level	3/4
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	APT, AMBER, BiOrbic, CirculEire
Industry Ecosystem	Key Plastics, Bioplastech

- Determine work carried out in this area already;
- Identify and develop scalable extraction processes for keratin;
- Develop prototype bioplastic processes;
- Determine performance of bioplastics;
- Technoeconomic assessment.

Isolation and Cultivation of Irish Micro-organisms Capable of Producing Keratinases, using Wool as Source Biomass

Keratinase production	
Technology Readiness Level	3/4
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	BiOrbic, Shannon ABC (TUS/MTU), MiCRA (TUD)
Industry Ecosystem	Niskus Biotec

- Bacterial samples to be taken from sites where wool has been dumped;
- Bacteria grown on media containing keratin and species that grow selected;
- Identification and characterisation of selected species;
- Laboratory trials to determine ability to grow on wool (scoured and non-scoured) in a liquid fermentation;
- Keratinases extracted, quantified and characterised.

Pilot Scale Production of Keratinases and Delivery of Technoeconomic Assessment

Pilot scale production of keratinases	
Technology Readiness Level	2/3
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	Shannon ABC (MTU), MiCRA (TUD)
Industry Ecosystem	IBF

- Pilot scale trials of optimum conditions identified above ability of selected organisms to produce keratinases from wool;
- Measurement of inputs and outputs to contribute to technoeconomic assessment.

8. Cosmetics

Lanolin is the cosmetic related compound most associated with wool, it is the waxy material found at the base of the fleece that provides water-proofness to the sheep's fleece. It is harvested as part of the scouring process and incorporated into a range of cosmetic products, where it provides a moisturisation and skin protection function. In general, breeds of sheep that have finer wool have greater amounts of lanolin (reportedly twice as much), than coarser wool breeds [115].

A lesser well-connected compound from sheep's wool are ceramides. Ceramides can reinforce skin barrier integrity and improve wound healing and the skin's water holding capacity. Ceramides are internal lipids in the wool structure (whereas lanolin would be external). In this circumstance the ceramides have to be extracted. The internal lipid content of wool is approximately 0.2-1.9% with ceramides comprising 15-30% of this. Ceramides have been extracted from wool using Soxhlet (solvent and heat) as well as super critical fluid extraction (green extraction technology). Reports have indicated that the ceramides obtained from wool are very similar to human ceramides and so may find application in both the cosmetics and healthcare sectors [116]. The cost of purified ceramides in the cosmetics sector can be as high as €2,000/Kg [117].

Research Projects:

Proposed research projects that may support the development of this application area for wool include:

Determination of Lanolin Content of Irish Wool

Lanolin content of Irish Wool	
Technology Readiness Level	2/3
Level of Research required	Major
Recommended support mechanism	Innovation Voucher
Research Ecosystem	Shannon ABC (MTU), PMBRC (WIT)
Industry Ecosystem	Kerry Woollen Mills

- Samples taken from sheep across the country;
- Lanolin measured using standardised methods.

Determination of Ceramide Content of Irish Wool

Ceramide content of Irish Wool	
Technology Readiness Level	2/3
Level of Research required	Major
Recommended support mechanism	Innovation Voucher
Research Ecosystem	Shannon ABC (MTU), BiOrbic, PMBRC (WIT)
Industry Ecosystem	

- Samples taken from sheep across the country;
- Ceramides measured using standardised methods.

Validation of Extraction Processes Already Established to Extract Ceramides from Irish Wool

Validation of extraction methods	
Technology Readiness Level	3/4
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	Shannon ABC (TUS), BiOrbic , PMBRC (WIT)
Industry Ecosystem	

- There are a number of methods reported in the literature for the extraction of ceramides from Irish wool; their efficacy for Irish wool would have to be established.

Delivery of a Range of Cosmetic and Healthcare Studies to Determine Activity of Ceramides

Development of cosmetic/healthcare products	
Technology Readiness Level	2/3
Level of Research required	Major
Recommended support mechanism	Innovation Partnership/Agile Innovation Fund/SFI/IRC
Research Ecosystem	Shannon ABC (MTU), Design+
Industry Ecosystem	Lynoslfe, SPV Healthcare, PBC Biomed

- Ceramides extracted above would be tested for a range of skin supporting activities including antioxidant, anti-inflammatory and wound healing;
- Extracted ceramides would be incorporated into prototype formulations and tested for ability to support skin barrier efficacy and increase moisturisation.

Patent Landscape

In addition to the brief description of relevant patents in the packaging section above, we have also reviewed the patent landscape at a top level to determine activity in this space. Already existing patents in a particular area can be a good indication that there are commercialisation opportunities. Included in the table below are the search terms used to identify patent number in the relevant area. Not all patents will be relevant and more detailed review would be required to further refine this number, however it does give an indication of research and patent activity in each area.

There are almost 640,000 patents on Espacenet (online service for patent searches) under the search term “wool”. As the search is refined to focus more on the areas identified in this report, a clearer picture is provided; exclusion terms were incorporated where a clear pattern of irrelevant patents was identified. Patent searches resulted in the following:

Table 1. Summary of patents associated with sheep’s wool.

Search terms	Exclusions	Patent Numbers
Sheep Wool Insulation	Mineral	1,100
Sheep Wool Compost		233
Sheep Wool Keratin		1,462
Sheep Wool Ceramide		487
Sheep Wool Peat		396
Sheep Wool Enzyme	Molecular	1,274
Sheep Wool Hydroponic	Rockwool	243
Sheep Wool Weed Control		665
Sheep Wool Fertiliser		45
Sheep Wool Plasma Textile		282

Search terms	Exclusions	Patent Numbers
Sheep Wool Solid state fermentation		869
Sheep Wool Green Urban Garden		838
Sheep Wool Filtration VOC		284
Sheep Wool Packaging Cold		1,544
Sheep Wool Allergy	Feed	1,056
Sheep Wool Furniture		935
Sheep Wool Oil Sorbent		142
Sheep Wool Heavy Metal Sorbent		39
Sheep Wool Keratin Extraction	Molecular	88
Sheep Wool Keratin Extraction Medical Device	Molecular	29
Sheep Wool Bioplastic		21
Sheep Wool Keratinase		66
Sheep Wool Ceramide		487

Mechanisms to Support a Commercially Sustainable Wool Sector

The wool sector in Ireland has the potential to turn itself into a significant success story bringing new income sources and positive imagery and reputation for the island of Ireland if well supported. The supports sought from speaking with various industry actors manifest in various forms. While the consortium spoke to various parts of the industry, and will identify their requests below, it also tried to seek out opportunities which could be put in place to put the sector on an economically and environmentally sustainable footing for the future.

Wool Council

The need for a democratic representative body for the Wool industry became apparent during the interviews across this project. While there are existing bodies and groups all active in the sector, there is a need for a representative body, with government support and close links to the Department of Agriculture, Food and the Marine. This body needs to become the 'market maker' for the sector and try to meet all interests at a strategic level. The body needs to represent various interest groups from industry to co-ops to processors and educators/skills networks in the area.

If the sector is to build on the work done to date and to meet the aspirations of these various groups, there is a need to bring a vision for the sector onto a more strategic pathway. Current individual and fragmented thinking need to be harnessed and brought forward with the innovations discussed in the Research section. The wider skilling-up of the sector and a keen eye on marketing an Irish Grown Wool brand so that there is one central point for existing and future stakeholders to find support, is also important. We consider that the setting up of a Wool Council with appropriate governance, objectives, and government support, including access to relevant government departments will help boost the industry and create a clearer vision of what the future of Irish wool can look like. Supports don't necessarily all have to be financial – a body which acts as an Irish wool 'champion' for the entire sector could be the go-to entity for the many facets of the Irish wool sector.

Incentives

As might be expected, parts of the industry, being accustomed to a subsidy per ewe in the Common Agricultural Policy, see another pathway to better quality wool production. A potential option for them is to add a further subsidy to the current mechanism in recognition of well-maintained and presented wool as it arrives to market. In particular, wool merchants considered this to be a potential means to attract better quality wool for existing and innovative applications while compensating the primary producer.

They mainly called for it to be rolled into the Sheep Welfare Scheme (Sheep Improvement Scheme). The suggestion was that the producer would need to produce proof from an approved wool merchant that the wool was presented in a saleable manner. This could also be administered through quality assurance audits such as the board Bia BLAS scheme. One suggestion was to have proof of sale to a registered merchant as a condition of receiving certain subsidies such as the Sheep Welfare Scheme.

The consortium noted that with the innovations highlighted in this report in sight, there is an opportunity to recognise wool as a key ingredient in supporting a circular bioeconomy and in having strong and reputable green credentials across a range of products. With an elevated understanding and perception of wool, consumers and therefore, manufacturers may move to view wool in a new light that answers their Economic, Social and Governance (ESG) goals. With strong green credentials and primary producers, located in rural

economies, the story they can tell and support, brings a win-win for all parts of the value-chain. Most importantly however, it elevates the wool sector to a new level, potentially propelling it into becoming a key player for a greener and more socially just future for the economy and society.

***“opportunity to
recognise wool as a
key ingredient in
supporting a circular
bioeconomy”***

Having spoken to Andy Cooper at AgResearch New Zealand, the experience there has shown that the market itself is able to compensate sheep farmers. At 2\$/kg average, the market brings this value inside the farm gate without the need for state intervention. It was also noted that New Zealand had a ‘levy’ system in place in the past and the withdrawal of this system was quite painful for sheep farmers at the time.

The consortium therefore suggests that an initiative to kick-start the circular bioeconomy aspects of wool in Ireland would be in line with CAP green objectives and the Green Deal. It would also support regional development objectives of the government. This initiative could be in place for 3 years to ensure adequate take-up of the scheme, communication and education of sheep farmers and the wider sector.

The introduction of a countrywide wool classification grid which would enable merchants to fairly differentiate the price that is given to farmers would also help to support development of a wool industry. This is currently non-existent and is seen as something that could be put in place as a ‘quick win’ to begin the pathway to seeing a difference in price paid to the primary producer, based on the quality of the wool collected at the farm gate. Some wool merchants raised the issue of smaller unlicensed agents collecting wool for larger merchants. They called for some measure to stamp this out. Wool merchants would also be in favour of subsidized wool collection from remote farms such as North and West Donegal, West Mayo, and Connemara.

Some merchants also raised the possibility of seeking a new classification for wool i.e. removal of the category 3 label. Finally, wool merchants are also feeling the shortage of labour more generally for the sector, and would welcome government support to increase the number of skilled people involved.

Skills & Education

The skills required at different steps of the value chain are varied. Currently there is no Irish-based opportunity for these skills to be learned through accredited courses or through apprenticeship schemes. In the UK, apprentices are brought in by the British Wool Market and trained on site for 2 to 5 years in duration. British Wool has offered to allow Irish participants onto their skills courses and for the Irish wool sector to more generally learn from their experience in training people to work in the sector. The Irish Sheep Shearers Association has also suggested that it could facilitate training and education programmes.

“skilling-up Irish graders of wool so that they can play a role in the value chain”

The need for shearers, collectors, grading agents and commercial professionals is one of the major weaknesses for the Irish wool industry. We rely heavily on the UK to provide for our needs and on travelling shearers to service the industry at certain times during the year. Wool is part of our heritage and giving it the attention and due care will reap rewards for the island more generally if well organised and properly skilled.

Education

Educating existing sheep farmers and the next generation of sheep farmers is essential to achieve a fresh insight into the potential income streams and quality management of the clip more generally for Ireland. Clear communication and opportunities to join wool education initiatives, such as workshops, farm walks or visits to wool depots on the island would help to create a community of educated sheep farmers who can then see themselves as valuable primary producers of not just meat but also wool from their flock. With the drive for sustainable agricultural practices and the push for circular bioeconomy, these farmers could better understand their role in potential new business models based on the quality of their wool. These are new pathways for income which they may not be fully aware of or understood. Bringing them in through education initiatives will help build a strong wool sector across the island.

As we support sheep farmers for better maintenance and wool presentation, we need a skilled and knowledgeable labour force to harness the value of wool and properly manage its quality while it is on the island and as it is exported to receive a fair price for the primary producer. Skillnet Ireland is one means to achieve this skilled workforce. It should be investigated if there is an opportunity for Skillnet to support this upskilling objective as they have done in 2021 in the area of sustainable agriculture courses for the dairy sector. There are already sheep farmers bringing apprentices/labourers onto their farm and allowing them to learn sheep shearing skills during the shearing season. This has gained a keen interest from different age groups and with more government support, could be rolled out on a national scale. There may be a role for Údarás na Gaeltachta here in supporting such schemes which directly affect the northwest and west regions.

In Educational Settings

There is currently a program known as [Wool in School](#) which aims to increase awareness of Irish Grown Wool and its production within schools and other educational facilities. There is an opportunity to have programs of this nature formally incorporated into the curriculum or as part of green flag certification. Promotion of wool in a school setting has great potential for lifelong awareness and consumption of wool-based products. There are also opportunities to incorporate these programs into care settings, addiction centres, rehabilitation facilities, social farms, and other settings as appropriate.

Grading of Wool - an Untapped Opportunity

The ability to accurately grade wool is a unique skill which is one of the key cogs in the wheel of wool processing and valuation of wool. As Ireland does not have any skilled graders today, we rely exclusively on wool merchants and their staff in the UK to examine our clip and deem its value. Wool can have up to 200 different grades and each at different price levels depending on origin, wool quality and amount. We see it as a quick win for the sector if investment in skilling-up Irish graders of wool so that they can play a role in the value chain and not relinquishing this to others as is currently the case.

Wool Hub

With considerable innovation pathways for wool and still under development in many cases, the case for a specialised Wool Hub in Ireland is strong. In New Zealand, there has been a focus on different aspects of innovation around wool for value-added products as part of their Agricultural Research and Innovation agenda over the past 10 years. Our interviews showed that there is a keen focus on additive manufacturing, digitalisation for traceability and heritage management, and liaising with different sectors (e.g. construction, pharmaceutical) to meet their sustainability and quality requirements. While in Ireland, a focus has been on quality meat production, it is time to consider establishing such a Hub to bring a focus on Wool Innovation, further examining the opportunities for value-added products made from wool. Interviewees also spoke of the need to look at the scope of current wool research networks and how these can be harnessed to partner up on projects and future funding programmes.

Furthermore, where it is possible to take benefit from current 'micro' efforts across the country in terms of innovation on-site, there may be technologies or practices which, if better supported, could become plug and play solutions for the wider sector. Again, a dedicated hub could work on these solutions and bring them to a larger group of sheep farmers for uptake and efficiency gains.

The wider industry and in particular, primary producers will see the establishment of such a hub as an indication from government that it is serious about supporting their part of the circular bioeconomy and the opportunities that can arise from it for wool produced here. With a visionary Hub in place, wool production in Ireland would be on a more stable footing, supporting the sector well into the future.

Traceability

To build a strong Irish Grown Wool brand, one of the main foundation blocks is traceability of the wool produced on the island. Innovative solutions using blockchain (a distributed ledger technology) is already being seen as an efficient means to manage this complex product while keeping the underlying data secure and verifiable. Having spoken to British Wool CEO Andrew Hogley, it is clear that a sector specific solution would help here. Work on this is already underway at British Wool with counterparts in Norway and elsewhere. Ireland would be encouraged to join these efforts rather than re-inventing the wheel.

A number of companies are proving the traceability and provenance of their product using blockchain technology, as the information cannot be altered or tampered with once entered. This helps companies prove their values and branding of their product. In the case of the traceable British wool project run by British Wool, they invested in ICT systems for traceability. As a result, it has created an added value of 25 cents to each kilogram of wool, as the buyers want to prove provenance to the customers and are willing to pay for it. Potential pilots could take place with Irish companies, like Verifact, who are offering this traceability solution with interested farmer groups and Co-operatives to enhance the value of the wool and tell their story.

Genetics

Breeding for wool traits is not likely to be widespread in Ireland since there is little or no economic incentive to do so. Discussions with Teagasc and Sheep Ireland revealed that the focus will be on the promotion of breeding for traits with a higher return on investment. While widespread breeding for wool traits is understandably impractical, there may be scope for small scale breeding programs through collaboration between wool processors and specialist producer groups. The Galway Wool Co-op had expressed an interest in developing a wool index and are seeking support to initiate a program. A major Irish wool processor indicated that it is investigating a program of breeding for finer Irish wool, but research is at a very early stage.

Sheep Ireland have indicated that they could facilitate a wool quality index for specialist groups in theory, however there are certain criteria that any breeding program need to be successful.

Traits must be:

- a. Easily and cost effectively recorded in a repeatable manner;
- b. Variable;
- c. Socially or economically desirable.

Sheep Ireland informed us that their Central Progeny Testing flocks are available for any trials that may be carried out.

There is currently no testing facility in Ireland to measure the various parameters of wool. The nearest testing facility, operated by British Wool, is in Caernarfon, Wales. Any efforts to improve wool quality in Ireland would benefit from a domestic testing laboratory. Processors using imported fibres also expressed support for the establishment of a local and independent testing facility.

Heritage & Wool Knowledge Exchange

Interviewees considered that the story of Irish wool is currently under-represented and under-marketed in general. While there are pockets of knowledge scattered around the country, the information on wool heritage and sharing more materials on wool knowledge would benefit all parts of the value chain and ultimately, consumers.

Certification

There is currently no system in place for the certification of Irish Grown Wool. While certification in itself can cover different aspects, in terms of industry support, it is a common denominator for the wool sector under which Irish Grown Wool could then build its brand. The depth of certification would be for the industry to determine, based on requirements from downstream users. Information that may be required could include physical and chemical measures, as well as traceability and organic status determinants. There are a range of commercial entities who provide a certification service, and once end-point measures are determined, could be outsourced.

From market research interviews and from reviewing consultation submissions it was found a number of certifications can be used to demonstrate benefits of wool products:

- Irish Organic Association. The Irish Organic Association does reportedly certify organic wool, however, this does not appear to widely known even within the wool industry and among organic farmers. Yarn Vibes is a Cork based initiative selling yarn made from Irish Grown Organic Wool. There is an opportunity to support initiatives like this and others using organic wool;
- Nature Plus Eco-Label: The NaturePlus eco-label is a recognised label that offers consumers and construction professionals in Europe clear selection guidance for products in the building sector. It attests compliance with high standards of quality for all areas relevant to sustainability;
- Environment Product Declaration: EPDs signal a manufacturer's commitment to measuring and reducing the environmental impact of its products and services and report these impacts in a hyper-transparent way. With an EPD, manufacturers report comparable, objective and third-party verified data that show the environmental performance of their products and services. The program is operated in accordance with a.o. ISO 14025, ISO/TS14027, ISO 14040, ISO 14044 and ISO/TS14067. For construction products, the EPD programme also complies with the European standard EN 15804 (A1 and A2) as well as ISO 2193;
- In addition, it was noted a number of the manufacturers of wool products follow Quality Management ISO 9001 and Environmental Management ISO 14001 standards. This helps with market entry for higher end markets, like pharmaceuticals and food industry.

Branding

With certification in place, the ecosystem becomes more aligned and consistent in terms of the output it produces for the market and its pull factors. In order to stand out from other brands, a consistent Irish Wool brand is suggested here. A common brand for all Irish grown wool is an umbrella brand which Irish sheep farmers can find their place and identify their wool. Just the act of creating a brand identity and values will embed a sense of quality and higher value for money if well managed.

Marketing

With a solid set of steps in terms of traceability, certification and branding, the time for a strong marketing effort becomes more relevant and more credible. As with other brands, an Irish Grown Wool brand can then be marketed at country or all-island level allowing customers to have confidence in the provenance and standard of wool product they are consuming. A fully fledged marketing strategy would need to be conceived for the overall 'brand' and individual existing Irish brands could then also seek to be recognised under this while keeping their own marketing at the same time. This is a win-win for everyone. The Campaign for Wool and Woolmark are good examples of this type of initiatives operating elsewhere.

Currently, apart from individual wool co-ops and businesses already marketing their wool products, there are also a few noteworthy local initiatives such as the Kildare Yarn Bomb group. There is an annual Yarn Bomb 'festival' which promotes the use of wool, knitting activities and art and crafts, bringing wool closer to citizens and helping it take centre stage. Such initiatives and others across the Island are another source of marketing for an Irish Grown Wool brand and should be included in future endeavours here.

Socio-Economic Model

Producing a positive impact on rural economies while sharing the objective of putting primary producers and their communities first, is an admirable objective when it comes to the sheep farming sector in Ireland and across Europe. Fostering socio-economic cohesion in new business models for the wool sector will help to show sheep farmers that the government is committed to growing the sector. At EU level, so-called 'living labs' are being rolled out to tackle a number of social innovation areas. These living labs are composed of 5 key elements according to the European Network of Living Labs, namely:

- a. Active User involvement;
- b. Real-life setting;
- c. Multi-stakeholder participation;
- d. A multi-method approach;
- e. Co-creation of solutions/business models.

With primary producers at the core, there are already existing supporting organisations and Wool co-ops working in the area. With an altered focus and more holistic approach to the perception of wool as an economic driver for sheep farmers, it could be an option to consider a living-lab approach to any new efforts to restructure the wool sector and its outcomes for the Irish economy.

In the case of wool, when considering its heritage, its link to rural communities across the island and our strong tradition in attracting significant tourist numbers, it is worth reflecting on how the end consumer could help to shape what steps are taken next for the different pathways outlined earlier. Consumer co-creation is becoming a new tool to use for product creation and design – this is where consumers are more active in the value-creation process. Bringing in consumers early and actively as part of the business model and value proposition is a growing trend across the EU and is something that Ireland could also look at in this case.

Local Business/Enterprise - Green and Sustainable

The rural economy and rural entrepreneurship continue to build on individuals taking decisions to try something new, to look at innovation and to build a business based in a rural setting. Specific supports which are currently administered through Local Enterprise Offices (LEO) are welcome. It is worth reviewing in more detail if these supports are adequately meeting the needs of aspiring entrepreneurs and co-ops in the area of wool to see how these might be tailored for a specific funding call to support the sector's ambitions. While circularity and sustainability are sought after objectives, wool related endeavours can help to create businesses which can thrive with innovative thinking and determined project promoters. This can take various forms whether it be tourist visits of sheep farms, wool knowledge workshops, textiles processing and skills demonstration, knitting and weaving demonstrations etc.

Some of the funding supports may be around the financing of start-up costs, mentoring for business modelling and innovation supports (such as the existing Enterprise Ireland operated Innovation Voucher schemes). An awareness campaign about these possibilities and showcasing examples that are already existing may encourage others to create their own local business and breathe new life into an existing sheep farming enterprise. Innovation Vouchers are provided for small and medium enterprises; sole traders are not eligible. In 2016 Enterprise Ireland made a defined number of vouchers available for artisan food producers that included sole traders. This approach would be of great benefit for sole traders involved in the wool sector. In addition, Enterprise Ireland have historically considered and supported Industry Led Research Partnerships, the wool sector would be an ideal candidate for this type of approach.

Social Science Study

Sheep farmers are a key enabler for change among the wool sector and its socio-economic outcomes. Research from a social science perspective would be welcome here to identify what the main obstacles and perceptions are for sheep farmers to engage with a different future for wool. Farmers need to be informed, supported, advised and convinced about the merits for changing how they manage their wool. A new perspective about the co-created potential of value-added products from wool needs to be embedded in their thinking around wool management. Interviewees we spoke to would welcome a study in this sense and an action plan to tackle the current thinking around sheep farming and its potential economic value.

A further observation the group noted was the age profile of sheep farmers in Ireland. The industry has an aging farmer problem. The consequences of this may need to be considered more deeply. More than 40% of all sheep farmers are aged over 60 (2020 census).

Looking to the long term (2030), there is a need to promote the sector and to attract more young sheep farmers to enter this profession. Ireland will need to consider how to attract the next generation in order to ensure a smooth takeover of current sheep farms, to help maintain the flock and to ensure the current population of sheep and sheep farmers is maintained and expanded.

Specific Products and Related Market Support

Insulation & Packaging

When considering ways to help and incentivise consumers turn to more sustainable and circular products in the building and packaging sectors, it was suggested by interviewees and within the consortium that a levy on materials which cannot be easily disposed at end of life such as polystyrene, could be introduced. A parallel strategy could incorporate a Green/Circular premium for sustainable insulation products. With the combination of Irish wool branding and certification steps above, this could become a go-to product for the Irish consumer.

Policy and implementation could be supported by SEAI to give a preference for natural fibers to be used in retrofits, especially in older buildings which may require breathable insulation types. Furthermore, support for natural fiber insulation could be ratified by the National Standards Authority of Ireland (NSAI) - this relates back to the certification section above.

In line with this approach, a packaging tax could be considered which would favor biodegradable and natural products to be used as opposed to synthetic materials. Finally, a welcome development would be more focused on wool through increased funding for research and development of wool packaging and insulation.

Textiles

Currently, Irish wool is sometimes misrepresented in overseas wool products. The introduction of tighter rules around labeling and mislabeling of wool products would help to combat this. More strategically, establishing a long-term plan for the processing of wool in Ireland to serve the crafts and weaving industries should be considered. Within this strategy, various ideas could be set out including co-operative scouring initiatives and incentives for innovation in the crafts and supply chain. Support to positive and existing small-scale initiatives and linking these to the bigger picture supports (such as sourcing, scouring, marketing efforts, branding and education and skills).

Funding

Two exercises of funding scoping were undertaken as part of the project covering funds at (1) local & national and (2) EU budget level. Funds were researched under various headings such as business supports (e.g., Start-up supports, SME supports, Training). Further searches were performed following a 'product' approach namely, insulation, bio fertiliser, crafts, wool and textiles. In Appendix 1, these results are grouped by 'entity type' so that entities seeking opportunities can find their respective opportunity for which they are eligible.

Business Funding Supports

Local funds include LEO funding as part of the regular micro and SME business funding supports and are a possible avenue for wool-based businesses. LEO funding has proven useful to start-ups and established businesses alike where employee numbers are less than 10 staff. These supports include start-your-own-business courses, feasibility study grants, priming grants and business expansion grants. At national level, there are Innovation Partnerships, SFI grants and Innovation Vouchers available which could support new ideas arising for the use of wool. Some Enterprise Ireland grants are also available which would cover innovative and competitive start-type businesses. Again, innovation in the use of wool and applying new technologies to help companies use wool as a biobased

feedstock is an opportunity which could attract funding. The Agile Innovation Fund is one such source if an Enterprise Ireland client were to take on such processing possibilities. These supports are all listed and included in the research section above and in Appendix 1.

Perspective on Economic Feasibility

Introduction

The economic feasibility analysis is a high-level assessment of the key economic factors that shape the current value chain and potential new markets. The aim is to understand the current situation and potential implications for developments that the Irish Wool industry and producers could take. Given the time available for this study of market opportunities for Irish Wool these will be broad analyses covering economic, environmental, and societal considerations. High level insights will be developed, and suggestions made for further study and research projects to validate propositions around wool products.

The key economic concern for producers is that the price achieved for farmers is less than the cost of shearing. Current lowest level fleece pricing from wool merchants is around €0.20/kg for lowland wool; for a fleece weight of approximately 2.5Kg provides approximately €0.50 per ewe (and likely worse for coarse wool hill sheep at possibly as little as €0.10/ewe). With shearing costs at €2-3 per animal there is a loss from producing the wool in the region of €1.50 to €2.50 per ewe. Therefore, annual shearing is really viewed as an animal welfare task and the wool a low value by-product or even an unprofitable waste stream.

In addition, from a sheep farmer's economic viewpoint, the real value from sheep farming is the lamb meat sales. Teagasc quotes an average output per ewe of €150 for lamb sales – so the wool sales contribution for Irish farmers can be less than half a percent of farm income.

The key areas for this study to review are the following:

- The wider considerations than purely economic (i.e., sustainability);
- Current value chain through to main products;
- Economic impact for Ireland exporting to the world market;
- Feasibility assessment of current and potential products.

Note on Scouring

There are currently no scouring facilities of commercial scale on the island of Ireland. There are a small number of micro-scale scouring enterprises serving the crafts industry with very small capacity. The nearest scouring plants of scale are located in Yorkshire and operated by Haworth Scouring and Thomas Chadwick's. It is worth noting that both businesses have wool merchant subsidiaries operating in the Irish market. Most of the Irish clip is processed in one of these scouring plants, with the remainder going to smaller plants in Europe or directly to the far east in greasy form. While the Irish clip makes up a small portion of the volume of wool scoured at these plants, they are working under-capacity and appear to have an interest in continuing to scour a majority of the Irish grown clip.

Based on discussions with the Department of Agriculture, Food and the Marine, on acceptance of the brief, it was agreed that the introduction of scouring at scale in Ireland was beyond the scope of this report. Many submissions and stakeholders have indicated a desire to see scouring facilities in Ireland. There are several barriers to the establishment of scouring facilities in Ireland including perceived need for economies of scale, environmental concerns, potential capital investment required and the availability of skilled labour. The last scouring plant of significant scale closed in Dublin in the early

1980's due to environmental concerns with effluent. While there have been various attempts to assess feasibility in the interim, no significant scouring ventures have materialised.

With this said, scouring is clearly a dependency for all applications mentioned in The Review & Summary Feasibility of Key Potential Products section, except for fertiliser and horticultural uses. On the other hand, one stakeholder went as far as to describe it as unethical to offshore the environmental impacts of scouring. We understand that the UK scouring plants have excellent waste management accreditations. However, to introduce a similar high-water volume-based process on a greenfield site in Ireland in 2022 and beyond appears implausible from a planning perspective. It appears that it would require that such a scouring plant be co-located with an equivalent scale water treatment facility.

Our conclusion is that any plan to develop scouring capabilities must be a long-term strategic approach using novel technological solutions. There are also many steps which could be taken with less risk to capture more of the value of Irish Grown Wool. In the short term, a large portion of Irish wool will inevitably continue to be processed in the UK. In order to capture more of the value of wool, it makes sense to collaborate within these existing supply chains and make incremental improvements. There are opportunities for improved traceability to verify the origin of Irish Grown Wool within these supply chains so that we may stand over its provenance. Collaboration could also take the form of contract scouring and blending. Using these existing supply chains while improving and promoting the brand of Irish wool in the short to medium term would be the best way to validate the decision to pursue on-island scouring or not.

European Success Stories

A 2019 study, KRUS[115], explains in detail the history and renaissance of the wool sector in Norway. Most of the wool in Norway is bought by a company called Norilia which has a controlling share in Curtis Wool. Wool is gathered in collaboration with a farm organisation, Norwegian Sheep and Goat ("NSG").

NSG receive a subsidy from Norilia to help with the collection. The wool is then graded in detail according to the Norwegian Wool Standard by Norilia. The wool is then scoured and combed in the UK, at Curtis Wool's Haworth Scouring Facility before returning to Norway for manufacture in felting, yarns and tops. Companies using Norwegian wool have become more visible in showing the wool's origin, especially by developing their own labels along with information available on their websites.

The Ullialt project, led by the Norwegian Folk Art and Craft Association, has a website that lists yarn made with Norwegian wool, which was an important contribution. The level of product and provenance awareness among employees in retail stores has increased. It is now reportedly very difficult to source Norwegian wool as most of it is used in Norway.

The Norwegian authorities have paid a subsidy for wool production under the Norwegian Wool Subsidy. Up to 2016 it covered all wool that was sent to a "wool station" after which some of the lower grades of wool were omitted from the subsidy scheme. The value of the subsidies is in the region of €4/kg of dry, skirted wool free of faecal matter. This incentivises sheep farmers to better present wool for sale and discourages dumping.

Iceland also has a functioning value chain for wool with much of the wool scoured and used within the country and used as a marketing theme for tourism. Hand knitting is a strong tradition in Iceland, and this suits the type of wool produced. Sweden has a small but vibrant wool industry with its own scouring plant and numerous mills.

It is worth noting that in each of these examples the grade and volume of wool produced puts them at even more of a disadvantage, yet they have still managed to create some value for wool-based products. With the correct support mechanisms, Irish Grown Wool could experience a wool renaissance.

Destination Market Volumes for Irish Wool and Predictions

Most Irish Grown Wool is sold to merchants at or near the farm gate, and there is very little publicly available data available on the value chain of Irish Grown Wool. For the purposes of this report estimates based on discussions with industry participants were incorporated as solid end-market use data for Irish wool was not readily available. As a result, it is recommended that further study / data collection is pursued to understand how Irish Grown Wool is used and how and where value is added to the raw wool. This data will better enable the development of well-grounded future plans to drive expansion into higher value markets, and the commercial impacts of subsequent implementation tracked to enable return on research and development investment to be properly assessed.

The total Island of Ireland clip is estimated to be around 7 thousand tonnes (7 million kgs) which is estimated based on 2.64m ROI ewes (Census 2020) and 968k NI ewes (DAERA Sheep Census 2021) at 2kg average fleece weight. Further data on the breakdown of the end uses of Irish wool is not well researched since once it is exported it is generally blended with wool from all over the world. Further analysis could be performed based on the various grades of wool produced in Ireland and their corresponding end uses. Anecdotally we know that most Irish wool is greater than 32micron fibre diameter and was mostly used for carpet in recent decades.

The estimate for current destination uses of Irish wool is depicted in the figure below:

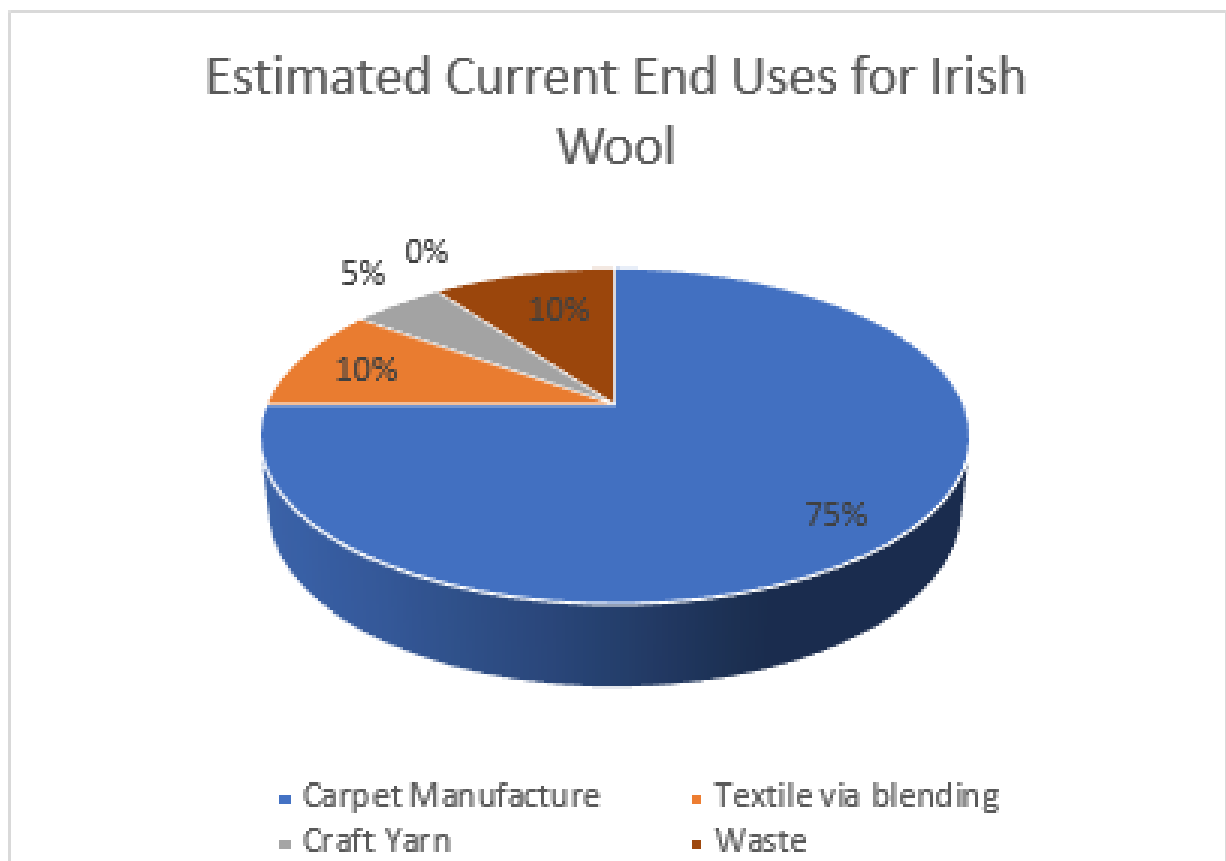


Figure 7. Estimates of current end use for wool in Ireland.

A future potential plan which recognises how the impact of a continued trend in the fall in carpet volumes could be more broadly spread and developed, as the marketing strategy for Irish Grown Wool is indicated below for illustration:

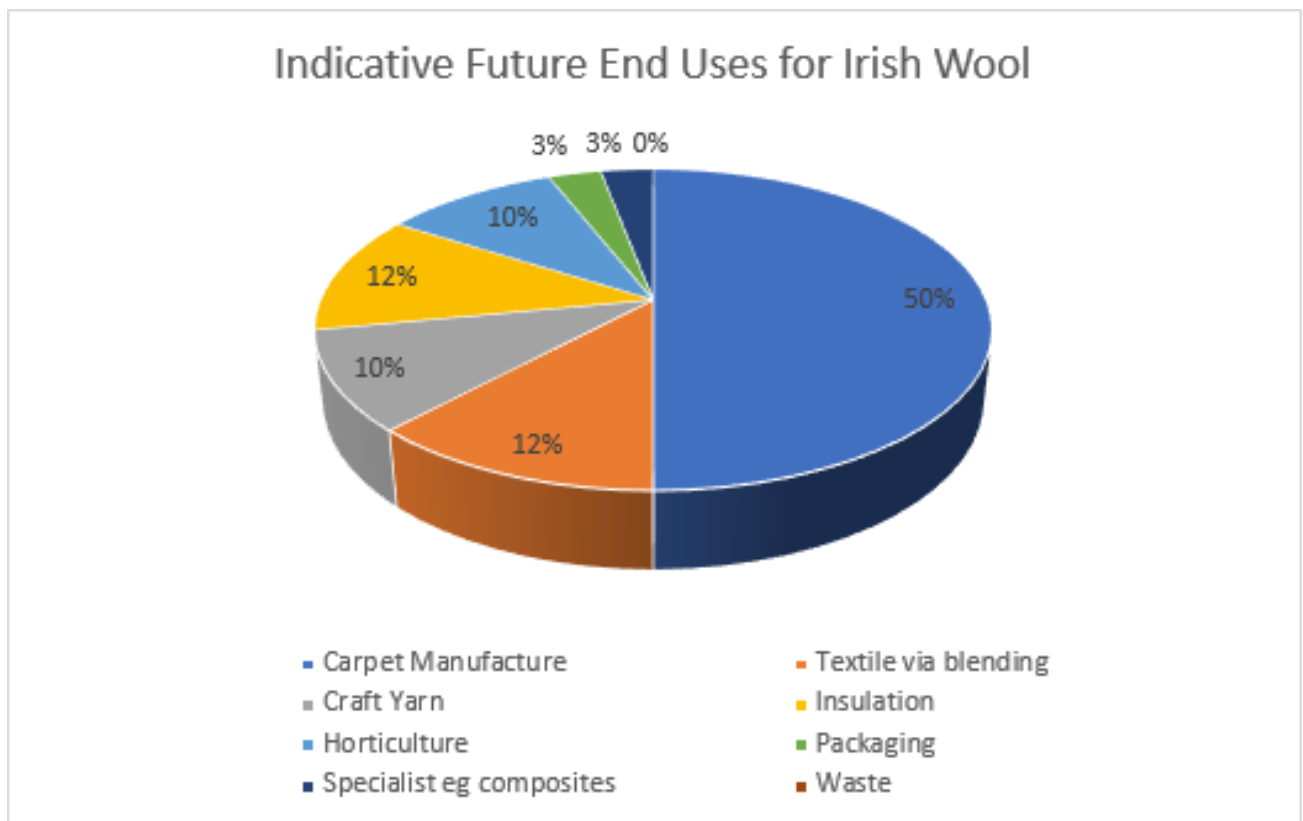


Figure 8. Estimates of potential future end uses for wool in Ireland.

The future potential are indications based on the recommendations of this report. These assume a shortening of the value chain to a number of direct uses in Ireland that would take the appropriate clip qualities. A modest increase in the proportion going to higher value markets is suggested based on a greater focus provided by a dedicated Irish Grown Wool marketing, traceability and building the quality, value, and branding of Irish Grown Wool across a range of uses.

Sustainability and Environmental Footprint Review

The broader considerations when reviewing sustainability fall into three categories of Environment, Social/ethical and Economic. These align with the 17 UN Sustainable Development goals that the Irish Government have adopted:

<https://www.gov.ie/en/policy-information/ff4201-17-sustainable-development-goals/>



1. Environmental / Climate Change Considerations

Wool is a natural product and has been used for centuries by humans as a warm insulation material in clothing, bedding and even housing. That is not to say it does not have an environmental or carbon footprint, but it is part of nature's shorter-term cycle than for example fossil fuel-based products.

The IWTO present the following environmental positives for wool products:

- Sheep are part of the natural carbon cycle, consuming the organic carbon stored in plants and converting it to wool. Fifty per cent of the weight of wool is pure organic carbon;
- Wool products have long lifespans, meaning they are used or worn longer than other textile fibre products;
- Wool textile products tend to be washed less frequently at lower temperatures which has a lower impact on the environment;
- Wool is readily recyclable: with a market share of 1.3% of all textile fibres, wool claims 5% within the recycled fibres market share;
- Wool biodegrades readily on land and in water – as a protein-based fibre, wool does not contribute to microplastic pollution.

Completing a full environmental / carbon footprint analysis would be a standalone research project, but a good example has been carried by Wiedemann et al (2020)[116] on environmental impacts associated with the production, use, and end-of-life of a woollen garment. This paper studied the

whole life-cycle from production through processing to retail and consumer use, including end-of-life. Included in the study were greenhouse gas emissions, fossil fuel use and water stress.

In summary, the most influential factor in reducing garment impact was usage, i.e., the number of times the garment was used and opportunity to recycle/reuse. Thus, a significant factor is left with the consumer to retain and use the garment for a long lifespan – the opposite of fast fashion.

This comprehensive analysis of the wool lifecycle from cradle to grave is a useful reference point, but it does not specifically compare with other garment examples, for example synthetic alternatives. However, this paper notes some comparative benefits, and these are included below with other sustainability benefits of wool.

Environmental benefits of wool over competing textiles (e.g., synthetics, cotton):

- Natural product with long history of use;
- High insulation properties;
- Maintains coolness as well as heat;
- Continued performance in wet conditions (moisture repellent);
- Breathable and Odour resistant (requiring few washes);
- Recyclable;
- Will eventually rot away;
- No microplastic contamination of waterways/seas;
- Has heritage and specific sheep breed interest;
- Can be traced back to specific farms (and thus farming practices in use);
- Farming process not as highly reliant on water use as is cotton;
- Sheep generally use less favourable land and do not displace arable/food producing land;
- Sheep farming can be low intensity, thus allowing for biodiversity.

A significant debate for wool's carbon intensity is whether wool is categorised as a Category 3 Waste By-product in the production of lamb meat. If not, then the carbon dioxide and methane emissions from sheep farming and indeed any land use change impacts might need to be included. This classification is critical to make for a fair allocation of the farming impacts between meat, as the main high value product, and wool as the (waste) by-product that is removed from ewes as an animal welfare activity.

2. Social / Ethical Considerations

These are important considerations to understand the wider contribution that wool products make to its communities. Sheep farming has been a feature of Irish agriculture for centuries and in some hilly and low-quality land areas is one of very few viable farm products. It has therefore supported many families in these traditionally remote areas with marginal quality land.

In addition to the sheep farmers, there are traditional woollen garment, rug and carpet producers across Ireland that rely on the production (or import) of wool. Finally, there are retailers and sellers across the country that focus on or include wool products in their offerings. This extends the number of people and businesses that are dependent on the continued profitable supply of wool to the market.

It must also be borne in mind that a large proportion of the national flock lives on the hills and lowlands such as the Western Seaboard and the Wild Atlantic Way and from Kerry to Donegal which are key tourism areas. The sheep is an iconic emblem of the Irish Tourism sector, thus, there is a related opportunity for wool-based tourism activity and incremental revenues for local communities in these typically disadvantaged areas with highly seasonal income flows from tourism and fishing. There is a growing trend towards activity-based tourism, including specialist tour groups of knitters and weavers, who seek destinations and experiences aligned to their hobbies and interests.

Wool shearing every April/May essentially happens ahead of the busy season for tourism and fishing and the wool can be processed after the busy season, thus generating potential incremental income to rural communities in the off season.

Animal welfare is a vital point to consider; the reason to continue shearing ewes (considering that there is no profitable value in the fleece) is for the sheep's welfare. If the fleece is not removed in the early Summer, the coat will become hot and uncomfortable for the animal causing discomfort and possible harm. The wool must be removed and is done by professional shearers taking care to do so without harm or distress to the ewe.

Ultimately, the greater proportion of the value chain (wool grading, scouring, and processing) that can be carried out close to the location where the sheep are shepherded, the better the relative socio-economic outcome. In particular this should enhance the probability of a core objective of this report brief, to optimise the value accruing to the primary producer sheep farmer, being achieved in the long run. In an ideal scenario, research projects will devise an environmentally acceptable scouring process that can work economically at modest volumes in regions where the wool is grown.

3. Economic Viability

Current Irish wool pricing is not making it an economic activity in itself. Only in large dedicated thin fibre flock herds (producing the higher value merino or cashmere varieties), such as found in Australia, justifies sheep farming dedicated to the production of wool. Elsewhere, including Ireland, it is therefore a by-product of producing meat. As such it is likely treated on-farm as a cost and there has been little incentive in recent decades to present the wool in a manner to maintain quality, avoid dampness, and to separate low quality/contaminants. This can further reduce its value and perpetuate the issue, whereby the merchant's minimal price for all wool presented, regardless of the quality and intrinsic value of the wool involved, creating further resentment among the primary producers and loss of job satisfaction.

Building a higher respect and perceived value in the product could assist the whole value chain. A more motivated primary supply chain with a higher end-use value would lead to greater care and attention on-farm when shearing and storing and also in distribution to processing and end use. Such triggers for increased respect could be broader than just value per Kg – for instance there being end uses in house insulation that improved comfort and energy efficiency of homes, displacement of imported plastics in packaging, removal of micro-plastic and non-recyclable waste and retaining produce for the home market that displaces imports.

Communicating these positive messages and building a story around the value and future for wool in a range of short distance, circular bioeconomy uses will improve perception and, through this, quality.

Value Chain Analysis

The value chain from producer to end product has a common start and early phases with variants in the latter stages to final consumer. The value chain steps are presented as follows:

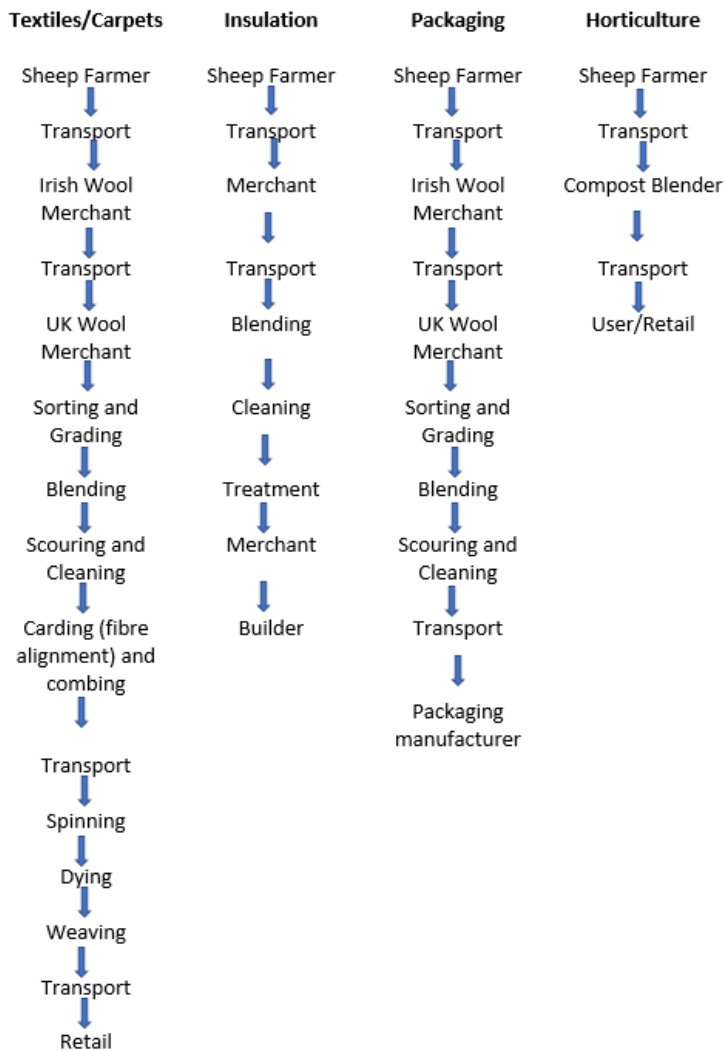


Figure 9. Illustration of value chain for target sheep's wool markets.

1. Value Chain for Textile Product:

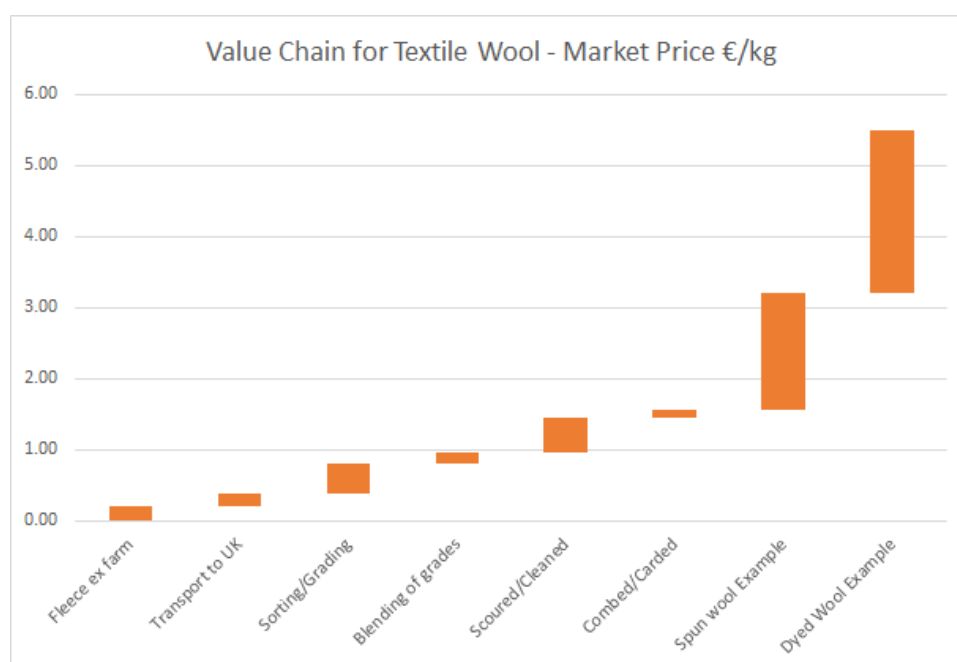


Figure 10. Illustration of value chain for wool textiles.

The value chain as estimated and presented for Textile wool demonstrates the small proportion the farmer receives for Irish quality wool (currently as low as €0.20 / kg – but is higher for higher grades of wool) versus the grading/processing and marketing as a finished product for weaving. Should it go into a retail garment selling for example at €50 at a weight of 300g, the price per Kg increases to over €150/Kg. Taking estimates through the processing cycle, the scoured/cleaned wool has increased its value to approximately €1.60 per Kg – potentially an eight-fold increase, though there would be some yield losses (potentially 30%) along the way.

Beyond this, the spun wool value will depend on the value of the blends being included cost of the dyes being applied. For Irish wool this stage makes quite a difference when higher grades of wool are incorporated. This is necessary in clothing textiles where the softer, smaller diameter threads are desired for comfort against the skin. Much of the global market in finer wools come from the Australian and New Zealand farms. Australia for example produces 294 million Kg from 67 million sheep:

Summary of Australian wool production

Parameter	2019/20	2020/21	Change y-o-y (%)	2021/22 Third Forecast	Change y-o-y (%)
Sheep numbers shorn (million head)	68.6	66.9	-2.5%	70.0	4.6%
Average cut per head (kg/head)	4.13	4.40	6.5%	4.54	3.2%
Shorn wool production (Mkg greasy)	284	294	3.7%	318	8.0%

Note: Totals may not add due to rounding. Source AWTA

Table 2. Summary of Australian wool production.

While the majority of this wool goes to the Eastern market, it is a price driver globally. There is a significant premium for quality as demonstrated by the auction prices in Australia for clean wool of different grades where the finer sub 20 micron fibres make more than €10 per Kg raw – 6 times the coarse wool grades of Ireland.

Recent Australian auction prices for clean wool grades:

Australian Wool prices w/e 11 February 2022

AWIS

Micron	AUDc/kg	€/kg	AUD/€ 0.636
EMI	1422	9.04	
17	2610	16.60	
18.5	1900	12.08	
20	1400	8.90	
22	1300	8.27	
26	730	4.64	
28	420	2.67	
30	360	2.29	
32	260	1.65	

Table 3. Australian wool price index as at Feb 2022.

The above table shows the Australian prices for context, with reports too that Turkish wool can be supplied to UK markets at £1/Kg cleaned, further shows that the market is highly competitive and driven by global commodity pricing.

The opportunity for producers to achieve a larger slice of this market opportunity is to maximise quality and niche market premiums – for example certified organic wools were reported to be attracting a £1 per Kg uplift in the January 2022 British Wool auctions. Likewise breed specific sales with clear traceability are achieving market-beating pricing (e.g., reports of Bluefaced Leicester at £4.50/Kg).

There is also opportunity for producer organisations to capture more of the downstream value chain. This may be in co-operative merchants, distributors and marketeers as seen in the UK's British Wool (previously their Wool Marketing Board) that represents 35,000 farmers dealing with grading, processing, and selling to the range of users in the global market. A further example in Ireland is a recent initiative by the Galway Wool Co-Op:

Case Study - Galway Wool Co-op

The Galway Wool Co-op's mission is to develop and promote a brand for wool from the Galway Sheep ensuring that its members have a route to market that maximises the return for their produce through promotion, education, and the development of the brand.



The Galway Wool Co-op was established in 2021 to promote the Galway Breed of sheep and its wool. It is a new farmer-led venture for the promotion of wool from one of Ireland's indigenous sheep breeds. The wool produced by the co-op members will be marketed as "The Galway Wool" - a snow-white fleece with excellent lustre. This wool will no longer be treated as a by-product, but form part of the circular bioeconomy, to the benefit of its producers, consumers, and the environment.

Significant traction was gained early in existence of The Galway Wool Co-op, with the discovery of its first customer, and a successful LEADER funding application. Donegal Yarns was the first customer of the Galway Wool Co-op with the purchase of 5,000 Kg of greasy wool from purebred Galway Sheep at a price far exceeding market value in June 2021. Sixty percent of this sales price went directly to the primary wool producers. This deal is a vote of confidence from Donegal Yarns and is based on a commitment from The Galway Wool Co-op to launch a marketing campaign to promote "The Galway Wool". Funding for this marketing campaign was provided by Galway Rural Development following a successful application to its LEADER program.

A Board of Directors elected by its members manage The Galway Wool Co-op on a voluntary basis. An e-commerce platform and social media presence has been established as part of a strategic marketing campaign which was designed by a professional brand consultant. The first "Galway Wool Meitheal" took place in June 2021 where member-suppliers gathered to present their wool to the customer in a gesture of community and collaboration.

The Galway Wool Co-op aims to be a catalyst for change in the Irish Wool industry, raising the profile of Irish Grown Wool and battling the perception of wool as a by-product.

2. Value Chain for Insulated Roofing Product

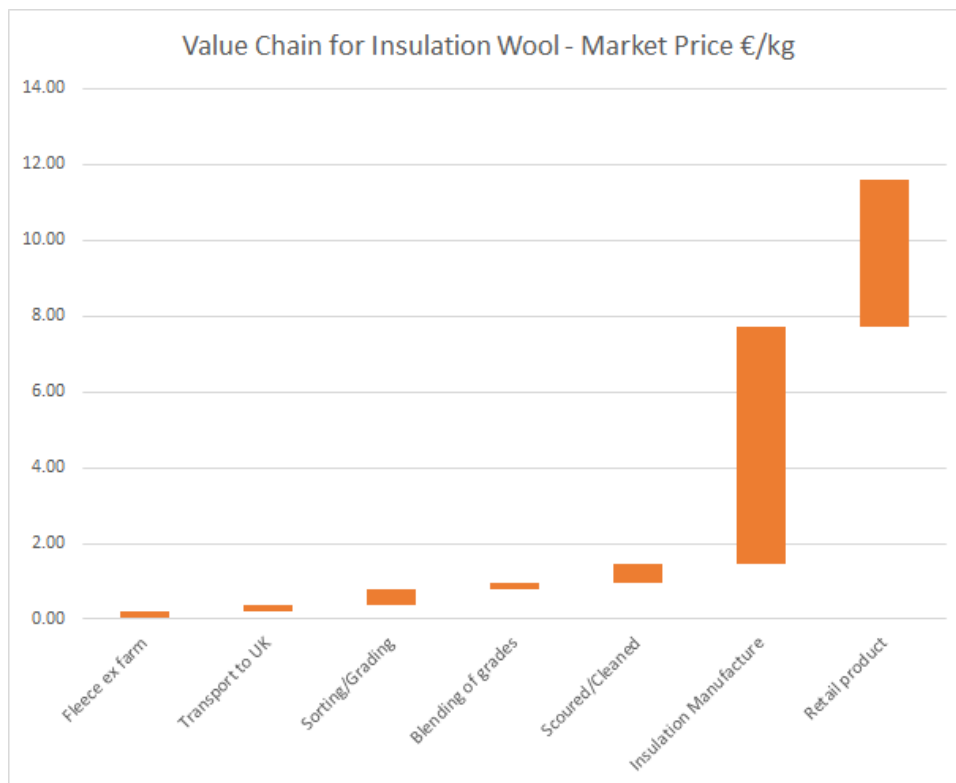


Figure 11. Illustration of value chain for wool insulation.

The estimated value chain for an insulated product, such as roof insulation roll, is shorter than the textile chain. However, in its direct routing it is not so different to the textile chain as much of this product is understood (at this time) to need a similar cleaning process. This is to remove contaminants that could attract undesirable pests. It does not require spinning and dyeing steps, and comes out at around €1.44 per Kg based on the estimated costs of transport and processing.

However, it is also understood that the insulation manufacturers purchase the offcuts, floor droppings and wool dust that the factory cannot process into yarn – so for this volume they will be buying at a rock bottom price. As volumes of wool based insulation grows (reports of a 4-fold increase in recent years in the UK) the manufacturers may exhaust scraps and need regular supply, albeit the lowest grades – so this might prove an opportunity for Irish producers.

Given its sustainability, fire resistance and humidity/moisture regulation, wool's inherent qualities may help growth if marketed as such. In parallel the insulation refit programmes being launched should help support growth and eventually pricing for these lower grades (e.g., coarse mountain wool). Thus, cleaned wool pricing would replace the scrap pricing they are paying now. However, this is not going to provide a premium outlet for wool unless it was possible for the producer, through, for example, co-op manufacturer, to manufacture the insulation.

Some additional stages are involved in making the insulation, mothproofing being a core treatment. The main approach is chemical treatment using borate at low concentrations. Other treatments have been used, one of these at commercial scale is Ionic Protection which according to manufacturer, changes the structure of the fibre to repel moths; given the long life of houses further testing /

guarantees may be needed. The second addition is the inclusion of polyester fibres – while this reduces the natural credentials, they have the effect of providing greater structural support to the insulation.

With cleaning, treating, blending, cutting, and marketing this would be a specialist operation to set-up, but if an operator was interested this could be an opportunity in Ireland given the expected growth.

These protection and blending processes add significant cost to the manufacture of wool insulation and can lead to costs up to four times as much as the cheapest glass-based insulation. This would appear to leave little chance to increase the proportion paid to the wool provider.

At these premiums it is (currently) a specialist product for sustainability, fire conscious or health focussed customers. There is also little room to develop a unique or specialist wool as it is the waste wool that is currently used.

However, if a simpler treatment process could replace the scouring done in UK/Bradford and a manufacturer was to decide to make the product in Ireland, this would eliminate the transport costs. With the significant retrofitting programme to insulate Irish homes over the next 15 years this is a potential opportunity certainly worth further research and consideration.

3. Value Chain for Compost Product

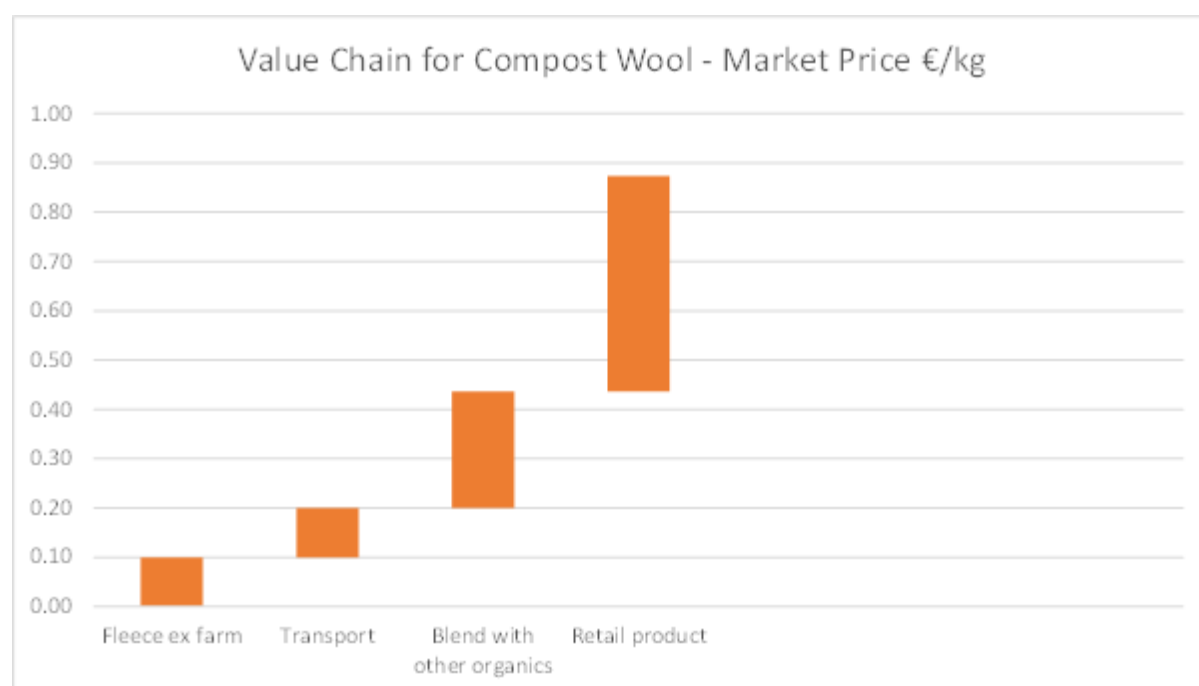


Figure 12. Illustration of value chain for wool compost.

The value chain for composting wool is hard to determine at this stage and values used here are only for illustration. As an example compost is sold under the brand, Dalefoot; they have a range of composts made with an (unknown) mix of wool, bracken and comfrey harvested on their Lake District farm. These are sold in 30 litre bags (as well as bulk) for £11.75 each as a specialist peat-free product. The quantitative performance of this product is not known, but commentators on the website are impressed.

A full study for what the best mix would be, the time required to compost and how it would be marketed is required to fully test this market opportunity. With the demise of the Irish peat business this looks like it could be an opportunity to explore. Given that this does not require transportation to UK for cleaning, is tolerant of the sometimes-poor quality ex-farm material and does not need a high grade of wool, it is certainly an outlet for some lower rung output.

With the overall product not achieving the economic prices of the better grade examples (although it should be said that other lower valued inputs go into the final mix) there does not appear to be a high value opportunity here, but further analysis might prove it still worthwhile for the less desirable portion of the clip – and in doing so raising the price available for the quality portion.

Impact of Exporting Raw Wool to Global Markets

Supply Chain and Logistics Cost

As has been seen in the global pricing similarities for wool, the market is truly international, and wool is shipped around the world by merchants for processing and to weavers and onto eventual consumers. In a more sustainable or local circular economy this may not always be desirable, but for the bulk of wool this is the present situation.

All Irish wool seeking markets in textiles, carpet weaving, insulation and other higher value uses needs to be graded and cleaned. This invariably means being shipped to the UK where the market is far larger and the two large scale scouring plants are based. Industry consolidation and investment has left these as the only two options in Britain/Ireland (there is additional plants in Belgium, Turkey and Belarus). The UK plants are working at an estimated half capacity (one of two lines operating) and at 5 day cycles; significant further capacity could be utilised if needed.

There is a cost in pick-up from farm that the merchants take for Irish wool; they store and sort / grade before either selling onto buyers or sending to the cleaning process themselves. After cleaning there is further transport for dyeing/weaving/garment or other uses. The transport cost to UK is around €0.18 per Kg and the return €0.15 per Kg (in tighter compressed bales).

The presence of competing wools (or higher value blending merino grades) from worldwide sources has been present for many years, however recent very large increases for shipping container freight particularly from East to West – or indeed availability of the containers has slowed this flow. It is expected to recover, but perhaps at a higher rate which could have a long-term impact and provide a slight benefit to local sourced wool for local markets.

For certain consumers and for products seeking a much more sustainable story this global market and high degree of shipping is again an opportunity for producers that can demonstrate their shorter supply chains. For Ireland this would be a limited market, but with good traceability data and a story of locally produced breeds, niche craft markets could offer an opportunity. Using blockchain technologies that tell a buyer the wool's provenance and building the message around that brand or product's heritage can achieve higher market interest and value.

Impact of BREXIT on Exporting Irish Wool to UK

The current situation is quite fluid and not all arrangements have either been agreed or set in place/implemented yet. However, at present there is no custom duties on wool exports to the UK, although VAT at 20% will be applied to the invoice total. We do not expect to see a tariff being applied here unless it places the indigenous UK product under threat. As tariffs are normally set by trade agreement or work in a retaliatory way, if either side doesn't implement these to protect their indigenous market, then it remains a tariff free trade.

As regards re-imports into Ireland/EU of potential products: insulation and compost do not have tariffs at the moment. However, if clothing contains 85% or more wool then a tariff of 8% is applied.

No physical checks are required, but wool is considered to be a product of animal origin (POAO) and so it will have to travel to the UK accompanied by Certificate of Origin and Health certificate issued by DAFM.

For returning raw or scoured wool there is the reciprocal requirement (e.g., this is a problem when the wool is scoured in the UK and returned to Ireland for processing) to come with a UK Dept of Agriculture Health certificate and certificate of origin. Technically it is now regarded as UK wool, unless its off loaded, scoured, and reloaded in a bonded warehouse.

The implications from Brexit for the free movement of animal products from Ireland to UK for processing and then back, are going to become more complicated as certificates of origin, Department of Agriculture health certificate documentation and customs declarations are required in both directions. Increasingly this will put pressure on the raw material price as these costs are unlikely to be accepted by processors or consumers while other sources (e.g., UK) remain available. A process hopefully may be introduced that deals specifically with this problem in similar processing situations as it not only affects wool. But if these issues cannot be addressed it raises the interest in making Irish produced wool able to be processed in Ireland for Irish markets.

Opportunity to Displace Imports / Island of Ireland (IOI) Approach

At present the wool that returns from UK scouring plants is indistinguishable from British wool (which is a blend from many other countries as well). Product for weavers, insulators, carpet makers or even horticulturists are in effect importing either the raw material or the finished product.

Thus, there is an opportunity to displace these imports with a truly Irish sourced wool product. In the first instance this will be coming back into the country from the UK based scouring mills and possibly other processing, but with appropriate traceability and certification management, an auditable Irish product could be achieved. This process would not be without cost; farm tracking (using herd and sheep numbering) would be required to trace back to the flock, recording through the distribution process, avoiding any mixing with non-native sources, ensuring a suitable batch was cleaned, processed, and repacked separately and then returned for Irish consumption. All this would add a margin that would of course need to be recouped by the 'Irish' brand.

This assumes that the constituent quantities are available in Ireland, if not then the product would need to be presented with a "% Irish" claim. Such decisions about what is acceptable or valuable to Irish retailers would need further investigation and comparison to the additional costs involved.

Review and Summary Feasibility of Key Potential Products

Key Market	Product	Market Size Est.	Economic Feasibility Analysis - Summary			Research needs	
			Value to Grower	Timescale	Import Substitution	Further areas to investigate	Long-term vision
Horticulture	Wool based compost	High	Low	Medium	Medium if replacing imported peat	Potential large outlet for lower quality wool, determine combined value with other compostable materials	Volume end market for the low quality wool that saves exporting to UK and devaluing the wider Irish clip
Horticulture	Fertiliser Pellets	Medium	Low	Medium	Low	Specific crops wool can fertilise particularly well	Unique benefits
Composites	Concrete	Medium	Low	Long	Low	Technical suitability and benefits for eco building	Part of the low carbon building future
Composites	Resin/fibre composites	Low	Low	Long	Low	Technical benefits wool has over current materials	Wool as an alternative to carbon fibre, polymers, glass, etc in specific use cases
Horticulture	Wool slug repellent pellets	Low	Low - Medium	Medium	Low	Actual effectiveness vs slugs	Unique benefits

Key Market	Product	Market Size Est.	Economic Feasibility Analysis - Summary			Research needs	
		Volume Potential	Value to Grower	Timescale	Import Substitution	Further areas to investigate	Long-term vision
Insulation	Thermal house insulation	High	Low - Medium	Short - Medium	High - displace Welsh/UK product	Ability to tie grants to Irish (or at least EU) product, full feasibility analysis and implementation path	Farm, treat and assemble wool insulation products on IOI for IOI use saving long distance delivery chains for a low density product
Packaging	Thermal insulation packaging	Low	Low - Medium	Medium	Low	Real market potential or a niche product for eco-labelled goods?	Natural, biodegradable alternative to wasteful plastic
Textiles	Carpets	Medium	Medium	Current	Medium	Reducing cost, maintaining Irish origin through offshore treatment process	Potential to bring treatment process to IOI
Textiles	Home interiors	Low	Medium	Medium	Low	Establishing product range, market and requirements	Specific premium uses in furniture for wool
Filled Products	Mattress toppers	Medium	Medium	Medium - to build market size	Medium - for Irish makers	Review supply chain for mattress manufacturers and how Irish sourced wool can be used	IOI supply to bulky products less suited for long distance delivery

Key Market	Product	Market Size Est.	Economic Feasibility Analysis - Summary			Research needs	
			Value to Grower	Timescale	Import Substitution	Further areas to investigate	Long-term vision
Filled Products	Pet bedding	Low	Medium	Medium - to build market size	Low	Potential manufacturers and attractiveness of Irish branding	Specialist circular economy product
Filled Products	Mattress filling	Medium	Medium	Medium - to build market size	Medium - for Irish makers	Review supply chain for mattress manufacturers and how Irish sourced wool can be used	IOI supply to bulky products less suited for long distance delivery
Composites	Furniture	Low	High	Long	Low	Determine the specific benefits that can attract a premium price	Unique properties from wool valued in range of home furnishing products
Textiles	Tweed	Low	High - for quality / traceable	Medium - to build traceability and Irish brand	Medium	Value of an Irish branded tweed, availability of suitable yarn, optimum quality mix, establishing traceable supply	High-end Irish wool branding
Textiles	Craft Yarn	Low	High - for quality / traceable	Medium - to build traceability and Irish brand	Medium	Establishing traceable supply	Local specialities in demand, eg Galway Wool

Key Market	Product	Market Size Est.	Economic Feasibility Analysis - Summary			Research needs	
			Value to Grower	Timescale	Import Substitution	Further areas to investigate	Long-term vision
Textiles	Apparel	Low	High - for quality / traceable	Medium - to build traceability and Irish brand	Medium	Steps for building branded Irish wool, quality required	High quality designers and manufacturers using Irish wool brand
Filled Products	Pillows	Medium	High - if based on health	Medium - to build market size	Low	Investigate further claims for health benefits and wool specification needed	Clear health benefits from wool to attract a premium
Filled Products	Duvets	Medium	High - if based on health	Medium - to build market size	Low	Investigate further claims for health benefits and wool specification needed	Clear health benefits from wool to attract a premium
Insulation	Air purification Panels	Low	High (as niche, specialist product)	Long	Low	Requires deep market research / development	Specialist product
Horticulture	Hydroponic growing media	TBD	Low - Medium	Long	Low	Research the potential opportunity from using wool in media for vertical farming etc	Unique benefits

The following schematic seeks to give the reader a sense of the product value relative to a 1KG input of raw wool. A point of emphasis here needs to be that, while the product value of Compost etc is lower, the fact that it does not require to be scoured means that it is a much simpler new/scalable product opportunity and timeliness to an impactful progress should be much shorter. Overall the development of unscoured products at scale is attractive as the level of complexity and capital investment should be significantly lower than for the higher value products involving scouring and other treatment/processing

There is also an environmental benefit in that localised pelletising or composting could significantly reduce the carbon footprint of these bio products as transportation will be minimised and the need to handling effluent etc arising from the scouring is naturally avoided.

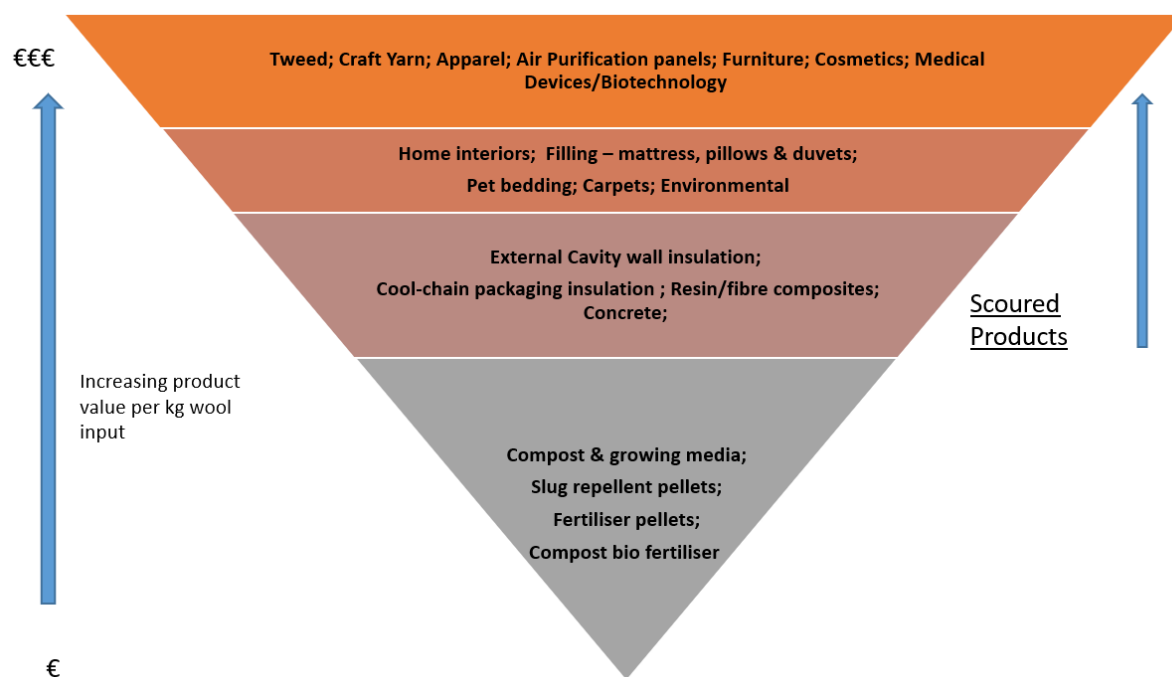


Figure 13: Summary of product value that can be achieved from use of wool as a feedstock.

Conclusions of Feasibility Analysis

The economic analysis of the wool end-use markets demonstrates the challenges for the Irish producer when they receive as little as 20c per Kg for lowland wool. These are global markets that have depressed the price as availability of wool from many geographic sources chase fewer outlets. Providing better quality wool from the farm would help achieve better prices, taking ownership of some of the early-stage sorting/grading would also lift the quality being presented to merchants/customers. Developing specific brands, such as the Galway Co-Op are attempting, is another way to gain margin but will require traceability controls and marketing investment.

New markets are also of interest that can use wool's undoubtable qualities – insulation is one where the circularity, sustainability and natural credentials should earn a premium in the large market for retrofitting homes – and if this could all be achieved without the material leaving the island then that will save on transporting a low-density product.

At the low-end of the market, the opportunity from compost and horticulture requires further investigation – as a new market, but also as the potential solution for the low-quality fibres, which will allow the proportion of better wool grades to rise and bring with it the value of the Irish wool going into processing.

Finally, scientific, and industry-wide research into specialist composites uses or component strengths of wool should continue to find new streams of value for this natural product.

Conclusions & Recommendations

This report contains proposals relating to a range of sectoral level strategic opportunities and proposed research projects. A core selection of these is included below. These represent those steps that are required to establish Irish Grown Wool as a sustainable and progressive sector. The research projects section provides a range of opportunities for innovation in the wool sector.

Sectoral

Short term

Establish an All-Island Irish Grown Wool Council (Industry/Producer Group) with responsibility for:

- Brand development for Irish Grown Wool;
- Marketing of Irish Grown Wool;
- Standards development for Irish Grown Wool;
- Determining feasibility of establishing a wool testing facility on the Island of Ireland;
- Establish Wool Hub;
- Establish Research and Innovation Cluster as a contact point for R&D as well as driving an R, D&I wool agenda.

Implement training:

- Improving wool handling, presentation and sorting at farm level;
- Provide training for wool grading;
- Create apprenticeship model for wool sector;
- Gather data on Irish grown wool;
- Prepare a Life Cycle Assessment (LCA) of Irish Grown Wool.

Medium to Long term

- Determine feasibility for scouring plant development;
- Determine feasibility for wool testing facility;
- Establish wool co-operatives;
- Educational programs to promote Irish Grown Wool;
- Determine potential to re-classify wool in terms of its animal by-product status;
- Incentivise use of natural fibre products.

Product Development

1. Horticulture:

Composting

- Priority for compost applications are dags and wool not suitable for scouring, or where farmers don't want to pay for the cost of scouring;
- Composters must have a licence for accepting class 3 animal by-products;
- A list of these composters should be provided to sheep farmers to provide an easy route to composting;
- In the absence of a unique selling point for sheep's wool compost, gate fees to get rid of sheep's wool will be a barrier to this option;
- R&D and branding may provide a route to adding value to sheep's wool compost.

Pelleting

- Clarity must be provided on whether pelleting wool is compliant with Regulation (EC) No 1069/2009;
- Pelleting may be an easy route for use of sheep's wool;
- Provide grants for co-ops and groups of farmers to invest in pelleting machines.

2. Construction

Insulation

- Wool required for insulation must be scoured, this adds cost;
- Waste wool collected during grading is the most cost-effective raw material for insulation; given the cost to produce the insulation, graded wool may be too high a cost raw material for insulation;
- The manufacture of Irish Wool insulation with a lower density and a higher thermal conductivity, is less suitable for use where greater space is available, e.g. in attic spaces. It may appeal to a smaller market because of the price difference between it and glass fibre products which achieve similar U value;
- The production of an Irish Wool insulation with higher density and lower Lambda value would seem the most likely route to market. Typically, this type of dense insulation is used in external cavity walls. The price difference here narrows significantly with competing glass fibre products of similar density and Lambda values. If price trends on glass fibre products continue to rise as they have in the recent past, then the gap should close further. It may still require some form of grant or subsidy to gain mass market uptake;
- The cost the market will bear is too low for it to be utilised here; incentives or grants would need to be in place to provide the opportunity for Irish wool to be used in insulation.

Cement

- We have had some indications that there may be a role for wool in applications such as quick drying cement where the wool staples offer stabilisation benefits.
- Further research in this area should be encouraged.

3. Packaging

- There are a selection of companies that have already advanced technically in this space; funding should be provided to determine freedom to operate within the current patent landscape, while providing for high performing product.

4. Filled Products

Bedding/Mattresses

- Leverage from 'Irish Grown Wool' brand to drive uptake of wool bedding products;
- Determine health benefits of use of wool in bedding products;
- Implement NSAI standards for wool in order to provide consistency and clarity in terms of its performance.

5. Textiles

- Establish PGI to generate a higher value market pull for Irish Grown Wool >30µm;
- Fund R&D to establish processes to produce a smoother fibre at >30µm;
- Leverage from 'Irish Grown Wool' brand to drive uptake of wool textiles.

6. Composites

- Fund R&D to develop composites incorporating Irish Grown Wool;
- Develop partnership with high profile MNC to champion this.

7. Medical Devices/Biotechnology

- Fund R&D to determine keratin extraction process from Irish Grown Wool and its functionality as a medical device structure.

8. Cosmetics

- Fund R&D to determine benefit of ceramides from wool for cosmetic and wound healing products.

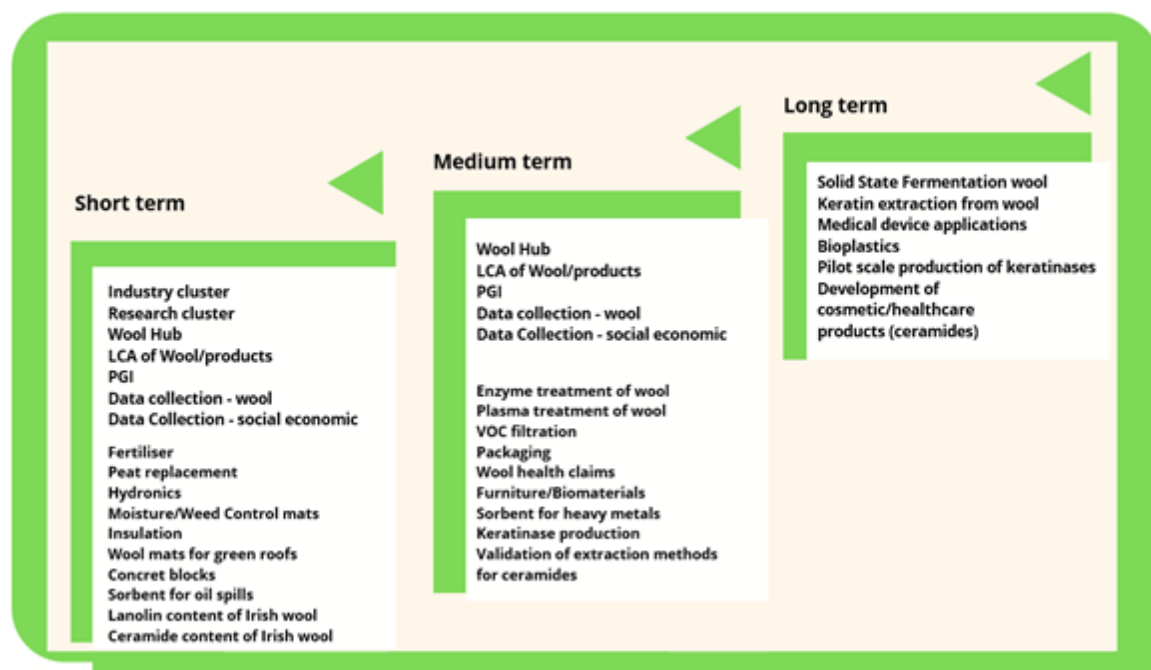


Figure 14. Illustration of core actions proposed from this study with associated timelines.

Appendix 1 Funding Opportunities

Funding opportunities are grouped below by 'entity type' and cover local, national and EU funding pathways. Funding calls are being opened and closed continuously and this review is accurate as of 5th March 2022.

General Supports

Funding Body	Launched by Dept of Enterprise, Trade and Employment
Fund	Regional Development Fund
Call Name	
Website	https://enterprise.gov.ie/en/News-And-Events/Department-News/2022/February/20220218.html
Key details	The €180m in funding will support the development and implementation of collaborative and innovative projects that can enable and sustain enterprise and employment growth in the regions. The Government has committed to nine enterprise plans, covering every region in the country. The €180m in funding is designed to generate new projects which create new jobs and help companies to grow in the region. The plans also complement Our Rural Future, the whole-of-government framework to develop rural Ireland in the coming years. The government want this to be a bottom-up approach, led by the local community, as they know what's best for their area.
Amount of funding	€180 m fund.
Key Dates	Announcement made Feb 18th, 2022.

Funding Body	Skillnet Ireland is funded from the National Training Fund through the Department of Further and Higher Education, Research, Innovation and Science.
Fund	Skillnet
Website	Skillnet Ireland Transforming Business Through Talent
Key details	<p>Skillnet Ireland is a business support agency of the Government of Ireland, responsible for advancing the competitiveness, productivity and innovation of Irish businesses through enterprise-led workforce development. Skillnet Ireland's mission is to help businesses in Ireland to be the best they can be, through innovative and enterprise-driven people development.</p> <p>Skillnet Ireland has partnered with over 55 industry bodies nationwide across most sectors and all regions to establish 73 Skillnet Business Networks.</p>
Amount of funding	Skillnet delivered upskilling and training programmes to the value of €51.2m to the Irish workforce in 2020
Key Dates	Ongoing

Funding Body	Department of Rural and Community Development
Fund	LEADER Programme
Grant	Transitional Leader Programme
Call Name	
Website	https://www.gov.ie
Key details	<ul style="list-style-type: none"> • LEADER is a rural development programme co-funded by the EU which operates a locally-led, bottom-up, approach to meeting the needs of local communities and businesses. The programme supports private enterprises and community groups in rural areas. • The Transitional LEADER Programme which came into effect on April 1 will bridge a gap between the wind-up of the 2014-2020 LEADER Programme and the start of the next EU programme, which is not likely to commence until 2023 due to delays at EU level. Key focus on building capacity in communities • A key focus of the Transitional Programme will be on building capacity within communities which have not received LEADER funding to date. • Under the Transitional Programme, the grant rate for enterprises and commercial projects will be increased from a maximum of 50% to a maximum of 75% to support enterprise development and job creation in rural areas. • Funding is delivered by 29 Local Action Groups (LAGs) in 28 sub-regional areas. These groups are partnerships of public and private entities from a defined geographical area. LAGs are responsible for local projects in accordance with the Local Development Strategies they develop themselves. • A key focus of the Transitional Programme will be on building capacity within communities which have not received LEADER funding to date. The programme will also support job creation, and projects which address the climate agenda, digital transformation and encourage rural communities to build on their existing strengths and assets.
Amount of funding	A total of €70 million has been allocated to support rural communities and private enterprises over 2021 and 2022.
Key Dates	LAGs can approve new projects from 1st April 2020 to 31st December 2022. All approved projects must be completed before the end of December 2023

Materials

Funding Body	Environmental Protection Agency (EPA)
Fund	The programme is funded by the National Waste Prevention Programme and the EPA Research Programme.
Call Name	Green Enterprise Fund
Website	EPA Green Enterprise Scheme Environmental Protection Agency
Key details	<p>Closed for 2021, new call expected in 2022. From our sources in EPA, while not confirmed it is expected that the 2022 call will be issued earlier than 2021 (approx. April / May timeframe) with a similar structure / funding as 2021 (funding may increase slightly). The summary information for 2021 is included below for information. In 2021, 7 applicants were successful.</p> <p>No information relating to 2022 is published as yet.</p> <p>2021: The EPA's Green Enterprise: Innovation for a Circular Economy programme is an annual funding programme that supports organisations to develop and demonstrate new circular economy approaches. In 2021 for it aimed to support Irish businesses develop circular solutions in product and service design, production, distribution and use of resources (including resources and raw materials)</p>
Amount of funding	<p>The 2021 call had a fund worth €625k. In 2021, applications for funding in the range of €50k-€100k were invited to apply.</p> <p>In 2021, the maximum amount of funding available was €100,000 per grant award. Grant aid was provided on a shared cost contribution basis, from 25%-95% of the total eligible project costs incurred.</p>
Type of Action	
Key Dates	New call for 2022.

Eco-system SME supports for innovation with wool

Funding Body	Enterprise Ireland
Fund	Innovation Partnership
Call Name	
Website	Enterprise Ireland
Key details	<p>The company must be a registered client of one of the following state development agencies: Enterprise Ireland, IDA Ireland, Local Enterprise Office, Údarás na Gaeltachta.</p> <p>The company must have the full support of their assigned Development Adviser/Agency Contact to participate in the programme. This support must be confirmed before any application forms are submitted. Clusters of companies and/or research institutes are welcome to apply to the programme.</p> <p>Enterprise Ireland Innovation Partnership Programme provides grants of up to 80% towards eligible costs of the research project. Funding from Enterprise Ireland will normally not exceed €200,000. Exceptions to this limit may be made for established clients of Enterprise Ireland and other State development agencies where the Innovation Partnership project and the follow-on activity will clearly lead to a significant increase in the company's employment and/or sales and exports.</p> <p>Grant funding to projects involving early stage companies and High Potential Start-Up (HPSU) clients will normally be capped at €100,000.</p>
Amount of funding	Up to €200,000
Key Dates	Rolling Call

Funding Body	Enterprise Ireland will lead the programme with the European Investment Fund acting as fund manager.
Fund	Irish Innovation Seed Fund Programme
Call Name	
Website	Enterprise Ireland
Key details	The Irish Innovation Seed Fund Programme will provide vital capital to innovative Irish companies at the crucial seed stage and will be an important step in developing and growing the Irish equity ecosystem. Investment will be targeted and prioritised in areas such as regional development, climate change and female entrepreneurship. This Programme will increase early-stage funding for SMEs and is an important step in supporting indigenous, high innovation enterprises to reach their full potential.
Amount of funding	€90m in total (The fund programme, totalling €90 million, will be made up of a €30 million contribution from the Department of Enterprise, Trade & Employment, whilst the European Investment Fund will match this investment by providing a further €30 million. The Ireland Strategic Investment Fund will seek to co-invest with a further €30 million on selected investments).
Key Dates	Calls to be launched on European Investment Fund

General Business / Start Up

Funding Body	Local Enterprise Office (LEO)
Fund	Feasibility Grant
Call Name	<p>Priming Grant</p> <p>Business Expansion Grant</p> <p>Agile Innovation Fund</p>
Website	
Key details	<p>Local Enterprise Offices (LEOs) provide a range of financial supports designed to assist with the establishment and/or growth of enterprises (limited company, individuals/sole trader, cooperatives and partnerships) employing up to ten people.</p> <p>These include:</p> <ul style="list-style-type: none"> • Feasibility Study Grants - Feasibility Study Grants are designed to assist the promoter with researching market demand for a product or service and examining its sustainability. It includes assistance with innovation including specific consultancy requirements, hiring of expertise from third level colleges private specialists, design and prototype development. • Priming Grants – this is a business start-up grant, available to micro enterprises within the first 18 months of start-up. • Business Expansion Grants – This is designed to assist the business in its growth phase after the initial 18 month start-up period. Note: A business that had availed of a Priming Grant will be ineligible to apply for a Business Expansion grant until 12 months after approval/drawdown date of Priming Grant whichever is the later except in cases of exceptional merit and where less than the maximum Priming Grant was drawn down, and subject to the provisions in respect of 'De Minimis state aid'. • Technical Assistance for Micro Exporters • European Globalisation Fund • New Agile Innovation Fund - this new fast-track from Enterprise Ireland, gives small companies rapid access to innovation funding. It offers a fast-track approval and a streamlined online application process.
Amount of funding	<p>Feasibility Study Grants -The maximum Feasibility Study Grant payable for the S&E Region shall be 50% of the investment or €15,000 whichever is the lesser.</p> <p>Priming Grant - The maximum payable here is 50% of the investment or €150,000 whichever is the lesser</p>

	<p>Business Expansion Grant - The maximum payable here is 50% of the investment or €150,000 whichever is the lesser.</p> <p>Agile Innovation Fund allows companies, including small companies, to access up to 45% or 50% in support for product, process or service development projects with a total cost of up to €300,000.</p>
Key Dates	Ongoing

Funding Body	InterTradeIreland is funded by the Department of Enterprise, Trade and Employment (DETE) and the Department for the Economy (DFE) in Northern Ireland.
Fund	InterTrade Ireland programme
Grant	Innovation Boost (previously known as Fusion)
Website	Innovation Boost InterTradeIreland
Key details	<p>Product development and innovation is at the heart of growth but often needs costly technology support. Previously known as Fusion, Innovation Boost can provide that support by helping to fund a high calibre science, engineering or technology graduate and partnering you with a third level institution with specific expertise.</p> <p>The graduate is employed and based in the company throughout the project (12 – 18 months) with mentoring from the academic partner and InterTradeIreland Innovation Boost consultant.</p>
Amount of funding	Funding is available up to €47,400 for 12-month innovation projects and up to €67,900 for 18-month innovation projects.
Type of Action	n/a
Key Dates	Get details by emailing fusion@intertradeireland.com or by phone 028 3083 4189 (048 from Ireland).

Funding Body	InterTradelreland is funded by the Department of Enterprise, Trade and Employment (DETE) and the Department for the Economy (DFE) in Northern Ireland.
Fund	InterTrade Ireland programme
Grant	IMPACT
Call Name	n/a
Website	Impact InterTradelreland
Key details	<p>The project must address a key challenge at an Industry level.</p> <p>B2B project (cross-border) which aims to solve an industry level challenge Impact is a game-changing partnership involving a minimum of two SME companies, one in Northern Ireland, and one in Ireland, aiming to develop a key solution to an industry level problem.</p> <p>Both partner companies need to be:</p> <p>Able to demonstrate innovation maturity and capability</p> <p>Ambitious with between 5 and 250 employees</p> <p>Trading for two years demonstrating financial viability</p> <p>Focused on delivering growth through cross-border collaboration</p>
Amount of funding	50% funded up to £250k. (details: Maximum available grant is £250/€293k (at a grant rate of 50% i.e., project costs of 500k) split between companies contributing their expertise, sharing the risk and the benefits. Eligible costs include staff (existing or new hire), overhead, technical consultancy, sub-contractors, equipment, IP, testing and travel).
Type of Action	n/a
Key Dates	<p>Contact Kevin Dardis, InterTradelreland IMPACT Programme Lead Consultant</p> <p>E: Kevin.Dardis@impactprogrammeiti.com M: +353 (0) 860487273</p>

Funding Body	InterTradeIreland is funded by the Department of Enterprise, Trade and Employment (DETE) and the Department for the Economy (DFE) in Northern Ireland.
Fund	InterTrade Ireland programme
Grant	Acumen
Call Name	n/a
Website	Acumen InterTradeIreland
Key details	The Acumen programme aims to enhance the capacity and capability of SMEs to take the first formal steps onto the export ladder by helping to fund an experienced and skilled sales resource to help businesses to identify new opportunities and win new sales in the cross-border market.
Amount of funding	50% funded sales resource for 12 months to boost cross-border sales up to £15k.
Type of Action	n/a
Key Dates	Get in touch by email acumen@intertradeireland.com , by phone 028 308 34188 (048 from Ireland) for further details

Funding Body	Department of Rural and Community Development
Fund	LEADER Programme
Grant	Transitional Leader Programme
Call Name	
Website	https://www.gov.ie
Key details	<ul style="list-style-type: none"> • LEADER is a rural development programme co-funded by the EU which operates a locally-led, bottom-up, approach to meeting the needs of local communities and businesses. The programme supports private enterprises and community groups in rural areas. • The Transitional LEADER Programme which came into effect on April 1 will bridge a gap between the wind-up of the 2014-2020 LEADER Programme and the start of the next EU programme, which is not likely to commence until 2023 due to delays at EU level. Key focus on building capacity in communities • A key focus of the Transitional Programme will be on building capacity within communities which have not received LEADER funding to date. • Under the Transitional Programme, the grant rate for enterprises and commercial projects will be increased from a maximum of 50% to a maximum of 75% to support enterprise development and job creation in rural areas. • Funding is delivered by 29 Local Action Groups (LAGs) in 28 sub-regional areas. These groups are partnerships of public and private entities from a defined geographical area. LAGs are responsible for local projects in accordance with the Local Development Strategies they develop themselves. • A key focus of the Transitional Programme will be on building capacity within communities which have not received LEADER funding to date. The programme will also support job creation, and projects which address the climate agenda, digital transformation and encourage rural communities to build on their existing strengths and assets.
Amount of funding	A total of €70 million has been allocated to support rural communities and private enterprises over 2021 and 2022.
Key Dates	LAGs can approve new projects from 1st April 2020 to 31st December 2022. All approved projects must be completed before the end of December 2023

Funding Body	Invest NI
Fund	New to R&D
Grant	n/a
Call Name	n/a
Website	Funding for innovation and R&D Invest Northern Ireland (investni.com)
Key details	For business that haven't carried out any previous R&D, have an idea for a new product or process that could help grow your business, and meet certain eligibility criteria, this fund can help
Amount of funding	Support is available up to £50,000 to: <ul style="list-style-type: none"> • Investigate or plan your idea • Make and test a prototype • Experiment and refine your design • Handle intellectual property costs
Type of Action	n/a
Key Dates	For further queries on the new process, please contact our Business Support Team, Tel 0800 181 4422. Read further information about Grant for R&D

Funding Body	Invest NI
Fund	New to R&D
Grant	n/a
Call Name	n/a
Website	Innovation Vouchers Funding to develop & grow Invest NI
Key details	<p>An Innovation Voucher offers you £5000 to ‘purchase’ specialist knowledge from one of 39 respected universities, colleges and research organisations throughout Northern Ireland and the Republic of Ireland. This knowledge can help you to expand, improve or create new products, services and processes.</p> <p>Typical projects supported include:</p> <ul style="list-style-type: none"> • Helping to create or improve products, services or processes • Access to specialist expertise in new materials • Tapping into research and scientific expertise
Amount of funding	The first voucher is funded at 100% of the project cost to max £5000 and customers pay the VAT.
Type of Action	n/a
Key Dates	For further queries on the new process, please contact our Business Support Team, Tel 0800 181 4422. Read further information about Grant for R&D

Funding Body	Invest NI
Fund	New to R&D
Grant	n/a
Call Name	n/a
Website	Innovation Vouchers Funding to develop & grow Invest NI
Key details	<p>An Innovation Voucher offers you £5000 to ‘purchase’ specialist knowledge from one of 39 respected universities, colleges and research organisations throughout Northern Ireland and the Republic of Ireland. This knowledge can help you to expand, improve or create new products, services and processes.</p> <p>Typical projects supported include:</p> <ul style="list-style-type: none"> • Helping to create or improve products, services or processes • Access to specialist expertise in new materials • Tapping into research and scientific expertise.
Amount of funding	The first voucher is funded at 100% of the project cost to max £5000 and customers pay the VAT.
Type of Action	n/a
Key Dates	For further queries on the new process, please contact our Business Support Team, Tel 0800 181 4422. Read further information about Grant for R&D

Funding Body	Environmental Protection Agency (EPA)
Fund	The programme is funded by the National Waste Prevention Programme and the EPA Research Programme.
Call Name	Green Enterprise Fund
Website	EPA Green Enterprise Scheme Environmental Protection Agency
Key details	<p>Closed for 2021, new call expected in 2022. From our sources in EPA, while not confirmed it is expected that the 2022 call will be issued earlier than 2021 (approx. April / May timeframe) with a similar structure / funding as 2021 (funding may increase slightly). The summary information for 2021 is included below for information. In 2021, 7 applicants were successful.</p> <p>2021: The EPA's Green Enterprise: Innovation for a Circular Economy programme is an annual funding programme that supports organisations to develop and demonstrate new circular economy approaches. In 2021 for it aimed to support Irish businesses develop circular solutions in product and service design, production, distribution and use of resources (including resources and raw materials)</p>
Amount of funding	<p>The 2021 call had a fund worth €625k. In 2021, applications for funding in the range of €50k-€100k were invited to apply.</p> <p>In 2021, the maximum amount of funding available was €100,000 per grant award. Grant aid was provided on a shared cost contribution basis, from 25%-95% of the total eligible project costs incurred.</p>
Type of Action	
Key Dates	New call expected for 2022.

Crafts / Heritage

Funding Body	The European Agricultural Fund for Rural Development (EAFRD) is the funding instrument of the second pillar of the EU's Common Agricultural Policy (CAP) and it is one of the European Structural and Investment Funds (ESIF).
Fund	The European Agricultural Fund for Rural Development
Call Name	
Website	https://www.fi-compass.eu/funds/eafrd
Key details	<p>Financial instruments supported by the EAFRD can contribute to the achievement of most of the established EU priorities for rural development including:</p> <ul style="list-style-type: none"> • fostering knowledge transfer and innovation in agriculture, forestry • promoting resource efficiency and supporting the shift towards a low-carbon and climate-resilient economy in the agriculture, food and forestry sectors; • promoting social inclusion, poverty reduction and economic development in rural areas, in particular with regards to creation and development of small enterprises, as well as jobs creation. <p>The European agricultural fund for rural development (EAFRD) finances the CAP's contribution to the EU's rural development objectives. The EAFRD can also provide investment support for rural enterprises and projects through financial instruments, such as loans, guarantees, or equity.</p>
Amount of funding	
Key Dates	This applies to 2022.

Funding Body	European Commission
Fund	Funding for Climate Action
Grant	Innovation Fund
Call Name	Small Scale Projects
Website	https://bit.ly/304iOao
Key details	Projects will be evaluated according to their potential to avoid greenhouse gases emissions, innovation potential, financial and technical maturity, and potential for scaling up and cost efficiency. The first call for small-scale projects funded innovative projects in clean energy and industry to support the deployment of key technologies needed to reach climate neutrality and contribute to Europe's green recovery.
Amount of funding	2021: The first call for small-scale projects opened on 1 December 2020 with a budget of EUR 100 million for breakthrough technologies in renewable energy, energy-intensive industries, energy storage, and carbon capture, use and storage. Details on next call will be available in early 2022.
Type of Action	
Key Dates	Calls open March 2022 with call deadline of late August 2022. Award of the grants as of Q2 2023

Appendix 2: Stakeholder List

Interviewees, Focus Groups, and Site Visits

The authors of this report would like to express their gratitude to those who participated in interviews, hosted site visits, and took part in focus group calls for this project. It was noted that participants were engaged and expressed great interest in supporting value add of Irish wool products.

Market Research Interviews

1. Cremins Compost
2. Larkfield Pellets
3. Target Fertilisers
4. Thermafleece
5. Sheep Wool Insulation
6. Cairn Homes
7. Kingspan Global
8. U-Value
9. Bí-Eco Building Insulation Energy Consultancy
10. The Sheepish Dog
11. Baavet/GreenerMe
12. Woolow
13. Donegal Yarns
14. Cushendale Woollen Mills
15. Hanley Woollen Mills
16. Ulster Carpets
17. Ceadogán Rugs
18. Woolcool Packaging
19. Puffin Packaging
20. Magee Heritage Clothing
21. CCP Grandsen
22. Respa
23. Kingcoil Odearest

Farming Groups

1. IFA
2. ICSA (Wool Steering Group)
3. INHFA
4. Galway Wool Co-op
5. Kerry Lamb and Wool Co-op
6. Irish Wool Discussion Group Representative

Industry Experts

1. The Irish Green Building Council
2. Sustainable Energy Authority of Ireland
3. British Wool
4. Standard Wool
5. Ulster Wool
6. Campaign for Wool
7. Woolmark
8. Teagasc
9. Sheep Ireland
10. Irish Sheep Shearing Association
11. AgResearch New Zealand

Wool Merchants

1. Dooley Wool
2. Laurence Pierce Wool Merchants
3. P Coffey & Sons Ltd.
4. Texacloth
5. Paul Lannen & Son Ltd

Site Visits

1. Donegal Yarns
2. Magee
3. Ulster Wool
4. Dooley Wool

Appendix 3. Table of Market Sizing Number

Market Area	Market Size Present	Market Size Future	Expected Growth	Source
Thermal Insulation	\$29.85 billion in 2021	\$40.34 billion in 2028	CAGR 4.4% in a forecast period	https://www.fortunebusinessinsights.com/building-thermal-insulation-market-102708
Fertilizer	The global fertilizer market amounted to more than 171 billion U.S. dollars in 2020.	It is forecast that the fertilizer market will surpass 210 billion U.S. dollars by 2027		https://www.statista.com/statistics/1266004/global-fertilizer-market-size/#:text=The%20global%20fertilizer%20market%20amounted,billion%20U.S.%20dollars%20by%202027
Amenity Horticulture – Gardening	2020 gardening market at consumer level was valued at €1.2bn in Ireland			https://www.teagasc.ie/media/website/publications/2021/Horticulture---Sector-characterisation-and-potential-market-opportunities.pdf
Bedding	The global home bedding market size was valued at USD 73.88 billion in 2020		CAGR of 9.0% from 2021 to 2028	https://www.grandviewresearch.com/industry-analysis/home-bedding-market
Mattress	The market value of the mattress market worldwide from 2017 to 2024. In 2017, the global mattress market was valued at 27 billion U.S. dollars. (https://www.statista.com/statistics/883510/mattress-market-size-worldwide/) The global mattress market is \$30.93 billion in 2021	\$42.84 billion in 2028	CAGR of 4.8% in the forecast period, 2021-2028	https://www.fortunebusinessinsights.com/mattress-market-102108

Market Area	Market Size Present	Market Size Future	Expected Growth	Source
Pillow	In 2019, the pillow market was valued at about 15.6 billion U.S. dollars worldwide.		This Statista estimate is based on the 2019 and 2024 values and the compound annual growth rate from 2019 to 2024 of 3%	https://www.statista.com/statistics/933485/sleeping-pillow-market-size-worldwide/
Pet Furniture	The pet furniture market size was valued at \$3,443.4 million in 2019	Projected to reach \$5,139.4 million by 2027, growing at a.	CAGR of 6.5% from 2021 to 2027	https://www.alliedmarketresearch.com/pet-furniture-market-A10832#:~:text=The%20pet%20furniture%20market%20size,6.5%25%20from%202021%20to%202027
Keratin	The industry was estimated to be over 3500 tons in 2014		CAGR of above 7.0% from 2015 to 2022.	https://www.grandviewresearch.com/industry-analysis/keratin-market
Lanolin	The global lanolin market size was valued at USD 222.0 million in 2018 and is		CAGR of 6.0% from 2019 to 2025.	https://www.grandviewresearch.com/industry-analysis/lanolin-market#:~:text=The%20global%20lanolin%20market%20size,key%20factor%20driving%20the%20market.
Cold Chain Packaging	The Cold Chain Packaging Market was valued at USD 20.08 billion in 2020	It is projected to be worth USD 36.65 billion by 2026	CAGR of approximately 10.36% during the forecast period (2021-2026).	https://www.mordorintelligence.com/industry-reports/cold-chain-packaging-market#:~:text=The%20Cold%20Chain%20Packaging%20Market%20was%20valued%20at%20USD%2020.08,period%20(2021%2D2026)

Market Area	Market Size Present	Market Size Future	Expected Growth	Source
Textiles	The global textile market size was valued at USD 993.6 billion in 2021	The global textile market size is anticipated to reach USD 1412.5 billion by 2028.	The market is expected to expand at a CAGR of 4.4% from 2021 to 2028.	https://www.businesswire.com/news/home/20211018005850/en/Global-Textile-Market-Analysis-Report-2021-2028-by-Raw-Material-Wool-Chemical-Silk-Product-Natural-Fibers-Polyester-Application-Household-Technical---ResearchAndMarkets.com
Upholstery	The global market for Automotive Upholstery, estimated at US\$3.6 Billion in the year 2020,	It is projected to reach a revised size of US\$5.2 Billion by 2026	CAGR of 6.6% over the analysis period.	https://www.businesswire.com/news/home/20220125005667/en/Global-Automotive-Upholstery-Market-Trajectory-Analytics-2021-2026---Environment-Friendly-Sustainable-Textile-to-Make-a-Big-Impact-on-the-Market---ResearchAndMarkets.com
Carpets	The European carpet market size was valued at USD 51.7 billion in 2018		CAGR of 3.0% from 2019 to 2025	https://www.grandviewresearch.com/industry-analysis/europe-carpet-market-analysis
Composites	The European composites market size was worth USD 16.6 billion in 2018		estimated to register a CAGR of 7.5% from 2019 to 2025	https://www.grandviewresearch.com/industry-analysis/europe-composites-market

Appendix 4. Summary of Research Projects

Table 5. This table summarises proposed research projects, along with approximate TRL, scale of research required to commercialise, funding options that may be appropriate for advancement and research and industry ecosystem to enable this. The organisations listed in this table are not exhaustive and should not be deemed as recommendations.

Application	Technology Readiness Level	Level of Research required	Recommended support mechanism	Research Ecosystem	Industry Ecosystem
Fertiliser	9	Minor	Innovation Voucher/LEO/Contract research	Teagasc, Shannon ABC (TUS/MTU), IT Sligo	Cremin's Compost, Larkfield Pellet Products, Cre
Peat Replacement	5	Medium	Innovation voucher/Innovation Partnership/Agile Innovation Fund	Teagasc, Shannon ABC (TUS)	Monaghan Mushrooms, CMP, Garryhinch Exotic Mushrooms, Cre
Hydroponics	9	Minor	Innovation Voucher/LEO/Contract research	UCD, Shannon ABC (TUS)	Emerald Greens Farm, Killarney Urban Farm, Farmony
Mulch mats	9	Minor	Innovation Voucher/LEO/Contract research	Teagasc	Fruit Hill Farm
Enzyme treatment of wool	4/5	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	TUD, IT Sligo, Shannon ABC (TUS), BiOrbic	Niskus Biotech, Cushendale Woollen Mills, Donegal Yarn, Magee Weaving, Irish Bioeconomy Foundation (IBF)

Solid state fermentation of wool	3	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	Teagasc, TUD, IT Sligo, Shannon ABC (TUS)	Niskus Biotec, Cushendale Woollen Mills, Donegal Yarn, Magee Weaving, IBF
Plasma treatment of wool	9	Medium	Innovation Partnership/Agile Innovation Fund	IT Sligo	Cushendale Woollen Mills, Donegal Yarn, Magee Weaving
Insulation	9	Medium	Innovation Partnership/Agile Innovation Fund	Teagasc, IT Sligo, CirculEire	Pierce Insulation, Bi-Eco, Thermafleece*, Kingspan
VOC filtration	6/7	Medium	Innovation Voucher/Innovation Partnership/Agile Innovation Fund	IT Sligo, Shannon ABC (TUS), AMBER	Ulster Carpets
Wool mats for green roofs	9	Minor	Innovation Voucher/LEO/Contract research	UCD, BiOrbic	Soprema, Cork Rooftop Farm
Concrete blocks	9	Minor	Innovation Voucher/LEO/Contract research	CREST, Teagasc	Ecocem
Packaging	9	Medium	Innovation Voucher/LEO/Contract research	CREST, APT, CirculEire, AMBER	Woolcool*
Wool health claims	7	Medium	Innovation Voucher/LEO/Contract research/Innovation Partnership	IT Sligo, Shannon ABC (MTU)	Allergy Standards Ltd, Woolow
Furniture/Bio materials	9	Medium	Innovation Voucher/LEO/Contract research	APT, UCC, CirculEire	Donegal Yarns
Sorbent for oil spill	9	Minor	Innovation Voucher/LEO/Contract research	Shannon ABC (MTU), CirculEire	AES-Marconi, Spilltech Environmental.

Sorbent for heavy metals	6	Medium	Innovation Voucher/LEO/Contract research/Innovation Partnership	NUIG, Shannon ABC (MTU), CirculEire	Galco Steel, Verde.
Keratin extraction from wool	4/5	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	Shannon ABC (TUS), BiOrbic, AMBER	IBF, Resolve Partners
Medical device applications	4/5	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	Shannon ABC (MTU), RCSI, AMBER, UCD	Resolve Partners, PBC Biomed
Bioplastics	3/4	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	APT, AMBER, BiOrbic, CirculEire	Key Plastics, Bioplastech
Keratinase production	3/4	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	BiOrbic, Shannon ABC (TUS/MTU), MiCRA (TUD)	Niskus Biotec
Pilot scale production of keratinases	2/3	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	Shannon ABC (MTU), MiCRA, (TUD) (TUD)	IBF
Lanolin content of Irish wool	2/3	Major	Innovation Voucher	PMBRC (WIT), Shannon ABC (MTU)	Kerry Woollen Mills
Ceramide content of Irish wool	2/3	Major	Innovation Voucher	PMBRC (WIT) Shannon ABC (MTU), BiOrbic	

Validation of extraction methods	3/4	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	BiOrbic , PMBRC (WIT) Shannon ABC (TUS)	
Development of cosmetic healthcare products	2/3	Major	Innovation Partnership/Agile Innovation Fund/SFI/IRC	Shannon ABC (MTU), Design+	Lynoslife, SPV Healthcare, PBC Biomed

References

- [1] “Briefing: What are Scope 3 emissions? | The Carbon Trust.”
<https://www.carbontrust.com/resources/briefing-what-are-scope-3-emissions> (accessed Mar. 19, 2022).
- [2] D. Callaghan, “Horticulture : Sector characterisation and potential market opportunities (20/4/2021)”.
- [3] “Ireland exporting 11 times more peat than it imports - amid horticulture supply fears.”
<https://www.thejournal.ie/peats-sake-pt1-exports-5605623-Nov2021/#:~:text=In%202021%20to%20date%2C%2042%2C800,Lithuania%2C%20Ukraine%2C%20and%20Belarus.> (accessed Mar. 19, 2022).
- [4] “gov.ie - Ag Climatise - A Roadmap towards Climate Neutrality.”
<https://www.gov.ie/en/publication/07fbe-ag-climatise-a-roadmap-towards-climate-neutrality/> (accessed Mar. 19, 2022).
- [5] “COMPO BIO Universal Longterm Fertilizer with Sheep Wool.”
<https://www.compo.com/int/products/fertilizer-plant-care/universal-fertilizer/compo-bio-universal-longterm-fertilizer-with-sheep-wool> (accessed Mar. 19, 2022).
- [6] “Building Thermal Insulation Market Size & Global Report [2028].”
<https://www.fortunebusinessinsights.com/building-thermal-insulation-market-102708> (accessed Mar. 19, 2022).
- [7] “Cold Chain Packaging Market | 2022 - 27 | Industry Share, Size, Growth - Mordor Intelligence.” [https://www.mordorintelligence.com/industry-reports/cold-chain-packaging-market#:~:text=The%20Cold%20Chain%20Packaging%20Market%20was%20valued%20at%20USD%2020.08,period%20\(2021%2D2026\).](https://www.mordorintelligence.com/industry-reports/cold-chain-packaging-market#:~:text=The%20Cold%20Chain%20Packaging%20Market%20was%20valued%20at%20USD%2020.08,period%20(2021%2D2026).) (accessed Mar. 19, 2022).
- [8] “What is a U-value? | Insulation | Kingspan | Great Britain.”
<https://www.kingspan.com/gb/en-gb/products/insulation-boards/insulation-technical-hub/articles-and-advice/what-are-u-values-r-values-and-lambda-values> (accessed Mar. 19, 2022).
- [9] “Mattress Market Size, Share, Trends & Industry Growth [2028].”
<https://www.fortunebusinessinsights.com/mattress-market-102108> (accessed Mar. 19, 2022).
- [10] “• Sleeping pillow market size worldwide 2019-2024 | Statista.”
<https://www.statista.com/statistics/933485/sleeping-pillow-market-size-worldwide/> (accessed Mar. 19, 2022).
- [11] “Pet furniture Market Size & Share | Industry Report, 2021-2027.”
<https://www.alliedmarketresearch.com/pet-furniture-market-A10832#:~:text=The%20pet%20furniture%20market%20size,6.5%25%20from%202021%20to%202027> (accessed Mar. 19, 2022).
- [12] “Global Home Bedding Market Size, Share Report, 2021-2028.”
<https://www.grandviewresearch.com/industry-analysis/home-bedding-market> (accessed Mar. 19, 2022).

- [13] “Pet furniture Market Size & Share | Industry Report, 2021-2027.”
<https://www.alliedmarketresearch.com/pet-furniture-market-A10832#:~:text=The%20pet%20furniture%20market%20size,6.5%25%20from%202021%20to%202027> (accessed Mar. 19, 2022).
- [14] “Global Automotive Upholstery Market Trajectory & Analytics, 2021-2026 - Environment Friendly Sustainable Textile to Make a Big Impact on the Market - ResearchAndMarkets.com | Business Wire.” <https://www.businesswire.com/news/home/20220125005667/en/Global-Automotive-Upholstery-Market-Trajectory-Analytics-2021-2026---Environment-Friendly-Sustainable-Textile-to-Make-a-Big-Impact-on-the-Market---ResearchAndMarkets.com> (accessed Mar. 19, 2022).
- [15] “Global Textile Market Analysis Report 2021-2028 by Raw Material (Wool, Chemical, Silk), Product (Natural Fibers, Polyester), Application (Household, Technical) - ResearchAndMarkets.com | Business Wire.” <https://www.businesswire.com/news/home/20211018005850/en/Global-Textile-Market-Analysis-Report-2021-2028-by-Raw-Material-Wool-Chemical-Silk-Product-Natural-Fibers-Polyester-Application-Household-Technical---ResearchAndMarkets.com> (accessed Mar. 19, 2022).
- [16] “Europe Carpet Market Size, Share | Industry Report, 2019-2025.”
<https://www.grandviewresearch.com/industry-analysis/europe-carpet-market-analysis> (accessed Mar. 19, 2022).
- [17] “Campaign for Wool | Join The Campaign, Live Naturally & Choose Wool.”
<https://www.campaignforwool.org/> (accessed Mar. 19, 2022).
- [18] “Europe Composites Market Size | Industry Growth Report, 2019-2025.”
<https://www.grandviewresearch.com/industry-analysis/europe-composites-market> (accessed Mar. 19, 2022).
- [19] “Where Are Composites Used? | CompositesLab.” <http://compositeslab.com/where-are-composites-used/> (accessed Mar. 19, 2022).
- [20] “Ford Sustainable Materials Factsheet | Enhanced Reader.”
- [21] “Lanolin Market Size & Share | Industry Analysis Report, 2019-2025.”
<https://www.grandviewresearch.com/industry-analysis/lanolin-market> (accessed Mar. 19, 2022).
- [22] “Keratin Market Size, Share | Global Industry Analysis Report, 2025.”
<https://www.grandviewresearch.com/industry-analysis/keratin-market> (accessed Mar. 19, 2022).
- [23] “Keratin Products Market Industry - Analysis Share, Size 2021-2030.”
<https://www.alliedmarketresearch.com/keratin-products-market-A12406> (accessed Mar. 19, 2022).
- [32] “Animal by-products specific guidance | Department of Agriculture, Environment and Rural Affairs.” <https://www.daera-ni.gov.uk/articles/animal-by-products-specific-guidance> (accessed Jan. 14, 2022).
- [33] “EUR-Lex - EN - EUR-Lex.” <https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX%3A32009R1069> (accessed Jan. 14, 2022).

- [34] G. D. Gillespie, O. Dada, and K. P. McDonnell, "The Potential for Hydrolysed Sheep Wool as a Sustainable Source of Fertiliser for Irish Agriculture," *Sustainability* 2022, Vol. 14, Page 365, vol. 14, no. 1, p. 365, Dec. 2021, doi: 10.3390/SU14010365.
- [35] "Wool is 100% biodegradable." <https://www.woolmark.com/industry/research/wool-is-biodegradable/> (accessed Jan. 14, 2022).
- [36] J. A. Rippon *et al.*, "Wool: Structure, Properties, and Processing," *Encyclopedia of Polymer Science and Technology*, pp. 1–46, May 2016, doi: 10.1002/0471440264.PST402.PUB2.
- [37] "BIODEGRADABILITY - International Wool Textile Organisation." <https://iwto.org/sustainability/biodegradability/> (accessed Jan. 14, 2022).
- [38] J. Barthod, C. Rumpel, and M.-F. Dignac, "Composting with additives to improve organic amendments. A review", doi: 10.1007/s13593-018-0491-9.
- [39] S. Senthilkannan, M. Miguel, and A. Gardetti, "Environmental Footprints and Eco-design of Products and Processes Green Fashion Volume 1." [Online]. Available: <http://www.springer.com/series/13340>
- [40] M. D. Berechet and C. Gaidau, "Alkaline-Enzymatic Hydrolysis of Wool Waste for Different Applications," 2018, doi: 10.37358/RC.18.7.6388.
- [41] M. Zoccola, A. Montarsolo, R. Mossotti, A. Patrucco, and C. Tonin, "Green hydrolysis conversion of wool wastes into organic nitrogen fertilisers".
- [42] P. Bhavsar, M. Zoccola, A. Patrucco, A. Montarsolo, G. Rovero, and C. Tonin, "Comparative study on the effects of superheated water and high temperature alkaline hydrolysis on wool keratin:," <http://dx.doi.org/10.1177/0040517516658512>, vol. 87, no. 14, pp. 1696–1705, Jul. 2016, doi: 10.1177/0040517516658512.
- [43] M. Böhme, I. Pinker, H. Grüneberg, and S. Herfort, "Sheep wool as fertiliser for vegetables and flowers in organic farming," *Acta Horticulturae*, vol. 933, pp. 195–202, Mar. 2012, doi: 10.17660/ACTAHORTIC.2012.933.23.
- [44] G. Z. G. E. and L. M. Ordiales Elena, "Assessment of Utilization of Sheep Wool Pellets as Organic Fertilizer and Soil Amendment in Processing Tomato and Broccoli," *Modern Agricultural Science and Technology*, vol. 2, no. 2, pp. 20–35, Dec. 2016.
- [45] P. D. Alexander *et al.*, "Peat in horticulture and conservation: the UK response to a changing world," vol. 3, p. 8, 2008, Accessed: Jan. 20, 2022. [Online]. Available: <http://www.mires-and-peat.net/>,
- [46] R. Noble and A. Dobrovin-Pennington, "Partial substitution of peat in mushroom casing with fine particle coal tailings," *Scientia Horticulturae*, vol. 104, no. 3, pp. 351–367, Apr. 2005, doi: 10.1016/J.SCIENTA.2004.09.004.
- [47] N. A. Siyoum, "Microbial dynamics of different casing materials in the production of white button mushrooms (*Agaricus bisporus*)," May 2013, Accessed: Jan. 20, 2022. [Online]. Available: <https://repository.up.ac.za/handle/2263/30785>

- [48] H. Grogan, "Technology Updates Crops, Environment and Land Use," 2013, Accessed: Jan. 20, 2022. [Online]. Available: <http://www.teagasc.ie/publications/>
- [49] Y. Sassine, M. Kharrat, M. H. Böhme, and A. M. R. Abdel-Mawgoud, "Waste Paper as an Alternative for Casing Soil in Mushroom (*Agaricus bisporus*) Production Implementing local agro-industrial wastes in mushroom production View project Evaluation of magnetic nano-composite effects on relative expression of flowering gene in three cyclamen cultivars: An approach to reducing production period View project," 2005. [Online]. Available: <https://www.researchgate.net/publication/280102016>
- [50] S. H. Hosseini, M. Rafiee, and R. Barzegar, "Effects of the replacing vermicompost and perlite instead of peat as casing soil on growth and yield of mushroom," *Journal of Crops Improvement*, vol. 19, no. 4, pp. 837–852, Feb. 2018, doi: 10.22059/JCI.2018.220952.1583.
- [51] "Peat and alternative material for mushroom casing | AHDB." <https://ahdb.org.uk/knowledge-library/peat-and-alternative-material-for-mushroom-casing> (accessed Jan. 20, 2022).
- [52] "rock wool as a casing ingredient - Mushroom Cultivation - Shroomery Message Board." <https://www.shroomery.org/forums/showflat.php/Number/14047356> (accessed Jan. 20, 2022).
- [53] "ADAPTING TO CLIMATE CHANGE 02. ALTERNATIVE CASING MATERIALS - Google Search." https://www.google.com/search?q=ADAPTING+TO+CLIMATE+CHANGE+02.+ALTERNATIVE+CASING+MATERIALS&client=firefox-b-d&sxsrf=AOaemvKQ5X_aVxPkBJ_oQ_UgB-CL87QnqA%3A1642776448628&ei=gMfqYcfpJf6ChbIPr8yrsAU&ved=0ahUKEwjHqamVi8P1AhV-QUEAHS_mCIYQ4dUDCA0&uact=5&oq=ADAPTING+TO+CLIMATE+CHANGE+02.+ALTERNATIVE+CASING+MATERIALS&gs_lcp=Cgdnnd3Mtd2l6EAM6BwgAEecQsANKBAhBGABKBAhGGABQrQFYrQFg_wVoAXAcEACAAdMBiAHTAZIBAZltMZgBAKABAcgBCMAABAQ&scient=gws-wiz (accessed Jan. 21, 2022).
- [54] M. H. Böhme, S. Herfort, and I. Pinker, "Cucumber grown in sheepwool slabs treated with biostimulator compared to other organic and mineral substrates Effect of some beneficial microorganisms on rooting of some Bougainvillea stem cuttings View project GIS avd RS, Land evaluation View project", doi: 10.17660/ActaHortic.2008.779.36.
- [55] D. Dannehl, N. T. Nhut, J. Suhl, C. Ulrichs, and U. Schmidt, "Evaluation of substitutes for rock wool as growing substrate for hydroponic tomato production," *Journal of Applied Botany and Food Quality*, vol. 88, pp. 68–77, 2015, doi: 10.5073/JABFQ.2015.088.010.
- [56] D. W. Maxwell *et al.*, "410 Biologically Based Weed Control in Strawberry," *HortScience*, vol. 35, no. 3, pp. 463E – 464, Jun. 2000, doi: 10.21273/HORTSCI.35.3.463E.
- [57] L. M. Duppong *et al.*, "The Effect of Natural Mulches on Crop Performance, Weed Suppression and Biochemical Constituents of Catnip and St. John's Wort," *Crop science*, vol. 44, no. 3, p. 861, 2004, doi: 10.2135/cropsci2004.8610.
- [58] A. Sahoo, "Potential use of waste wool in agriculture: An overview," *Article in Indian Journal of Small Ruminants*, 2019, doi: 10.5958/0973-9718.2019.00019.9.
- [59] "The Coloration of Wool and Other Keratin Fibres - Google Books." <https://books.google.ie/books?hl=en&lr=&id=->

[CxOUIZmFQcC&oi=fnd&pg=PA1&dq=coarse+wool+versus+fine+wool&ots=hwrlxStRRh&sig=i06xEkOdRvo1U8vJkPVZ-LEICOG&redir_esc=y#v=onepage&q=coarse%20wool%20versus%20fine%20wool&f=false](http://www.irisshexaminer.com/farming/arid-40369481.html) (accessed Jan. 22, 2022).

- [60] P. R. Lord, "Textile products and fiber production," *Handbook of Yarn Production*, pp. 18–55, 2003, doi: 10.1533/9781855738652.18.
- [61] M. M. Hassan and C. M. Carr, "A review of the sustainable methods in imparting shrink resistance to wool fabrics," *Journal of Advanced Research*, vol. 18, pp. 39–60, Jul. 2019, doi: 10.1016/J.JARE.2019.01.014.
- [62] P. E. Sharma and N. Fatima, "Quality Improvement of Wool Fabric Using Protease Enzyme," *Environment and Ecology Research*, vol. 2, no. 8, pp. 301–310, Nov. 2014, doi: 10.13189/EER.2014.020803.
- [63] M. A. Hassan, "ENZYMATIC STUDIES FOR IMPROVING WOOL QUALITY," 2015, Accessed: Jan. 22, 2022. [Online]. Available: <http://www.journalcra.com>
- [64] K. Mojsov, "Enzymatic treatment of wool fabrics - opportunity of the improvement on some physical and chemical properties of the fabrics," *Journal of the Textile Institute*, vol. 108, no. 7, pp. 1136–1143, Jul. 2017, doi: 10.1080/00405000.2016.1222856.
- [65] M. Niaounakis, "Surface Treatment," *Biopolymers: Processing and Products*, pp. 303–326, 2015, doi: 10.1016/B978-0-323-26698-7.00008-8.
- [66] "Plasma Treatment of Textiles." <https://www.thierry-corp.com/plasma-knowledgebase/plasma-treatment-of-textiles> (accessed Jan. 23, 2022).
- [67] C. W. Kan and C. W. M. Yuen, "Plasma technology in wool," <http://dx.doi.org/10.1080/00405160701628839>, vol. 39, no. 3, pp. 121–187, 2007, doi: 10.1080/00405160701628839.
- [68] D. Biniaś, A. Włochowicz, W. B.-F. & T. in Eastern, and undefined 2004, "Selected properties of wool treated by low-temperature plasma," *fibtex.lodz.pl*, Accessed: Jan. 23, 2022. [Online]. Available: http://www.fibtex.lodz.pl/46_16_58.pdf
- [69] A. Nazari, M. Montazer, and M. Dehghani-Zahedani, "Mothproofing of wool fabric utilizing ZnO nanoparticles optimized by statistical models," *Journal of Industrial and Engineering Chemistry*, vol. 20, no. 6, pp. 4207–4214, Nov. 2014, doi: 10.1016/J.JIEC.2013.12.112.
- [70] A. Nazari, "Efficient mothproofing of wool through natural dyeing with walnut hull and henna against *Dermestes maculatus*," *The Journal of The Textile Institute*, vol. 108, no. 5, pp. 755–765, May 2016, doi: 10.1080/00405000.2016.1186340.
- [71] K. Schäfer, M. Möller, and J. Knott, "STUDIES ON THE MOTHPROOFING OF WOOL WITH MYSTOX MP."
- [72] "Wool as insulation should be mandatory in all public buildings and homes - IFA." <https://www.irisshexaminer.com/farming/arid-40369481.html> (accessed Jan. 24, 2022).

- [73] K. W. Corscadden, J. N. Biggs, and D. K. Stiles, "Sheep's wool insulation: A sustainable alternative use for a renewable resource?," *Resources, Conservation and Recycling*, vol. 86, pp. 9–15, May 2014, doi: 10.1016/J.RESCONREC.2014.01.004.
- [74] A. Aluigi, C. Vineis, C. Tonin, C. Tonetti, A. Varesano, and G. Mazzuchetti, "Wool keratin-based nanofibres for active filtration of air and water," *Journal of Biobased Materials and Bioenergy*, vol. 3, no. 3, pp. 311–319, Sep. 2009, doi: 10.1166/JBMB.2009.1039.
- [75] A. Ghosh and S. R. Collie, "Keratinous materials as novel absorbent systems for toxic pollutants," *Defence Science Journal*, vol. 64, no. 3, pp. 209–221, 2014, doi: 10.14429/DSJ.64.7319.
- [76] S. F. Curling, • C Loxton, and G. A. Ormondroyd, "A rapid method for investigating the absorption of formaldehyde from air by wool", doi: 10.1007/s10853-011-6163-7.
- [77] S. Thome, "Untersuchungen zur Sorption von Innenraum-Luftschadstoffen durch Wolle," 2006.
- [78] E. Mansour, "Wool fibres for the sorption of volatile organic compounds (VOCs) from indoor air," 2017.
- [79] F. Bianchini and K. Hewage, "How 'green' are the green roofs? Lifecycle analysis of green roof materials," *Building and Environment*, vol. 48, no. 1, pp. 57–65, Feb. 2012, doi: 10.1016/J.BUILDENV.2011.08.019.
- [80] A. Graceson, M. Hare, J. Monaghan, and N. Hall, "The water retention capabilities of growing media for green roofs," *Ecological Engineering*, vol. 61, no. PA, pp. 328–334, Dec. 2013, doi: 10.1016/J.ECOLENG.2013.09.030.
- [81] A. Graceson, M. Hare, N. Hall, and J. Monaghan, "Use of inorganic substrates and composted green waste in growing media for green roofs," *Biosystems Engineering*, vol. 124, pp. 1–7, Aug. 2014, doi: 10.1016/J.BIOSYSTEMSENG.2014.05.007.
- [82] P. Vacek, K. Struhala, and L. Matějka, "Life-cycle study on semi intensive green roofs," *Journal of Cleaner Production*, vol. 154, pp. 203–213, Jun. 2017, doi: 10.1016/J.JCLEPRO.2017.03.188.
- [83] R. Alyousef *et al.*, "Utilization of sheep wool as potential fibrous materials in the production of concrete composites," *Journal of Building Engineering*, vol. 30, p. 101216, Jul. 2020, doi: 10.1016/J.JOBE.2020.101216.
- [84] V. Fiore, G. di Bella, and A. Valenza, "Effect of Sheep Wool Fibers on Thermal Insulation and Mechanical Properties of Cement-Based Composites," <https://doi.org/10.1080/15440478.2019.1584075>, vol. 17, no. 10, pp. 1532–1543, Oct. 2019, doi: 10.1080/15440478.2019.1584075.
- [85] D. Gelana, G. Kebede, and L. Feleke, "Saudi Journal of Civil Engineering Investigation on Effects of Sheep Wool fiber on Properties of C-25 Concrete," 2019, doi: 10.36348/sjce.2019.v03i06.001.
- [86] M. C. M. Parlato and S. M. C. Porto, "Organized Framework of Main Possible Applications of Sheep Wool Fibers in Building Components," *Sustainability 2020, Vol. 12, Page 761*, vol. 12, no. 3, p. 761, Jan. 2020, doi: 10.3390/SU12030761.

- [87] I. Oancea, C. Bujoreanu, M. Budescu, M. Benchea, and C. M. Grădinaru, "Considerations on sound absorption coefficient of sustainable concrete with different waste replacements," *Journal of Cleaner Production*, vol. 203, pp. 301–312, Dec. 2018, doi: 10.1016/J.JCLEPRO.2018.08.273.
- [88] G. Wortmann and F. J. Wortmann, "Sorption of Indoor Air Pollutants by Sheep's Wool: Formaldehyde as an Example," 1999. [Online]. Available: <https://www.researchgate.net/publication/328107686>
- [89] M. Angela, S. Curling, O. A. Graham, D. L. Jones, and P. A. Williams, "Effectiveness of a Wool Based Packaging System on the Abundance of Surface Spoilage Microorganisms on Meat Products," *Assiut J. Agric. Sci*, no. 47, pp. 24–28, Accessed: Jan. 25, 2022. [Online]. Available: http://www.aun.edu.eg/faculty_agriculture/arabic
- [90] P. Bhavsar, T. Balan, G. Dalla Fontana, M. Zoccola, A. Patrucco, and C. Tonin, "Sustainably Processed Waste Wool Fiber-Reinforced Biocomposites for Agriculture and Packaging Applications," 2021, doi: 10.3390/fib9090055.
- [91] "Wool Bedding - GreenerMe." <https://www.baavet.ie/the-house-that-will-irish-home-and-interiors-blog/> (accessed Feb. 20, 2022).
- [92] "Anti-Allergy Bedding can help you Sleep Better | Sienna." <https://www.sienna.ie/blog/anti-allergy-bedding-can-help-you-sleep-better> (accessed Feb. 20, 2022).
- [93] J.-H. Park, D. L. Spiegelman, H. A. Burge, D. R. Gold, G. L. Chew, and D. K. Milton, "Longitudinal Study of Dust and Airborne Endotoxin in the Home," *Environmental Health Perspectives* •, vol. 108, no. 11, 2000, Accessed: Feb. 21, 2022. [Online]. Available: <http://ehpnet1.niehs.nih.gov/docs/2000/108p1023-1028park/abstract.html>
- [94] G. Ricci, A. Patrizi, and F. Bellini, "Use of Textiles in Atopic Dermatitis," *Current Problems in Dermatology*, vol. 33, pp. 127–143, Feb. 2006, doi: 10.1159/000093940.
- [95] J. G.-C. C. M. A. Journal and undefined 1991, "Growing number of asthma cases, deaths baffles physicians," *ncbi.nlm.nih.gov*, Accessed: Feb. 21, 2022. [Online]. Available: <https://www.ncbi.nlm.nih.gov/pmc/articles/pmc1335801/>
- [96] M. H. Garrett, B. M. Hooper, and M. A. Hooper, "Indoor environmental factors associated with house-dust-mite allergen (Der p i) levels in south-eastern Australian houses," *Allergy*, vol. 53, no. 11, pp. 1060–1065, Nov. 1998, doi: 10.1111/J.1398-9995.1998.TB03815.X.
- [97] "Bedding | New standard for bedding containing Merino Wool | Allergy Standards." https://www.allergystandards.com/news_events/new-standard-for-bedding-containing-merino-wool/ (accessed Feb. 21, 2022).
- [98] "Solidwool furniture | Woolmark." <https://www.woolmark.com/interiors/new-purpose-solidwool-furniture/> (accessed Jan. 28, 2022).
- [99] M. M. Radetić, D. M. Jocić, P. M. Jovančić, Z. L. Petrović, and H. F. Thomas, "Recycled Wool-Based Nonwoven Material as an Oil Sorbent," *Environmental Science and Technology*, vol. 37, no. 5, pp. 1008–1012, Mar. 2003, doi: 10.1021/ES0201303.

- [100] G. Asachi, S. Sergiu Maier Gheorghe Asachi, H. Rajabinejad, I.-I. Bucîşcanu, and S. Sergiu Maier, "Current Approaches For Raw Wool Waste Management And Unconventional Valorization: A Review Ingrid-Ioana Buciscanu CURRENT APPROACHES FOR RAW WOOL WASTE MANAGEMENT AND UNCONVENTIONAL VALORIZATION: A REVIEW," *Article in Environmental Engineering and Management Journal*, vol. 18, no. 7, pp. 1439–1456, 2018, doi: 10.30638/eemj.2019.136.
- [101] V. Havryliak and V. Mykhaliuk, "The comparative analysis of the methods for keratin extraction from sheep wool and human hair," *The Animal Biology*, vol. 22, no. 4, 2020, doi: 10.15407/animbiol22.04.009.
- [102] G. J. Dias, P. Mahoney, M. Swain, R. J. Kelly, R. A. Smith, and M. A. Ali, "Keratin–hydroxyapatite composites: Biocompatibility, osseointegration, and physical properties in an ovine model," *Journal of Biomedical Materials Research Part A*, vol. 95A, no. 4, pp. 1084–1095, Dec. 2010, doi: 10.1002/JBM.A.32908.
- [103] G. J. Dias, N. Ramesh, L. Neilson, J. Cornwall, R. J. Kelly, and G. Anderson, "The adaptive immune response to porous regenerated keratin as a bone graft substitute in an ovine model," *International Journal of Biological Macromolecules*, vol. 165, pp. 100–106, Dec. 2020, doi: 10.1016/J.IJBIOMAC.2020.09.133.
- [104] L. A. Sharma *et al.*, "Healing response of rat pulp treated with an injectable keratin hydrogel," *Journal of applied biomaterials & functional materials*, vol. 15, no. 3, pp. e244–e250, 2017, doi: 10.5301/JABFM.5000346.
- [105] D. O. Sanchez Ramirez *et al.*, "Design of Asymmetric Nanofibers-Membranes Based on Polyvinyl Alcohol and Wool-Keratin for Wound Healing Applications," *Journal of Functional Biomaterials 2021, Vol. 12, Page 76*, vol. 12, no. 4, p. 76, Dec. 2021, doi: 10.3390/JFB12040076.
- [106] M. Konop, M. Rybka, and A. Drapała, "Keratin Biomaterials in Skin Wound Healing, an Old Player in Modern Medicine: A Mini Review," *Pharmaceutics 2021, Vol. 13, Page 2029*, vol. 13, no. 12, p. 2029, Nov. 2021, doi: 10.3390/PHARMACEUTICS13122029.
- [107] Y. Dou, B. Zhang, M. He, G. Yin, and Y. Cui, "The structure, tensile properties and water resistance of hydrolyzed feather keratin-based bioplastics," *Chinese Journal of Chemical Engineering*, vol. 24, no. 3, pp. 415–420, Mar. 2016, doi: 10.1016/J.CJCHE.2015.11.007.
- [108] N. Ramakrishnan, S. Sharma, A. Gupta, and B. Y. Alashwal, "Keratin based bioplastic film from chicken feathers and its characterization," *International Journal of Biological Macromolecules*, vol. 111, pp. 352–358, May 2018, doi: 10.1016/J.IJBIOMAC.2018.01.037.
- [109] S. Sharma, A. Gupta, A. Kumar, C. G. Kee, H. Kamyab, and S. M. Saufi, "An efficient conversion of waste feather keratin into ecofriendly bioplastic film," *Clean Technologies and Environmental Policy 2018 20:10*, vol. 20, no. 10, pp. 2157–2167, Feb. 2018, doi: 10.1007/S10098-018-1498-2.
- [110] E. Slaveva Vasileva-Tonkova *et al.*, "Keratinase Production by Newly Isolated Antarctic Actinomycete Strains," *Article in World Journal of Microbiology and Biotechnology*, 2005, doi: 10.1007/s11274-004-2241-1.

- [111] Z. Fang, J. Zhang, B. Liu, G. Du, and J. Chen, "Biodegradation of wool waste and keratinase production in scale-up fermenter with different strategies by *Stenotrophomonas maltophilia* BBE11-1," *Bioresource Technology*, vol. 140, pp. 286–291, 2013, Accessed: Jan. 28, 2022. [Online]. Available: <https://reader.elsevier.com/reader/sd/pii/S0960852413007153?token=1F3D50EDD311DCC625738566EA355973CA84259C51C1BBCEEB291B72A490BE36874F7C53D4C69CE6CCED4B2107B90468&originRegion=eu-west-1&originCreation=20220128162419>
- [112] M. Abou and T. H. El-Sayed, "Preparation and characterization of lanolin-based condensate and its utilization as a nonionic softener for wool fabric surface," *Journal of Applied Research and Technology*, vol. 19, pp. 508–520, 2021, doi: 10.1016/j.jart.2017.02.005.
- [113] "Ceramides From Sheeps Wool Similar To Those Of The Human Skin -- ScienceDaily." <https://www.sciencedaily.com/releases/2005/04/050426215247.htm> (Accessed Jan. 28, 2022).
- [114] R. Ramírez, M. Martí, and A. Manich, "Ceramides Extracted from Wool: Pilot Plant Solvent Extraction," 2009, doi: 10.1177/0040517507083369.
- [115] "KRUS final report: Enhancing local value chains in Norway - Clothing research." <https://clothingresearch.oslomet.no/2019/09/09/krus-final-report-enhancing-local-value-chainsin-norway/> (accessed Mar. 19, 2022).
- [116] S. G. Wiedemann *et al.*, "Environmental impacts associated with the production, use, and end-of-life of a woollen garment," *International Journal of Life Cycle Assessment*, vol. 25, no. 8, pp. 1486–1499, Aug. 2020, doi: 10.1007/S11367-020-01766-0, doi: 10.1007/S11367-020-01766-0/FIGURES/3.