Investigating products made from Swedish wool with LCA

- Part of The Swedish Wool Initiative

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Miljögiraff

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Miljögiraff is an environmental consultant specialising in product Life Cycle Assessment and Life Cycle Design. We believe that combining analysis and creativity is necessary to meet today's challenges. Therefore, we provide Life Cycle Assessment to evaluate environmental aspects and design methods to develop sustainable solutions.

We create measurability in environmental work based on a life cycle perspective on ecological aspects. The LCA methodology establishes the basis for modelling complex systems of aspects with a credible assessment of potential environmental effects.

Miljögiraff is part of a global network of experts in sustainability metrics piloted by PRé Sustainability.

Picture on front page: Authors own picture (2025)

Abbreviations and Expressions

Clarification of expressions and abbreviations used in the report

CO_2 eq – Carbon dioxide equivalents
EPD – Environmental Product Declaration
GWP – Global Warming Potential
GHG – Greenhouse Gas
ISO – International Organization for Standardisation
IPCC – Intergovernmental Panel on Climate Change
LCA – Life Cycle Assessment
LCI – Life Cycle Inventory Analysis
LCIA – Life Cycle Impact Assessment
PCR - Product Category Rules
RER – The European region
RoW – Rest of the world
GLO – Global
APOS – Allocation at the point of substitution (system model in ecoinvent)
Cut-off in ecoinvent – Allocation cut off by classification (system model in ecoinvent)
Cut-off in general – Environmental impact that contributes insignificantly to the overall results.

Environmental aspect - An activity that might contribute to an environmental effect, for example, “electricity usage”.

Environmental effect - An outcome that might influence the environment negatively (Environmental impact), for example, “Acidification”, “Eutrophication”, or “Climate change”.

Environmental impact - The damage to a safeguarding object (i.e., human health, ecosystems, health, and natural resources).

Life Cycle Inventory (LCI) data – Inventory of input and output flows for a product system

Carbon footprint of a product (CFP) – sum of GHG emissions and GHG removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change

Abstract

This study investigates methodological aspects of assessing the climate impact of Swedish wool-based products through Life Cycle Assessment (LCA). It aims to clarify why climate impact results for wool vary widely across datasets and to explain how co-product allocation at the farm level fundamentally influences LCA outcomes. The study assesses the climate impact of two current Swedish wool supply chains and explores a future, more integrated scenario, while identifying key data gaps and methodological needs to enable Environmental Product Declarations (EPDs) for Swedish wool products.

Results demonstrate that the allocation of environmental impacts between wool and meat at the farm level is the dominant methodological choice affecting results. For Swedish conditions, where sheep farming primarily serves landscape management and meat production while wool remains a low-value by-product, economic allocation is found to most accurately represent the system's purpose and market dynamics. Economic allocation for the co-products at the farm provides a climate impact result of about 4–5 kg CO_2 eq/kg greasy wool and 28 kg CO_2 eq/kg meat, compared with 43 kg CO_2 eq/kg greasy wool and 11 kg CO_2 eq/kg live weight with biophysical allocation by protein mass.

Beyond allocation, the study emphasizes that Swedish sheep farming delivers significant ecosystem services, such as biodiversity maintenance and landscape preservation, that are poorly captured in conventional LCA. These services are partially recognized through subsidies, suggesting that their economic value could be integrated into LCA through extended economic allocation approaches.

The analysis identifies wool production at the farm stage as the main climate hotspot for the assessed supply-chains, which highlights the need about transparency in data choices and allocation method for LCA on wool products. The analysis also shows that regionalized supply chains powered by renewable electricity could reduce total emissions. The report concludes that evolving LCA frameworks to better represent multifunctional farming systems and adopting economic allocation can improve both the representativeness and fairness of environmental assessments for Swedish wool. Furthermore, it outlines practical steps toward EPD readiness.

Sammanfattning

Denna studie undersöker metod aspekter av att bedöma klimatpåverkan från produkter gjorda av svensk ull med hjälp av livscykelanalys (LCA). Syftet är att förklara varför resultaten för ull varierar kraftigt mellan olika datakällor och att belysa vilken roll allokering av miljöpåverkan mellan produkter från fårfarmen påverkar resultaten. Studien visar en klimatbedömning av två nuvarande leveranskedjor för svensk ull samt ett framtidsscenario med en mer integrerad värdekedja. Dessutom identifieras dataluckor och metod behov som måste åtgärdas för att möjliggöra miljövarudeklarationer (EPD) för produkter av svensk ull.

Resultaten visar att valet av allokering av miljöpåverkan mellan ull och kött på gårdsnivå är den mest avgörande faktorn för resultatet. Under svenska förhållanden, där fårhållning främst syftar till att hålla landskapet öppet och producera kött medan ull länge betraktats som en biprodukt med lågt ekonomiskt värde, bedöms ekonomisk allokering ge den mest rättvisa bilden av systemets syfte och marknadsförutsättningar. Ekonomisk allokering mellan produkterna på gården ger ett resultat på cirka 4–5 kg CO_2-ekv/kg råull och 28 kg CO_2-ekv/kg kött, jämfört med 43 kg CO_2-ekv/kg råull och 11 kg CO_2-ekv/kg levande vikt vid bio-fysisk allokering baserad på proteininnehåll.

Utöver allokeringsfrågan betonar studien att svensk fårhållning bidrar med betydande ekosystemtjänster – såsom bevarande av biologisk mångfald och öppna landskap – som i liten utsträckning fångas upp av konventionell LCA-metodik. Dessa tjänster erkänns delvis genom jordbruksstöd, vilket antyder att deras ekonomiska värde skulle kunna inkluderas i LCA via utvidgade ekonomiska allokeringsmetoder.

Analysen visar att ullen är den största källan till klimatpåverkan för de bedöma leveranskedjorna, vilket belyser vikten av transparens kring data och allokeringsval vid LCA av ullprodukter. Analysen visar också att regionala och mer integrerade leveranskedjor, med kortare transporter och användning av förnybar el, har potential att minska påverkan. Rapporten drar slutsatsen att LCA-ramverk bör utvecklas för att bättre spegla multifunktionella jordbrukssystem och att ekonomisk allokering kan bidra till mer rättvisa och representativa miljöbedömningar för svensk ull. Vidare presenteras konkreta steg för att öka beredskapen för framtida EPD:er.

1 Introduction

This study is part of the Swedish Wool Initiative – an initiative aiming to strengthen the Swedish wool value chain by fostering structure, knowledge, and collaboration. The overarching goal of the initiative is to promote the increased use of Swedish wool while ensuring environmentally responsible practices, animal welfare, and fair working conditions across the entire value chain - from sheep farming to finished products.

A central objective of the initiative is to generate reliable and up-to-date environmental data specific to Swedish wool. Currently available international datasets are often outdated and do not accurately reflect Swedish conditions. To address this, the project builds upon the climate impact research conducted by Ahlgren et al. (2022) which provides data tailored to Swedish sheep farming practices. This assessment extends the scope by evaluating the climate impact of full product supply chains based on Swedish wool. The reason why only the climate impact is assessed is that data for other impact categories could not be found for Swedish wool within a reasonable effort in this study.

The assessment is carried out in accordance with the ISO 14067 standard for quantifying and reporting the carbon footprint of products. It focuses specifically on the climate impact associated with wool-based supply chains in Sweden. The study includes the following supply chains:

- **Wool yarn production by Klippan Yllefabrik**
- **Wool fabric production by VERK**

In addition to these two case studies, a future production scenario in **Holma-Helsingland** will be assessed. This scenario examines the potential climate impact reduction when the entire production process, from raw wool to dyed yarn, is geographically located at the same place.

The focus with the study is also to discuss methodological aspects for assessing Swedish wool-based products with LCA. Furthermore, to extract and discuss the data gaps and methodological needs that must be addressed to enable an environmental product declaration (EPD), encompassing multiple environmental impact categories, for assessed products.

The aim is that these findings will help guide the Swedish wool industry what is relevant when making an LCA for Swedish wool. The intended audience of this report includes stakeholders involved in the Swedish Wool Initiative, as well as other actors interested in environmental data for Swedish wool's climate performance.

In conclusion:

After reading this report you should know the answer to:

- Why does the climate impact result for different wool data differ allot?
- What is co-product allocation in LCA and how does it affect the result in an LCA study off wool?

Furthermore, the study presents:

- Assessment of the climate impact of products made from Swedish wool
- Discussion how LCA frameworks can evolve to favour materials like wool

1.1 Reading Guide

The purpose of the report is to provide valuable insight to decision making and detailed information about how the study was made and the results. Readers can select sections of the report depending on focus.

Abstract - The abstract explains in short the purpose and the conclusions.

If you are new to LCA it is recommended to read chapter **2 Background.** It gives an introduction to why we measure the environmental impact and the LCA methodology. Furthermore, it introduces wool as a textile fibre and what challenges there are when doing an LCA for wool from a Swedish wool supply-chain.

LCA documentation for assessed products can be found in **chapter 3 Goal and Scope, 4 Life Cycle Inventory (LCI), 5** Result and discussion of the impact assessment of Swedish wool with different allocation methods**,** and **6 Result of the impact assessment of the supply-chains for Klippan yarn and VERK's fabric.** The result chapters also discuss what is important LCA methodology wise when making an LCA of Swedish wool. Lastly, it is discussed what could be required for making an Environmental Product Declaration (EPD).

Chapter **7 Scenario analysis on integrated supply-chain at Holma-Helsingland** shows a scenario of an integrated supply-chain at Holma-Helsingland.

Lastly, chapter **8 Conclusions and recommendations** summarise the conclusions from the study in terms of highlighting the most important outcomes and recommendations.

2 Background

Following sections gives background to why we measure the environmental impact and the LCA methodology. Furthermore, it introduces wool as a textile fibre and what challenges there are when doing an LCA for wool from a Swedish wool supply-chain.

2.1 The Sustainability Challenge – the environmental pillar

Sustainability comprises meeting our own needs without compromising the ability of future generations to meet their own needs. Industrial and natural systems depend on a stable Earth system to function. A quantitative planetary boundary within which humanity can continue to develop and thrive for generations to come has been proposed (Richardson et al., 2023) . These researchers describe nine processes that determine the resilience and stability of the Earth system, such as climate change, water use, and land use. Crossing these boundaries increases the risk of abrupt and irreversible environmental change, while staying within the boundaries represents a safe operating space for a sustainable society, see figure below.

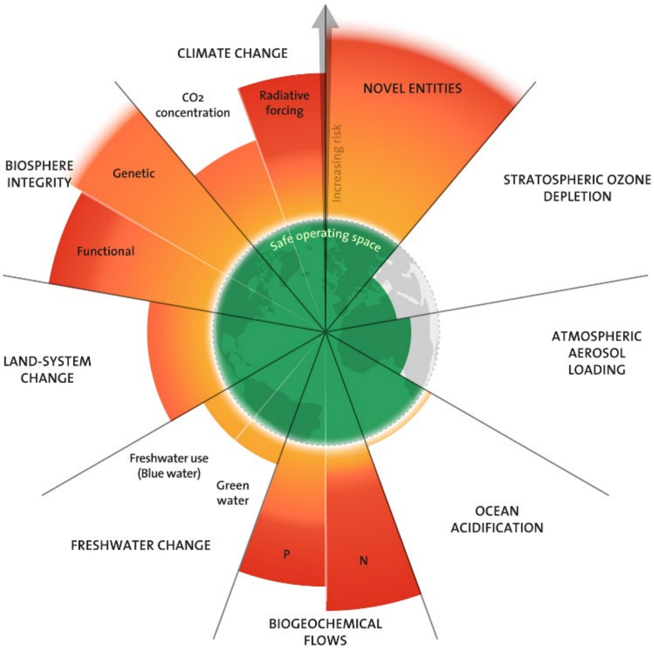


Figure 1 The 2025 update to the Planetary boundaries from Azote for Stockholm Resilience Centre, based on analysis in Sakschewski and Caesar et al. 2025

One critical environmental problem we face today is climate change. The report from the Intergovernmental Panel on Climate Change (IPCC), shows that only the most ambitious of five scenarios for greenhouse gas emissions would result in a temperature increase within 2°C (IPCC, 2021a), see Figure 2. Considering that limiting temperature rise below 1.5°C is the ambition of the Paris Agreement 2016, it is evident that the available space for mitigating radical climate change is ever-shrinking, necessitating decisive action in all parts of society. This is also evident in the latest report from IPCC (IPCC, 2022).

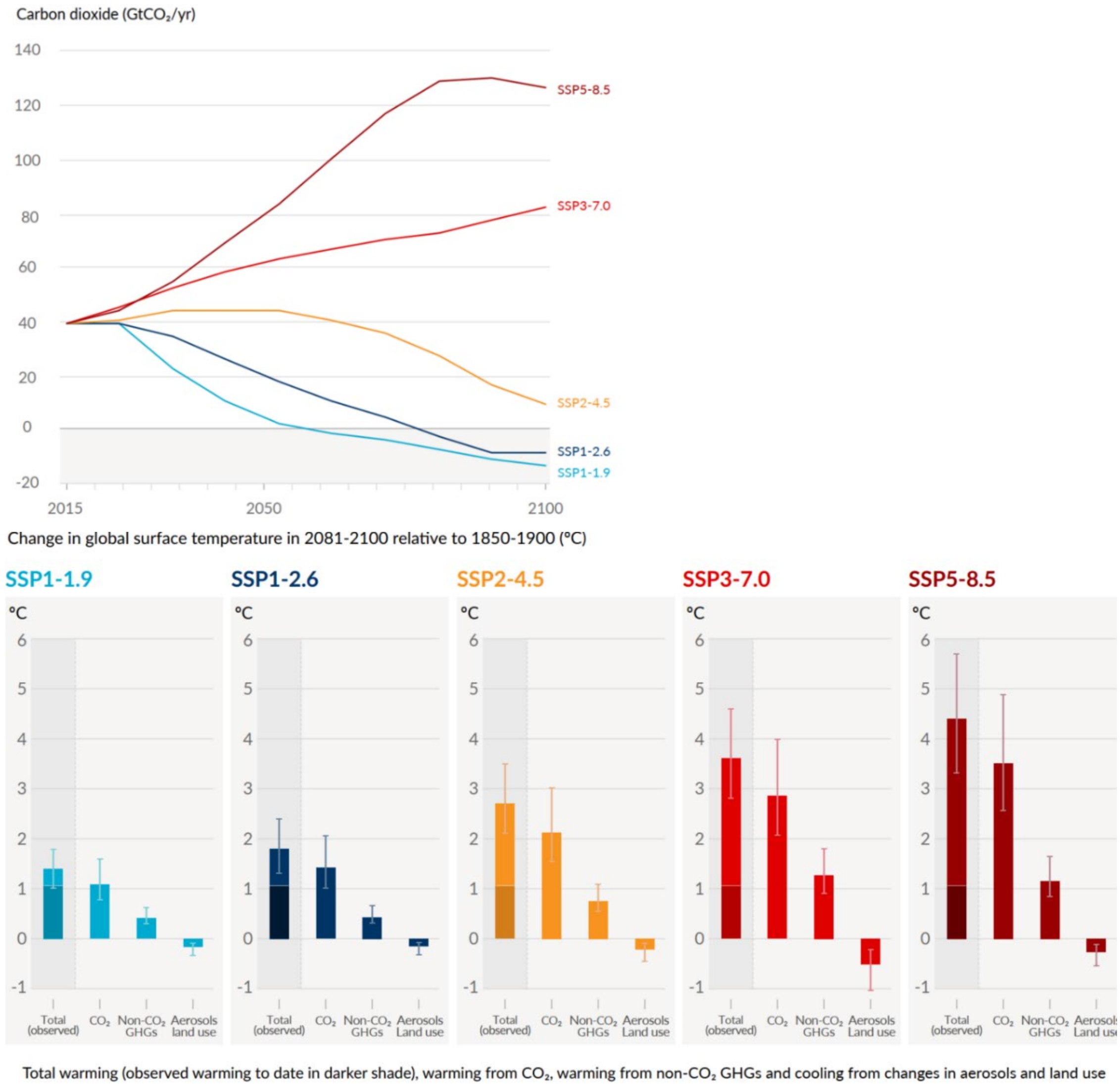


Figure 2: Future annual emissions of CO_2 (top) and contribution to global surface temperature increase from different emissions, with a dominant role of CO_2 emissions (bottom) across five illustrative scenarios. Image from IPCC (2021b).

2.2 Life Cycle Assessment (LCA) methodology

Quantifying environmental impact through Life Cycle Assessment (LCA) involves evaluating the entire life cycle of a product - from raw material extraction and manufacturing, to use and end-of-life treatment (see Figure 3). Furthermore, the results should be quantified in relation to the function of the product. In the context of wool - a function of a wool sweater could be to be number of uses or the function of a wool fabric could be its technical quality. Analysing the environmental impact in a relevant way is the key challenge when conducting an LCA. It is therefore important to set a clear goal and scope, answering what the environmental impact result should be used for and who should use the result.

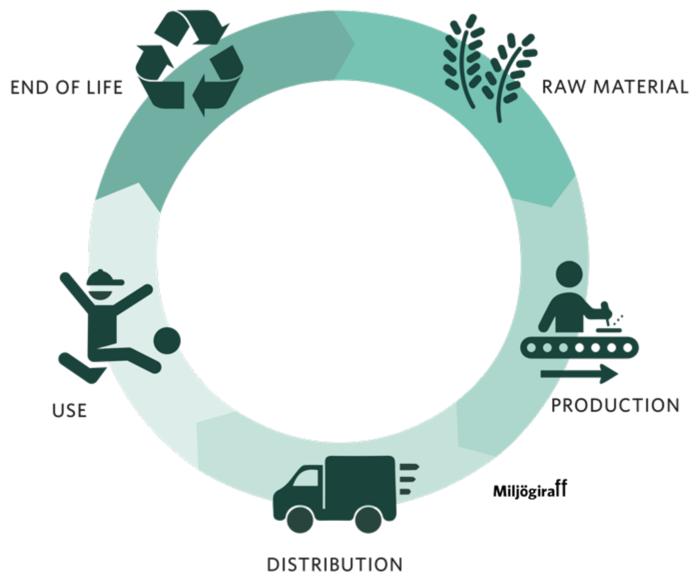


Figure 3: The Life Cycle concept, starting from raw material extraction, production, and distribution, followed by use and end-of-life.

The contribution of LCA and its limitations

Understanding the potential environmental impact in connection with the manufacture and use of products is increasingly important. LCA is an accepted standardised method that is applied to create this understanding. Being a quantitative tool, LCA can contribute to more sustainable development by identification of hotspots and by guiding actionable measures to reduce environmental impacts. A business can use the results of an LCA to develop strategy, management and communication of environmental issues related to products. By including environmentally relevant input and output flows through a product's entire supply chain, from raw material extraction to final disposal, LCA provides a comprehensive basis for the environmental impact of a product's supply chain.

Products' supply chains are complex and involve numerous connections. Therefore, to analyse a product's entire life cycle, LCA practitioners must simplify it into a model which involves limitations, as those as summarised by Guinée et al. (2002):

- Localised aspects are typically not addressed, and LCA is not a local risk assessment tool
- LCA is typically a steady-state approach rather than a dynamic approach
- LCA does not include market mechanisms or secondary effects on technological development
- Processes are considered linear, both in the economy and the environment, meaning that impact increases linearly with increased production.
- LCA involves several technical assumptions and value choices that are not purely science-based
- LCA focuses on environmental aspects and excludes social, economic, and other characteristics

Standards for LCA

Already in 1997, the European Committee for Standardisation published their first set of international guidelines for the performance of LCA. This ISO 14040 standard series has become widely accepted amongst the practitioners of LCA and is developing along with progressions within the field of LCA (Rebitzer et al., 2004). The guidelines for LCA are in two documents: ISO 14040, which contains the main principles and structure for performing an LCA, and ISO 14044, which includes detailed requirements and recommendations. Furthermore, a document containing the format for data documentation (ISO/TS 14048) and technical reports with guidelines for the different stages of an LCA are available in ISO/TR 14047 and ISO/TR 14049 (ISO, 2012b, 2012a).

The LCA methodology

In short, the LCA methodology follows four phases: the goal and scope definition phase, the inventory analysis phase, the impact assessment phase and the interpretation phase. Below is a conceptual picture of this in Figure 4.

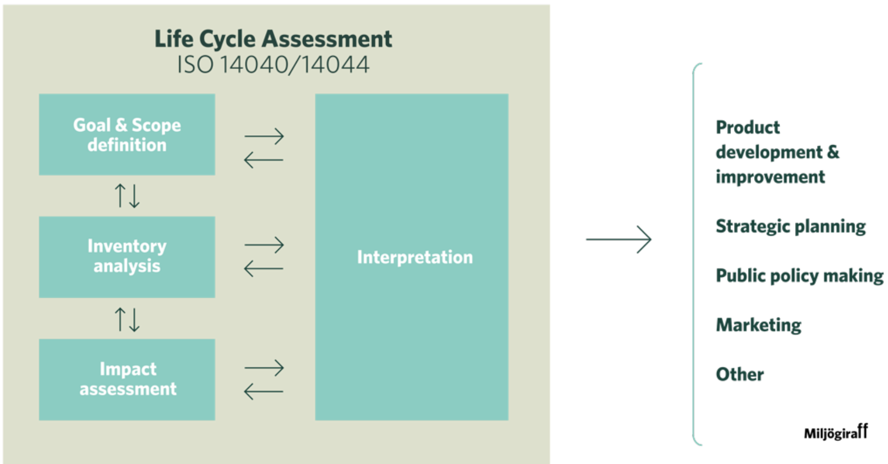


Figure 4. The four phases of the Life Cycle Assessment

The first phase is the definition of goal and scope. The goal and scope, including system boundary and level of detail, of an LCA depend on the subject and the intended use of the study. The depth and breadth of LCA can differ considerably depending on the goal of a particular LCA. The goal also affects the choice of system boundaries and data requirements.

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study and is often the most time-consuming step that may require iterations when results reveal significant data.

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance. Mandatory steps in the lifecycle impact assessment are classification and characterisation. An optional step is weighting. Readymade methods for classification, characterisation and weighting have been used to evaluate environmental effects (either from a broad perspective or for a single issue) and find the categories or parts of a system with the most potential impact. Some of the most common LCIA methods are e.g. Environmental Footprint 3.1 providing result in 16 different impact categories and IPCC GWP100 2021 which focusing of results for the climate impact.

The life cycle interpretation phase of an LCA or an LCI study comprises several elements:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA
- an evaluation that considers completeness, sensitivity and consistency checks
- conclusions, limitations, and recommendations.

The interpretation of the results in this study is carried out by first identifying the aspects that contribute the most to each individual environmental effect category. After that, the sensitivity of these aspects is evaluated, and the completeness and consistency of the study are assessed. Conclusions and recommendations are then based on the results and a clear understanding of how the LCA was conducted with any subsequent limitations.

Ingredients for making an LCA

In conclusion, making an LCA is an iterative process of evaluating if the study is complete and consistent to fulfil the goal and scope of the study. Part from the ISO standard ISO 14040 and ISO 14044, making an LCA requires some tools like scientific and reliable background data and an LCA software. For example, ecoinvent data library and LCA software SimaPro for calculation and modelling (see Figure 5). More in-dept description about the LCA methodology can be found in Appendix 1.

Figure 5: Ingredients for making an LCA: ISO standard combined with reliable data from ecoinvent and the LCA software SimaPro.

2.3 Environmental Product Declaration (EPD)

What is an EPD?

An Environmental Product Declaration (EPD) is a standardized and verified environmental report for products and services, based on Life Cycle Assessment. EPDs are Type III environmental declarations according to ISO 14025 standards. They are intended to provide transparent, comparable, and third-party verified information of environmental performance. Hence EPDs are preformed when results of environmental assessments are to be communicated externally. The EPD document packages the LCA into a standardized format for external communication.

What is required to comply with EPD rules?

To develop an EPD, the LCA must follow the Product Category Rules (PCR) defined for the relevant product type. PCRs set the methodological framework, including:

- System boundaries: defining cradle-to-gate or cradle-to-grave coverage.
- Mandatory impact categories: EPDs require a broader set of categories beyond climate change (e.g. ozone depletion, acidification, eutrophication, photochemical ozone formation, resource use, and waste indicators).
- Allocation rules: defining how to treat co-products consistently.
- Data quality requirements: including temporal, geographical, and technological representativeness.
- Reporting format: ensuring transparent and comparable communication of results.

EPD programme operators facilitates the process of making sure PCRs are developed and updated along with EPD registration, verification and publication. In this study the EPD programme operator referred to is EPD International – as this is the established EPD operator in Sweden.

2.4 Wool as a textile fibre

The global textile industry needs to undergo a paradigm shift toward sustainability, traceability, and circularity (European Commission, 2025). Among the diverse range of textile fibres available today, wool is unique due to its natural origin, properties, and complex environmental profile. While it represents a small fraction of the global fibre market by volume, wool's high value, biodegradability, and multifaceted use make it a fibre of particular interest for environmentally conscious innovation and analysis. This chapter explores wool within the broader landscape of textile fibres, drawing on life cycle assessment (LCA) data, and the sustainability challenges of modern wool production.

Global textile fibres: market share & trends

The global production of textile fibres has grown significantly in recent years, reaching an all-time high of approximately 124 million tonnes in 2023, up 7% from 2022 (Textile Exchange, 2024) . Synthetic fibres, particularly polyester, dominate the market with a share of approximately 67%, followed by cotton at around 20%. Plant-based fibres such as jute, flax, and hemp also contribute significantly with about 25%. In contrast, wool represents a small share, about 1% of global fibre market by weight (Textile Exchange, 2024). Despite this, wool retains economic relevance due to its high quality, durability, and use in specialized applications, from fashion to industrial insulation materials.

Wools quality and application

Wool is valued for its exceptional properties, including thermal insulation, breathability, flame resistance, and elasticity. These characteristics make it suitable for a wide array of applications—from high-end fashion garments and athletic wear to upholstery, bedding, and technical textiles.

Wool fibers can absorb moisture without feeling damp, making wool comfortable and hygienic for clothing. Furthermore, wool is naturally odor-resistant and less likely to retain bacteria compared to synthetic materials. These features make wool an attractive option in consumer markets.

The quality of the wool and its application is largely determined by the diameter of the fibre (IWTO, 2016). The merino breed produces the finest wool with grades ranging from ultrafine (<5.0 microns) to broad wool of ≤24.5 microns. Other sheep breeds and crossbreeds have higher diameter fibres with this coarser wools (up to 35-45 microns), commonly used for floor coverings (IWTO, 2016).

Global wool production
The wool supply chain begins at sheep farms, which are distributed across approximately 100 countries, spanning a wide range of geographic and climatic regions (IWTO, 2016). The top producers of raw (greasy) wool include Australia, China, and New Zealand.

Wool processing and manufacturing are significant industries in several countries (IWTO, 2016). China plays a central role, not only as a major producer and importer of wool but also as the global hub for processing, spinning, and weaving. Italy and the United Kingdom are also important centres for spinning, knitting, and weaving, while various countries across Asia contribute to the production of wool fabrics and garments (IWTO, 2016).

Sustainability challenges in global wool production
While wool offers numerous environmental advantages, such as renewability and biodegradability, it also presents sustainability challenges (Gonzalez et al., 2023; Vade et al., 2024). One of the most pressing issues is methane emissions from sheep, a potent greenhouse gas contributing to climate change. Land degradation, caused by overgrazing and poor pasture management, also affects soil health and biodiversity. Moreover, animal welfare concerns, such as mulesing which is a controversial practice to prevent flystrike in sheep which have raised ethical questions in consumer markets. Water pollution from scouring and chemical treatments further complicates the environmental footprint of wool processing (Gonzalez et al., 2023; Vade et al., 2024). However, innovative approaches, including regenerative grazing, organic certification, and mechanical wool recycling, offer pathways toward more sustainable production.

Since wool production comes with environmental impact it is important to make the most use of the material. Due to the quality of wool, it has the potential to end-up in quality products. Wiedemann et al. (2020) concluded in a study assessing the environmental impacts from the whole lifecycle of a wool garment that the number of garment wear events and length of garment lifetime was the most influential factor in determining garment impacts. Furthermore, garment care with washing and drying can be hots-spots for the climate impact and water use. This indicated that consumers have the largest capacity to influence the environmental impact of their woollen garments by maximising the active garment lifespan which will reduce overall impacts (Wiedemann et al., 2020).

2.5 The challenge with a Swedish wool supply-chain

Sheep farming in Sweden is primarily motivated by landscape management and the preservation of semi-natural pastures. Grazing helps maintain biodiversity in species-rich areas and sustains cultural landscapes, while also utilizing land unsuitable for other food production (Ahlgren et al., 2022; Glimskär et al., 2023)

Sheep grazing in Sweden has partly been assessed in a study conducted by Ahlgren et al. (2022) were they state that it contributes to keeping the landscape open and preserving semi-natural pastures. These pastures are often highly species-rich and have significant ecological value. Grazing by sheep can therefore help maintain and strengthen biodiversity, particularly in areas that would otherwise risk becoming overgrown. The report also highlights that sheep can utilize land that is not suitable for other types of food production, such as poor soils or land with lower productivity. This means that sheep farming can play an important role in maintaining cultural landscapes and environments that would otherwise not be managed (Ahlgren et al., 2022; Glimskär et al., 2023).

After grazing, the primary focus of having sheep in Sweden is to produce meat and the wool is currently viewed mainly as a byproduct (Svenska fåravelsförbundet, 2020). Swedish wool historically comes with widely varying fibre quality which depend on breed to breed, from old sheep to young lambs, and depending on how well it's handled. Since the Swedish wool has been viewed as a by-product of meat farming rather than for textile use, it has been difficult to process the wool using established industrial methods. Until recently, over half of the wool produced was typically discarded due to inconsistencies, lack of classification systems, and poor infrastructure (Behrman & Lindfred, 2025; Svenska fåravelsförbundet, 2021). This has made transport and profitable value chains for Swedish wool challenging (Arena Svensk Ull, 2025; Behrman & Lindfred, 2025), especially since wool of a certain quality is hard to collect in larger volumes (Behrman & Lindfred, 2025). According to Svenska fåravelsförbrundet (2021), up to 83% of Swedish wool was burned, destroyed, or thrown away in 2016 and by 2020, this share was 54%, marking improvement yet still indicating persistent under use of Swedish wool and the same year around 1750 tons wool were imported.

Swedish wool is a regional, biobased, and renewable resource with significant potential. There is an industry demand for finding local raw materials and to develop supply-chains for these. But as mentioned, there are challenges in establishing entirely new supply chains for Swedish wool. Cooperation among various stakeholders and organizations is essential. Swedish sheep farms are small or medium-sized enterprises, often geographically dispersed. These individual companies lack the resources needed to independently shear, collect, sort, handle, store, and distribute the wool produced by the sheep. Therefore, scaling up the dispersed operations is necessary to capitalize on Swedish wool, which can be achieved through collaboration and innovative solutions.

Efforts led by the Swedish Wool Initiative have begun to transform the landscape. With the launch of the Swedish Wool Standard in 2023 and the development of improved collection and broker networks, wool sorting and quality assurance now have a unified framework. These developments are paving the way for more consistent, usable Swedish wool across industries, from fine apparel to home textiles, outdoor gear, and furniture (Behrman & Lindfred, 2025).

2.6 Challenge of quantifying the environmental impact of wool with Life Cycle Assessment

As mentioned in chapter 2.2, Life Cycle Assessment (LCA) is the established method for evaluating the environmental impact of products and services. LCA is designed to quantify environmental impacts in terms of emissions and resource use (e.g., CO_2, water use, eutrophication). For wool, positive contributions such as maintaining biodiversity, keeping landscapes open, and preserving cultural values are not fully captured. These important benefits of grazing are difficult to integrate into standard LCA categories.

When performing an LCA of wool, one key complexity is the allocation of environmental impacts among the various co-products of sheep farming. Sheep farms typically produce not only wool, but also meat, hides, and sometimes milk. Because these products are generated from a common system, their environmental burdens must be divided in a rational and transparent manner. When making an LCA this is called an allocation problem and requires an allocation method.

Several allocation methods exist, each of which can significantly influence the result. In a report from IVL Swedish Environmental Research Institute (Moberg et al., 2023) assessing different methodological choices for LCA on wool, the allocations applied in LCA studies on wool are economic allocation, no allocation to wool (wool and other non-meat by-products are accounted as waste), biophysical allocation, and mass allocation. The most common in other LCA studies are described in more detail below:

- **Biophysical allocation**: Considers biological or physical relationships, such as the amount of feed required to grow wool versus meat. Or the protein content of the wool versus meat.
- **Economic allocation**: Distributes impacts according to the economic value of each co-product.

The choice of allocation method is a critical decision in LCA, as it directly influences how much of the total environmental impact is assigned to wool. When selecting an allocation method, it is important to ensure that it aligns with the purpose of the production system and reflects both the function and market reality of the product being assessed. A key difference between different systems lies in whether the wool is considered a low-value by-product or an important driver of the production. This varies between countries. For example, as described in Wiedemann et al. (2015) sheep production in New Zealand and Australia is often optimized for both wool and meat. In systems with a larger focus on wool outputs, the amount of wool generated per kg meat output in generally higher.

For example, the IVL study by Moberg et al. (2023) concluded that when using economic allocation for Swedish sheep farming systems primarily focused on meat production, wool was assigned 0.3–0.7% of the total environmental impact from the farm (Ahlgren et al., 2022; Moberg et al., 2023). In contrast, in Australian sheep systems primarily focused on wool production, economic allocation resulted in wool carrying 65% of the farm's environmental impact (Cottle & Cowie, 2016). This difference highlights how the main driver of the production system, whether it is meat or wool, affects the allocation outcome. In Australia, the higher degree of specialization in wool production, along with more efficient wool harvesting and use, increases its economic value, which in turn raises its share of the environmental burden under economic allocation.

In a study by Wiedemann et al. (2015) investigating co-production of wool and meat using case studies from major global producers, they concluded recommending biophysical allocation for attributional LCA studies (in particular, the alternative that they name BA2 in which the maintenance requirements for the breeding flock are split between wool and meat according to the wool to sheep meat ratio while all maintenance requirements for slaughter lambs and all direct requirements for growth are attributed to meat). The protein requirements depend on the local conditions where the sheep are farmed and should be calculated for the specific location for which a study is conducted.

Regardless of how impacts are divided between the different products, sheep farming always comes with an environmental footprint. This includes emissions of greenhouse gases, use of land, and water consumption. On the other side, Swedish sheep farming has been recognized for its positive contributions to several of Sweden's environmental objectives. One key benefit is the role of grazing animals in maintaining biodiversity (Ahlgren et al., 2022). Additionally, Swedish agriculture, especially grass ley cultivation, has been highlighted for its potential to contribute to carbon sequestration (Moberg et al., 2023). The level of impact depends on factors such as farming methods, the health of the animals, and local environmental conditions. One way to reduce the negative environmental impact per product is to make full use of everything the sheep provide. By using not just the wool, but also the meat, hides, and any other co-products, the overall impact is spread out more efficiently. This helps make better use of the resources that go into sheep farming.

2.6.1 Allocation factors and GWP results from literature

Table 1 presents a range of values for allocation factors and resulting GWP impact per 1 kg wool, from different environmental databases as well as from the often-cited paper by Wiedemann et al. (2015). Three biophysical allocation based approaches are presented by Wiedemann et al. (2015): BA1, BA2 and BA3. All three are based on protein requirement as a biophysical basis for dividing the impact between wool and live weight. The difference between the three approaches lies in how the so called maintenance requirements are divided between wool and live weight, this is discussed in more detail in the allocation chapter 3.3.3.2 Allocation of co-products.

From Table 1 it is clear that the resulting impact per kg wool is strongly dependent on the allocation method used (see values for case study 1 from Wiedemann et al. (2015).

Table 1 also lists datasets that are available in the environmental databases ecoinvent, Agribalyse, WFLDB and EF3.1. The results for these are illustrated in Figure 6.

In the ecoinvent database (version 3.10), there are two types of datasets available for greasy wool: 1) wool from sheep production for meat, and 2) wool from sheep production for wool. The first option means the sheep production primarily serves the purpose of producing meat (output: 62.8 kg of sheep for slaughtering, live weight and a by-product of 4.2 kg of sheep fleece in the grease), while the second option means that the sheep production primarily serves the purpose of producing wool (4.2 kg of sheep fleece in the grease and a by-product of 7.85 kg of sheep for slaughtering, live weight). An important difference, according to the ecoinvent dataset documentation, is also that sheep for meat are typically farmed for 1 year while sheep for wool are farmed for 6-8 years. The allocation factors used in the two ecoinvent datasets are shown in Table 1. These are based on economic allocation. Ecoinvent does not report the underlying economic value considered per kg of meat and wool, respectively. However, we can see that the value per kg of wool must be higher than per kg of meat, given that the economic allocation factor for wool is higher than its mass share.

The World Food LCA database (WFLDB) uses a protein-based approach to allocation. The use protein-content values from Wiedeman et al., (2015) and (2016) – 18% in the living animal (sheep or lamb) and 68% in greasy wool (100% in pure wool).

The Agribalyse database is based on French data. They also state that they use bio-physical allocation, but it is not completely clear how they calculated their allocation factors. This is the database which contains the wool dataset with lowest GWP100 impact of all wool datasets available in SimaPro: Wool, organic, system number 1, at farm gate {FR} U, which has a GWP100 impact of 2.6 kgCO2eq/kg wool. However, it is clearly stated that this data is for a specific farm and might not be representative of other farms in France.

The EF 3.1 database contains datasets for wool that is compulsory to use for anyone producing a PEF study for a wool-containing product according to the PEF category rules for Apparel and Footwear (unless primary data is available from the sheep farm). The global production mix is modelled based on sheep farming in New Zealand and Europe. Biophysical allocation is applied for wool, milk and meat based on energy requirements. The allocation factors are not presented in the dataset documentation but are likely derived following the guidelines in the PEF method.

Table 1: Allocation factors and GWP impact of wool from different references

Dataset	Country	Allocation method	Amount output greasy wool per meat kg wool/kg meat	Allocation factor wool	Resulting GWP wool kgCO2eq/kg	Comment
ecoinvent Sheep fleece in the grease {RoW}| sheep production, for meat | Cut-off, U	Mixed (outside US)	Economic	6%	9%	8.98	Assumes that the farm's primary purpose is to produce meat.
Ecoinvent Sheep fleece in the grease {RoW}| sheep production, for wool | Cut-off, U	Mixed (outside US)	Economic	35%	45%	43.8	Assumes that the farm's primary purpose is to produce wool.
WFLDB Wool, mixed system, greasy weight, at farm (WFLDB)/AU U	Australia	Biophysical Allocation approach by protein mass	13%	36%	27.2	Based on a protein content of 18% in meat and 68% in greasy wool.
Wool, mixed system, greasy weight, at farm (WFLDB)/IE U	Ireland	Biophysical Allocation approach by protein mass	6%	19%	27.3	Based on a protein content of 18% in meat and 68% in greasy wool.
Agribalyse Wool, organic, system number 1, at farm gate {FR} S	France	Biophysical Allocation approach by protein requirement	?	?	2.6	Data from a specific farm, not representative for the country. Exact allocation factors not found.
Case study 1 (UK) from Wiedemann et al. (2015)	UK	Biophysical Allocation approach by protein requirement – "BA1"	6%	22%	37.5	
Case study 1 (UK) from Wiedemann et al. (2015)	UK	Biophysical Allocation approach by protein requirement – "BA2"	6%	15%	25.6	

Case study 1 (UK) from Wiedemann et al. (2015)	UK	Biophysical Allocation approach by protein requirement – “BA3”	6%	7%	11.9	
Case study 1 (UK) from Wiedemann et al. (2015)	UK	Economic allocation	6%	4%	6.8	
EF 3.1 database, Wool {GLO} | sheep | production mix, at farm | 1 kg wool | LCI result	GLO (based on NZ and Europe)	Biophysical allocation – energy requirement	?	?	Higher than all others	No exact allocation factors found, the PEF method states that 23.64% should be used for wool. Impact assessment results not presented here since the user agreement does not allow the use of the dataset for other purposes that to conduct a PEF-compliant study.

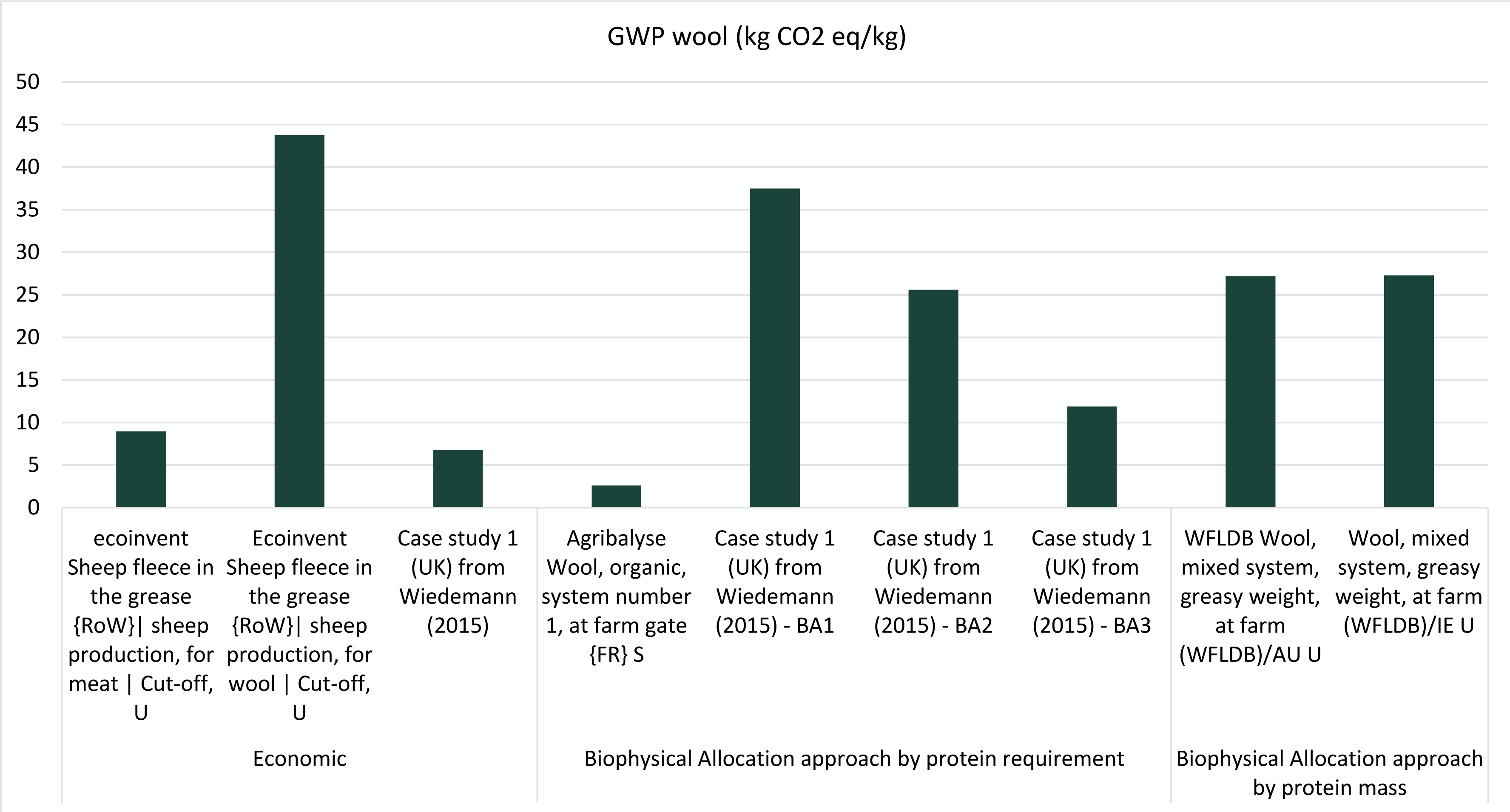


Figure 6 Comparison of climate data for greasy wool using different sources and divided by allocation method

2.6.2 Guidelines to allocation in standards

Allocation according to general LCA standard

The ISO 14044 standard on LCA recommends the following three-step procedure when allocating environmental burdens in multi-output systems (ISO, 2006b):

- Allocation should be avoided if feasible.
- If allocation is necessary, physical relationships should be used.
- If no valid physical allocation basis exists, economic or other proxy relationships should be applied.

Allocation according to Environmental Product Declaration (EPD) standards

When making an EPD, the LCA calculations must be performed according to product category rules (PCR) for assessed products. PCRs standardize how LCAs are done and reported so that EPDs published in the same product group are comparable. The PCR should for example state which allocation method needs to be applied.

Allocation of animal fibers in PCR for fabrics

The PCR for fabric by the International EPD system states that biophysical allocation for wool is required (EPD International, 2025).

Furthermore, the fabric PCR specify that the share allocated to the wool shall be calculated using the ratio of its metabolizable protein requirement to the total protein requirement for making all products like meat, milk, and wool.

Farm survey data should be used to define ruminant production systems and ruminant population. The data should be used to determine the protein requirements with the recommended hierarchy:
1. Apply a published country-specific model such as stated in Australian Livestock Feeding Standards – Ruminants.
2. Apply another model that has been peer-reviewed and published and that is applicable to the region and country.
3. Apply NRC (2007) metabolizable protein requirement model.

For biophysical allocation, a sensitivity analysis shall be carried out to illustrate the effects of the choice of biophysical allocation The biophysical allocation approach, protein requirements calculation model, sensitivity analysis methodology and sensitivity analysis result shall be available to the verifier and shall be presented in the EPDs.

Allocation in PCR for yarn and apparel

On the other hand, the PCR for yarn and apparel do not specify any certain allocation procedure for animal fibres but follows the ISO 14044 recommendation for allocation (EPD International, 2022, 2024).

Allocation according to IWTO guidelines for LCA on wool textile

In 2016, the international wool textile organisation (IWTO) published guidelines for conduction a LCA for wool textile (IWTO, 2016). The guidelines are consistent with ISO 14040 and ISO 14044 but should not be regarded as a standard or product category rules. They pointed out three main methodological challenges when conducting an LCA on wool products, mainly allocation of co-products, consumer use, and end-of-life treatment. The guidelines advise that allocation of environmental impacts should follow biophysical relationships rather than economic value, as this aligns with ISO 14044 standards and ensures that impacts are assigned based on the actual physical processes that generate each co-product. In practice, for sheep-based systems producing both wool and meat, impacts should be distributed based on the share of biological inputs (protein) leading to each output. If this method is hard to apply, they recommend using the protein content as an allocation factor (IWTO, 2016).

Allocation according to Product Environmental Footprint (PEF)
PEF is an EU-level methodology (developed under the European Commission) for assessing and communicating the environmental impacts of a product (goods or services) across its life cycle. Similarly to EPDs, there are product rules within PEF how to preform the LCA calculation so that they become comparable.

The PEF method states that allocation based on energy requirement should be used for sheep farming. The allocation factors to be used are: 2.51% to meat, 73.84% to milk and 23.64% to wool, given an annual wool production per sheep of 7.121 kg and an annual milk production per sheep of 550 lbs (250 kg). The average sheep weight at slaughter is set to 26.2. According to the PEF method, the rules build on Food and Agriculture Organization of the United Nations (FAO) guidelines for assessment Greenhouse gas emissions and fossil energy use from small ruminant supply chains. These guidelines recommend allocation based on energy requirements if milk or meat is the main product and allocation based on protein requirement if fibre (wool) is the main product (FAO, 2014). FAO, in turn, reference the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 4) for Agriculture, Forestry and Other Land Use (IPCC, 2006) as the guidelines to be follows, with the adjustment that the default energy requirement for fibre growth should be 157MJ/kg rather than 24MJ/kg as used by IPCC.

3 Goal and Scope of LCA

3.1 The goal of the Study

The main goals of this study are:

1. To discuss methodological aspects for assessing Swedish wool-based products with LCA.
2. Assess the climate impact of two supply-chains that are currently using Swedish wool and make a scenario for a future supply-chain with Life Cycle Assessment (LCA).
3. To extract and discuss the data gaps and methodological needs that must be addressed to enable an environmental product declaration (EPD), encompassing multiple environmental impact categories, for assessed products.

The aim is that these findings will help guide the Swedish wool industry what is relevant when making an LCA for Swedish wool. The intended audience of this report includes stakeholders involved in the Swedish Wool Initiative, as well as other stakeholders interested in environmental data for Swedish wool's climate performance.

3.1.1 Product description

This study assesses the climate impact of two established supply chains described below.

Wool yarn production by Klippan Yllefabrik

The supply chain for the yarn from Klippan Yllefabrik start from wool collected from the west coast of Sweden via Västkustens Ullinsamling who also do the sorting of the wool. Once the right quality is sorted out, it is sent to England where it is washed and carded before the wool is ready for spinning into yarn which is done in Lithuania.

Wool fabric production by VERK

The supply chain for the fabric from VERK start from wool collected from Gotland in Sweden via Ullkontoret Visby who also do the sorting, scouring, and carding of the wool along with spinning it into yarn. Some of the yarn is then sent to Textilhögskolan in Borås for warp production, and finished warp and additional yarn is then sent for weaving in Bollnäs. Once last step for the fabric after being woven is a surface treatment in Kinnahult.

3.1.2 Declared unit and product content

The primary purpose of the declared unit is to serve as a reference to which all input and output data, as well as the results, are normalised. This enables consistent reporting and facilitates comparison. In the context of life cycle assessment (LCA), a *functional unit* is generally preferred, as it allows for comparison between alternative goods or services based on the function they provide. Unlike a declared unit, the functional unit incorporates functional and qualitative aspects, such as performance and lifespan.

However, in this study, a *declared unit* is applied, as the assessed products are intermediate products that undergo further processing before becoming part of an end-product. This approach reflects how the results are most relevant to customers, who typically use the data at this intermediate stage.
It should also be noted that aspects such as lifespan and quality are not considered within the scope of this study. While these factors are important for assessing the environmental performance of the final product, they fall outside the scope of this assessment.

See the assed products and their declared units in the table below.

Table 2: Included products in this study

Product	Declared unit	Material composition	Intended application
Yarn	1 kg	100% wool	Used for producing fashion- and outdoor garments.
Fabric	1 m2 (weight 0,56 kg/m2)	100% wool	Used for furniture

3.2 Standards and Frameworks

Carbon footprint of a product (CFP) is sum of GHG emissions and GHG removals in a product system, expressed as CO2 equivalents and based on a life cycle assessment using the single impact category of climate change.

The standard for doing a CFP is ISO 14067 (CEN, 2020) which in tur builds on the standards for conducting an LCA which is ISO 14040 and 14044 standards (ISO, 2006b, 2006c). This study follows an attributional LCA approach (accounting) defined in the ISO 14040 standard.

The standards and frameworks guiding this LCA are in Table 1.

Table 3: Standards and framework conformance.

Standards conformance
ISO 14040 and 14044 (ISO, 2006a, 2006b)
ISO 14067 (CEN, 2020)

3.3 Scope of the Study

This section specifies the scope of an LCA, including a description of the system's functions (performance characteristics).

3.3.1 **System Boundary**

Since the products assessed are intermediate products, the system boundary for the study is defined as cradle-to-gate. This approach reflects how the results are most relevant to customers, who typically use the data at this intermediate stage. How different end-of-life scenarios, use phase aspects and product lifetime can affect the lifecycle impacts are discussed in the sensitivity analysis, see chapter 6.2.3.

Cradle-to-gate means that all processes needed for raw material extraction, manufacturing in the different supply chain steps, transports between supply-chain steps, and core manufacturing of assessed products are included. A simplified schematic representation of the cradle-to-gate systems under study is presented in the figure below.

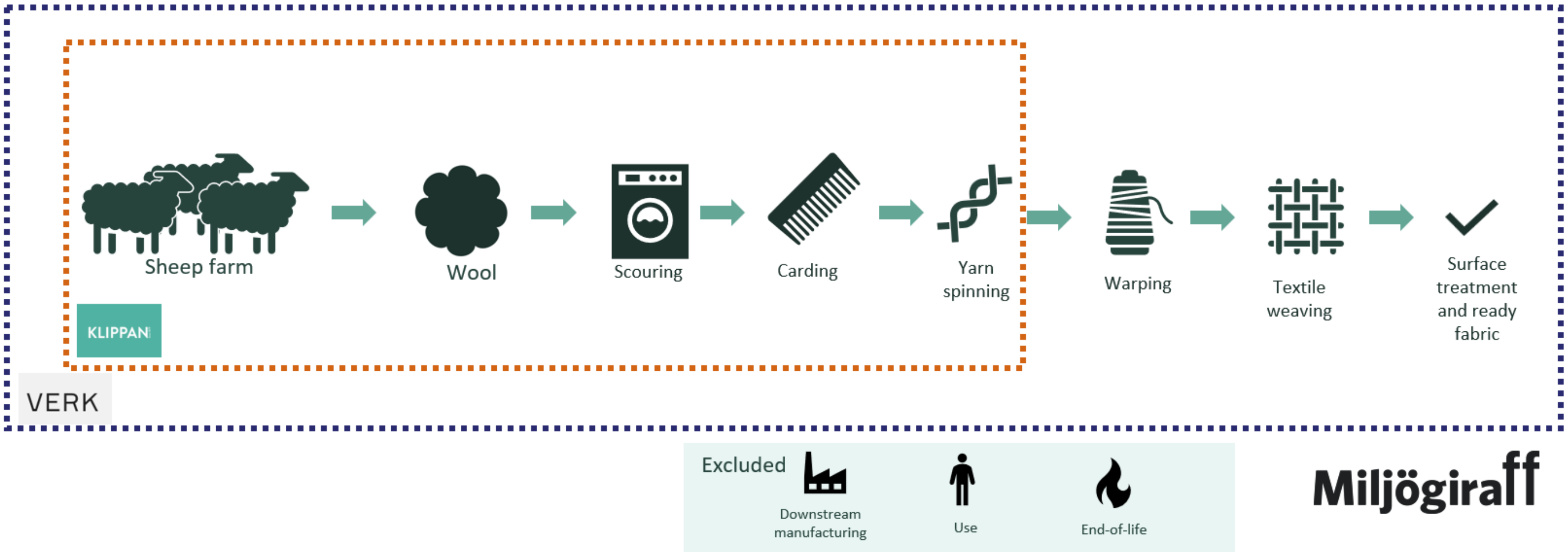


Figure 7: System boundaries for the model of the product system.

3.3.2 Cut-off Criteria

Life cycle assessment aims to include all relevant environmental flows related to a product's entire supply chain. Quantifying these impacts is done through a simplified model, as it is too time-consuming to obtain data and model every flow in practice. Specific cut-off criteria facilitate the comparison of LCA for different products. To ensure that all relevant environmental impacts were represented in the study, the following cut-off criteria were used:

Environmental relevance

Environmental relevance should be applied if the flow of a unit process has a potentially significant environmental impact. The environmental relevance was evaluated with experience and relevant external research on similar products. If an excluded material significantly contributed to the overall LCIA, more information was collected and assessed in the system.

Mass and energy

The sum of the neglected material flows should not exceed 5% of mass and energy per supply-chain step.

There can be other reasons to exclude activities or aspects of the life cycle. An overview of excluded activities is in Table 3.

Table 4: Overview of excluded activities and aspects.

Excluded processes	**Reason**
Applied for both supply-chains	
Sheep shearing	The sheep shearing is performed manually with a sheep shearing machine/clipper which is powered by electricity. Data about this could not be collected but is assumed to fall under cut-off. It can be so that the impact from the sheep sharing is included in the climate impact from the sheep farm as given in Ahlgren et al. (2022).
Applied for Klippan's supply-chain	
Energy use in sorting wool from Västkustens Ullinsamling	The sorting is manually performed. Data for energy consumption for the facility and for the compacting machine could not be collected but is assumed to fall under cut-off. Furthermore, some fuel for moving material with a tractor occurs. However, no data could be obtained for this, and it is assumed to fall under the cut-off criteria for this study.
Gas propane used for internal transport	No data was given, it is assumed to fall under cut-off.
Applied for VERK's supply-chain	
General electricity consumption at Ullkontoret (for facilities, etc)	This electricity consumption includes pumping water from the pond to the scouring facility, lighting in the scouring facility, electricity for operating the wood chip boiler, and the electricity required for the machine that presses bales of the washed wool. Additional electricity is used for charging the

	forklifts that transport the wool. All of this electricity comes from the subscription that also covers solar power production. Ullkontoret could not provide the data per kg wool for this as also other operations (not just wool handling) falls under this, they assume that the electricity consumption per kg wool is significantly small which is why this is excluded by cut-off.
Packaging of wool to Ullkontoret	Normally the wool is collected in metal cages or frames used for IBC tanks (with the plastic inner container removed) by Ullkontoret. These are reused, which is why any impact from these are assumed to fall under cut-off and are excluded. Furthermore, it is explained that farmers may leave the wool in bigbags, these are returned to the farmer by Ullkontoret for reuse. This is why these are also assumed to fall under cut-off and are excluded.
Warp production –Included is electricity- and raw material consumption but everything else is excluded	No specific manufacturing data from supplier were obtained, instead weaver could provide raw material consumption. Electricity is also regarded for making the warp using proxy data. Other aspects related to the warp production are assumed to fall under cut-off.
Lubricating oil weaving machine and spillage of warp at Väveriet I Bollnäs	About 3 liters are consumed yearly for the weaving machine, no information about the total yearly production of fabric in this machine so an average consumption per m2 cannot be calculated. But this is assumed to fall under cut-off. There is 0.00666 meters of waste in 300 meters of warp. Hence, 0.0000222 m for 1 m2 of fabric. This falls under cut-off.
Steam in the surface treatment for VERKs fabric.	Supplier could not estimate the amount of steam per m2 fabric but according to them the amount of steam per m2 is minimal which is why it is assumed to fall under cut-off.

3.3.3 **Allocation Procedure**

Allocation between lifecycles

The method chosen for separating consecutive life cycles is the cut-off method. This allocation of is described in ISO 14044 section 4.3.4.3.3 (ISO, 2006b) and uses the method of Allocation cut-off by classification. This approach used the Polluter Pays Principle, which for example says that only if the generating life cycle uses recycled material as input material will it account for the benefits of recycling.

3.3.3.1 Allocation for manufacturing data

Specific data collected for the different manufacturing in the supply-chain steps that was allocated included energy consumption and waste generation. These aspects were allocated equally to total amount produced based on mass.

3.3.3.2 Allocation of co-products

When dealing with a multi-output process, in other words, if a process creates several products or one product along with by-products, this is referred to in LCA as an allocation problem. This is the case for materials like wool, for which supply-chain can produce both wool, meat, skins, and lanoline (wool grease).

Allocation at the sheep farm

Since the allocation method applied for the products produces at the sheep farm highly affects the impact of the wool, the choice of allocation method were assessed. This based on the discussion about the recommendation for allocation when doing LCA on wool, see chapter 2.5. At the sheep farm the products produces are wool and live weight (which can be divided into further co-products).

From literature it was concluded that the main allocation methods applied for co-products from the sheep farm is allocated based on:

1. Biophysical allocation – protein requirement
2. Biophysical allocation – protein content
3. Economic allocation

These allocation methods were assessed to check if they were plausible to apply in this study.

To do so, the study by Wiedemann et al. (2015) were looked to as they have conducted the allocation methods. In this study the case study 1 (CS1) is most applicable – as this is a meat-oriented production where wool is a low-value by-product. CS1 is based on a United Kingdom Upland Sheep Farm.

Below in the table is a summary of the allocation methods applied for CS1 in Wiedemann et al. (2015)and the calculated allocation factor to wool and LW.

Table 5 Summary of allocation methods and allocation factors based on Wiedemann et al. (2015)

Method	Wool (%)	LW (%)	Essence of allocation	Conclusion in study
BA1 (Biophysical – maintenance shared by protein needs)	22	78	Partition all flock maintenance between wool and LW, proportional to their share of protein requirements (wool protein vs growth protein).	Wool receives a relatively high share compared to its economic role, because maintenance is spread across both products.
BA2 (Biophysical – lamb maintenance → meat; flock maintenance shared)	15	85	Lamb maintenance goes fully to meat; flock (ewe) maintenance split between wool and LW by protein requirement ratio.	More realistic for meat-oriented systems; wool gets less than BA1.
BA3 (Biophysical – all maintenance to meat)	7	93	All maintenance requirements are allocated to LW; only direct protein demand for wool growth goes to wool.	Minimizes wool's burden; reflects view that animals are kept mainly for meat, and wool just uses additional protein.
PMA (Protein Mass Allocation)	19	81	Divide impacts by protein mass in greasy wool vs protein in LW at farm gate.	Results fall between BA1 and BA2, easier to apply in practice.
EA (Economic Allocation)	4	96	Divide burdens according to farm-gate revenue shares (wool vs LW).	Wool gets a small share because it makes up about 4% of farm income. Highly sensitive to market prices.

The BA1-BA3 allocation factors presented in Wiedemann et al. (2015) were calculated using flock production data (e.g. ewe weight, lambing rate, wool yield, and live weight sold) combined with nutritional modelling of protein requirements based on the CSIRO feeding standards (CSIRO, 2007). In this approach, protein requirements were estimated for ewe and lamb maintenance, wool growth, live weight gain, and pregnancy.

Some conclusions from Wiedemann et al. (2015) about these allocation methods are that in meat-focused systems like CS1, BA1 is not ideal because it gives part of the lambs' maintenance to wool, even though lambs do not produce wool that can be sold. Wiedemann et al. (2015) suggest BA2 is more realistic, as it allocates all lamb maintenance to meat and shares ewe maintenance between meat and wool. This avoids giving wool too large a share of the impacts from producing meat. The authors describe that PMA as a simplified form of biophysical allocation. PMA avoids complex modelling of protein metabolism and maintenance, but produced results close to BA2, making it a useful proxy.

It was not reasonable within the scope of this study to calculate specific BA2 and BA3 allocation factors which is why the allocation factors in Wiedemann et al. (2015) were assessed if they could be used.

However, in the data for Swedish sheep farms from Ahlgren et al. (2022), the wool output is much smaller relative to LW than in CS1 in Wiedemann et al. (2015). Annual outputs in the CS1 are about 56,800 kg live weight (LW) and 3,410 kg greasy wool. And whole flock wool production is 3.4 kg greasy wool per ewe/year. Whereas for the Swedish systems assessed these amounts are about 32,920-34,660 kg LW and 1040-1160 kg wool, and with a whole flock wool production of 2 kg greasy wool per ewe/year.

In conclusion, 15% BA2 and 7% BA3 allocation factor to wool based on Wiedemann et al. (2015) would likely over-allocate to wool if these were applied in the Swedish context.

With above in mind, only economic allocation (EA) and protein mass allocation (PMA) were assumed to be feasible to conduct in this study.

To summarise, the allocation method applied in this study are:

- Economic Allocation
- Protein Mass Allocation

More information about the data required for these allocation methods and calculations are presented in chapter 4.3 Greasy wool production.

If this study were to become an EPD within the EPD International system - the fabric would have to

Allocation at wool scouring

In the supply-chain step scouring of the wool, both wool for spinning is created as well as lanolin (wool grease) and so-called shoddy (waste fiber and dust that is sold to be used as fertiliser). As both are products with economic value and have very different applications – economic allocation has been used for allocating the environmental impact between these products.

3.3.4 Method of Life Cycle Impact Assessment (LCIA)

The methods used to calculate the relevant environmental effect categories in this study is IPCC 2021 GWP 100, summarised in Table 4. For further details on the LCIA method, see Appendix 2.

Table 6: Impact categories, indicators and methods used in the study.

Impact category	Abbreviation	Category indicator	Method
Climate Change-total	GWP total	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2021
Climate Change-fossil	GWP fossil	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2021
Climate Change-biogenic	GWP biogenic	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2021
Climate Change-land use and land use change	GWP luluc	kg CO_2 equivalents	The baseline model of 100 years of the IPCC based on IPCC 2021

3.3.5 Data quality requirements (DQR)

The following requirements are used for all the central LCI data:

- Geographical coverage: The processes included in the data set are well representative of the geography stated in the “location” indicated in the metadata.
- Technology representativeness: Data of core processes: The collected data is representative for the technology used. Data of upstream and downstrean processes: Data is representative for the technology used (for example at suppliers) if possible. Otherwise average technology in the relevant region.

- Time-related coverage: Data of core processes: The collected data is ideally representative for the last 12 months but not older than 5 years. Data of upstream and downstream processes: The collected data is as recent as possible but not older than 10 years.

Specific data has been collected from the supply chain steps and where specific data could not be found, generic data were used.

Specific data and generic data are classified as following:

- Specific data:
    - data gathered from the actual manufacturing plant where product-specific processes are carried out;
    - actual data from other parts of the life cycle traced to the product under study, for example site-specific data on the production of materials or generation of electricity provided by contracted suppliers, and transportation data on distances, means of transportation, load factor, fuel consumption, etc., of contracted transportation providers; and
    - LCI data from databases on transportation and energyware that is combined with actual transportation and energy parameters as listed above.
- Generic data:
    - selected generic data: data (e.g. commercial databases and free databases) that fulfil prescribed data quality requirements for representativeness.

See documentation about the data collection for specific data in section 4.1 Data collection and data references.

The system model of secondary databases that are used in the LCA study is “Allocation, cut-off by classification” as specified in ecoinvent database.

3.4 LCA Software

The life cycle impact assessment (LCIA) was calculated using the LCA software SimaPro (PRé Sustainability, 2024) which includes regulary updated databases with libraries of LCI data (e.g. ecoinvent) and all relevant LCIA methods.

4 Life Cycle Inventory (LCI)

In the life cycle inventory, the product system is defined and described. Firstly, the material flows and relevant processes required for the product system are identified. Secondly, relevant data (i.e., resource inputs, emissions and product outputs) for the system components are collected, and their amounts are related to the defined declared unit.

4.1 Data collection and data references

Specific data about the assessed supply chains has been collected and is presented in the following sections in this inventory chapter.

Data on the climate impact research conducted by Ahlgren et al. (2022) which provides data tailored to Swedish sheep farming practices were checked with some of the authors. Since the study focuses on meat production, climate impact results for wool had to be extracted from the report.

The wool collector Ullkontoret Visby has been interviewed where information was collected along with a data inventory sheet that was sent out for them to be filled in.

Data from Västkustens Ullinsamling and data for the rest of the suppliers were collected from data inventory sheets that was sent out for them to be filled in.

Data was collected in 2025 and represent 2024-year production statistics.

See the sources for the data to each part of the different supply chains in the table below.

Table 7 Input data references

	Yarn by Klippan Yllefabrik		Fabric from VERK	
Supply chain step for wool	**Supplier**	**Contact**	**Supplier**	**Contact**
Sheep farm	Sheet farmer	Ahlgren et al. (2022)	Sheep farmer	Ahlgren et al. (2022)
Sheep shearing	Shearer	NA	Shearer	NA
Collection	Västkustens Ullinsamling	**Location:** Skottorp, Sweden	Ullkontoret Visby	**Location**: Visby, Sweden
Sorting				
Wash	Standard Wool/Thomas Chadwick And Sons	**Location of factory:** Dewsbury, UK		
Carding and Combing	George Ackroyd	**Location of factory:** Bradford, England		

Yarn spinning	Vernitas AB	**Location of factory**: MARIJAMPOLĖ, LITHUANIA		
Warping	-	-	Textilhögskolan Borås	(no reply)
Textile weaving	-	-	Väveriet i Bollnäs	**Location of factory**: Bollnäs, Sweden
Textile surface treatment	-	-	7H - Sjuhäradsbygdens färgeri	**Location of factory:** Kinnahult, Sweden

For most data referring to processes beyond the control of the core production, the ecoinvent database 3.11 is used. Ecoinvent is one of the world's leading databases with consistent, open, and updated Life Cycle Inventory Data (LCI). With several thousand LCI datasets in the fields of agriculture, energy supply, transport, biofuels and biomaterials, bulk and special chemicals, construction and packaging materials, basic and precious metals, IT and electronics and waste management, ecoinvent offers the most comprehensive international LCI database. Ecoinvent's high-quality LCI datasets are based on industrial data and have been compiled by internationally recognized research institutes and LCA consultants.

An important exception in the use of background data is the data from the sheep farm, which is based on a study from RISE assessing the environmental impact from Swedish beef- and lamb production (Ahlgren et al., 2022).This study has made a climate impact assessment for Swedish lamb production was based on the ClimAg model, which calculates greenhouse gas emissions from key agricultural sources using the IPCC 2021 GWP100 methodology. Due to limited official data for sheep farming, production parameters were derived from expert assessments supported by literature and national statistics. The model includes emissions from enteric fermentation, manure, soils, energy use, and input production, but excludes infrastructure and machinery.

4.2 Assumptions and methodological choices

4.2.1 General assumptions

Assumptions that are general to the entire LCA are:

- Choice of energy model is based on regional averages obtained from the Ecoinvent LCI database.
- Choice of transport model is based on regional averages from Ecoinvent.
- Transport distances have been based on Google Maps for road transportation and a port routing tool (e.g., Sea Distances or Port World) for sea transport if needed. Possible deviating routes have not been included in the calculations.
- Were no information were provided for transport means following assumptions were made: Truck transports are modelled with the dataset "*Transport, freight, lorry 3.5-7.5 metric ton, EURO5 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cut-off, U"* in ecoinvent, and boat transport are modelled with the dataset "*Transport, freight, sea, ferry, heavy fuel oil {GLO}| transport, freight, sea, ferry, heavy fuel oil | Cut-off, U*" in ecoinvent.

- Ecoinvent processes that contain market funds such as "*Diesel burned in building machine {GLO} | **market for** | Cut-off, U*" includes generic transports from producer to end customer. Therefore, no further transport is modelled for these data sets.
- Were no certificate or information about electricity source were given, a conservative assumption was made to represent the electricity with a residual mix on the market.
- Were transport of waste is missing, it is assumed to be 100km with truck represented with the dataset "*Municipal waste collection service by 21 metric ton lorry {CH}| municipal waste collection service by 21 metric ton lorry | Cut-off, U*".

4.3 Greasy wool production

In Sweden, there are currently two major players that collect wool on a larger scale. These are the Ullkontoret (Wool Office) on Gotland and Västkustens Ullinsamling (the West Coast Wool Collection) in Halland. These wool collectors are part of the supply-chain of assessed products.

In this study, no specific data was collected from sheep farms. Instead, this data was found in the research conducted by Ahlgren et al. (2022) were they assessed the environmental impact of Swedish beef and lamb production. More specifically they have assessed the environmental impact of various rearing systems for beef and lamb in the Swedish agricultural regions "Plain districts in northern Götaland", "Forest districts in Götaland", "Lower parts of Norrland", and part of "Central districts in Götaland" (the island of Gotland). Environmental impact categories included in the study by Ahlgren et al. are climate impact, land use, nitrogen emissions and impact on biodiversity. Ahlgren et al. (2022) thereby includes allot of data and information for Swedish sheep farm product systems that can be used for calculating the climate impact of Swedish wool.

Ahlgren et al. (2022) presents data for three production systems, based on the season in which the lambs are slaughtered. Data from the Gotland region was used for the VERK supply chain, and data from the Götalands skogsbygder (GSK) region was used for the Klippan supply chain. The wool used in VERK's fabric is mainly from the particular sheep breed "Gotland breed", but the data is for the region of Gotland and can thus include other breeds as well. Data from Ahlgren et al. (2022), along with additional background data for the RISE study provided by one of the co-authors of the study (Wirsenius pers. comm.) were used to calculate the climate impact from the sheep farms. This data is presented in the Table 8 below.

The co-products considered by Ahlgren et al. (2022a) are the following: slaughter weight (43% of live weight), wool, by-products from slaughter, and hides. The slaughter weight includes meat from lambs and ewes alike, but the majority is from lambs. The data provided by Ahlgren et al. (2022), an ewe provides 2 kg wool per year (mainly ewe that contributes to the wool production). This data is also in line with the information provided by Ullkontoret which stated that the ewes are sheared twice per year, each time giving 1 kg wool.

Table 8 Data for assessed sheep rearing systems, adapted from Ahlgren et al. (2022) and the study's background data

Sheep farm production 1 year		**Sheep herd (number of animals/year)**				**Products produced from the sheep farm (tons/year)**							**Climate impact [ton CO2 eq/year]**
Region	**System**	**Ewes (tackor)**	**Gimmer (ungtackor)**	**Rams (baggar)**	**Slauther lambs (slaktlamm)**	**Live weight (slaktdjur)**	**Slaugther weight (slakt-kropp)**	**Skins (skinn) *OBS pieces***	**Other by-products (övrigt)**	**Wool no value (slängd ull)**	**Wool sold (såld ull)**	**Total wool**	
Gotland	Autumn	150	27	4	108	11,49	4,50	*102,96*	0,75	0,23	0,08	0,30	139,55
	Spring	300	74	8	135	23,17	10,21	-	0,93	0,45	0,15	0,60	266,85
	Winter	130	25	3	145	9,30	3,63	*86,89*	1,00	0,20	0,07	0,26	131,57
	Total output products Gotland					**43,96**	**18,35**	**189,85**	**2,68**			**1,16**	**537,96**
Weast coast	Autumn	120	23	3	82	9,75	4,09	-	0,57	0,18	0,06	0,24	118,61
	Spring	300	74	8	135	23,17	10,21	-	0,93	0,45	0,15	0,60	268,94
	Winter	100	20	3	123	7,89	3,24	-	0,85	0,15	0,05	0,20	112,47
	Total output products West coast					**40,82**	**17,53**	**-**	**2,35**			**1,04**	**500,02**

Looking at the total climate impact from the regions over one year, the Gotland region has the climate impact of **538 tons CO2 equivalents/year**, and the West coast region has the climate impact of **500 tones CO2 eq/year**. According to Ahlgren et al. (2022), the largest climate impact is caused by methane emissions from enteric formation, emissions from organic soil and emissions from manure storage. The results include soil carbon sequestration and emissions from organic soils.

As mentioned in the allocation chapter 3.3.3, how to allocate the impact from the sheep farm can occur with different methods and the methods this study are looking into are:

1. Economic allocation (EA)
2. Biophysical allocation – protein mass allocation (PMA)

Following sections provide the additional data needed to perform these allocation methods.

4.3.1 Data for economic allocation of co-production from sheep farm

Economic allocation distributes the environmental impacts of a production system among co-products based on their relative economic value (e.g., market price, revenue share). See how the EA for wool is calculated in the equation below:

$$EA_{wool} = \frac{Q_{wool} \times P_{wool}}{\sum_i Q_i \times P_i}$$

Where:

$EA_{wool} = Economic\ allocation\ factor\ for\ wool$
$Q_i = Quantlty\ of\ output\ product\ i\ produced\ fom\ farm$
$P_i = Price\ of\ output\ product\ i\ from\ farm$

Hence, to calculate the economic allocation the price of all output produces had to be found. Most of the output from the sheep farm is meat. Data for meat prices were taken from the Swedish Board of Agriculture (2025) and represents 2024 years average prices for lamb meet. Data for skins and other by-products are provided in Ahlgren et al. (2022) since they also use economic allocation in their study. Although this data Is some years old, It Is used as a conservative assumption.

In Ahlgren et al. (2022), 25% of the greasy wool obtained from the sheep farm is sold and then the price for the wool is 10 sek/kg wool. This data from Ahlgren et al. (2022) is replaced by data collected for assessed supply-chains.

Regarding how much of the wool is taken care of, for Ullkontoret farmers get paid for about 90% of the wool collected and for Västkustens Ullinsamling this is about 80%.

Regarding the price of wool, the farmers are paid 15 sek/kg for the wool that becomes yarn according to Ullkontoret at Gotland. According to Västkustens Ullingsamling (West coast), the farmers are paid 5-15 sek/kg for the wool depending on quality. As a conservative assumption, 15 sek/kg is used. How this may affect the result is assessed in the sensitivity check in chapter 6.2.2.

Summary of data needed for economic allocation

See all the data needed for economic allocation for the wool from Gotland and West Coast below.

The prices for the different by-products used in the study is presented in Table 10. A simplification has been done by Miljögiraff regarding the price of the slaughter weight which is based on the price for the lambs slaughter weight as is assumed that the lambs stand for the highest share of the weight for the slaughter weight. The output products were presented in Table 8.

Table 9 Prices of co-products from the sheep farm, adapted from Ahlgren et al. (2022) and the study's background data. Wool prices are specific data collected.

<table>
<tr><th>System</th><th>Slaugther weight (slakt-kropp) [sek/kg]</th><th>Skins (skinn) [sek/pcs]</th><th>Other by-products (övrigt) [sek/slauther weight]</th><th>Wool from Västkustens ullinsamling (ull) [sek/kg]</th><th>Wool from Ullkontoret (ull) [sek/kg]</th></tr>
<tr><td>Autumn</td><td>68,89</td><td>258,00</td><td rowspan="3">1,27</td><td rowspan="3">15,00</td><td rowspan="3">15,00</td></tr>
<tr><td>Spring</td><td>86,09</td><td>-</td></tr>
<tr><td>Winter</td><td>70,61</td><td>77,00</td></tr>
</table>

4.3.2 Data for biophysical allocation – protein content for co-production from sheep farm

Biophysical allocation methods distribute environmental impacts based on measurable physical or functional properties of co-products. Protein Mass Allocation specifically uses the protein content of each co-product as the basis for distribution. See how the PMA for wool is calculated in the equation below:

$$PMA_{wool} = \frac{Q_{wool} \times PC_{wool}}{\sum_i Q_i \times PC_i}$$

Where:

$$PMA_{wool} = Protein\ mass\ allocation\ factor\ for\ wool$$
$$Q_i = Quantlty\ of\ output\ product\ i\ produced\ fom\ farm$$
$$PC_i = Protein\ content\ of\ output\ product\ i\ from\ farm$$

For this calculation, same methodology applied in Wiedeman et al. (2015) were applied where outputs from the farm are aggregated as wool and live weight (LW). This method is also applied in World Food LCA database (WFLDB) which uses a protein-based approach to allocation (Bayart et al., 2025). The protein-content values come from (Wiedemann et al., 2015, 2016) – 18% for live weight (sheep or lamb) and 68% in greasy wool (100% in clean wool).

4.3.3 Calculated allocation factors to greasy wool

With the given information above, the allocation factors become as presented in the table below.

Table 10 Calculated allocation factor to greasy wool

Method	Greasy wool from Gotland	Greasy wool from West coast
Economic allocation (EA) factor	0,9%	1,0%
Biophysical - protein mass allocation (PMA) factor	9,3%	9,0%

4.4 Supply-chain of yarn from Klippan Yllefabrik

This section describes all supply-chain steps required to produce 1 kg yarn from Klippan Yllefabrik and the data collected for these steps. The yarn assessed is used for knitting or weaving fashion garments for women as well as outdoor products.

What supply-chain steps are included is shown in the figure below. Following subsection in this chapter describe these supply-chain steps and the data collected for them.

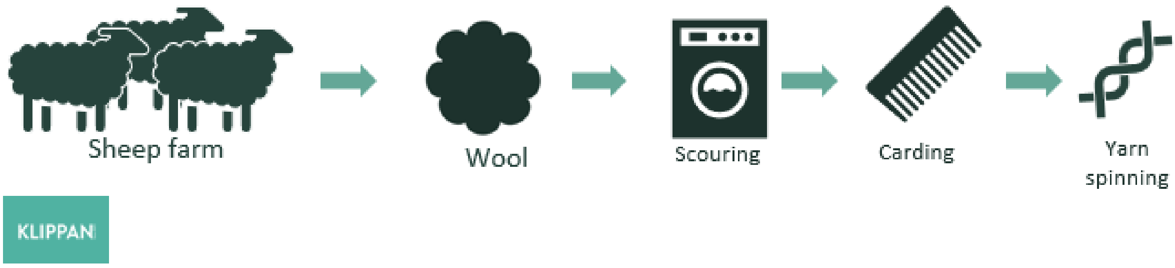


Figure 8 Supply-chain steps assessed for Klippans yarn

4.4.1 Greasy wool from Västkustens Ullinsamling

Västkustens Ullinsamling are located in Laholm and retrieve wool from farms from Ystad to Borlänge. They often receive pre-sorted wool that is then sorted further and packaged before sent to scouring. The sorting is done manually. Depending on the quality, the wool is used for yarn, felt, or as a filling material. Wool that cannot be used in products is dug down. The farmers receive between 5 and 15 SEK per kg wool, depending on quality.

Again, the data from Ahlgren et al. (2022) was used to estimate the impact from greasy wool. This time the data for Götalands skogsbygder (GSK) was used since it is the best fit with the collection area for Västkustens Ullinsamling. The data for the greasy wool were given in section 4.3.

The activities carried out by Västkustens ullinsamling require electricity and some fuel for moving material with a tractor. However, no data could be obtained for this, and it is assumed to fall under the cut-off criteria for this study. Thus, it is excluded from the analysis.

4.4.2 Scouring, England

Data was collected from the scouring facilities as seen in Table 12 below. The scouring process produces not only washed wool, but also lanolin and shoddy.
The impact was allocated to the co-products based on economic allocation. The price on the wool depends on quality and market price but are approximately £1.50-3.00/kg, here the high-range value was used as a conservative approach. The price of grease varies a lot, currently approximately £2.80/kg, but it can be as high as £5/kg. £3/kg has been used for grease in the calculations. The value of the shoddy is set to £0,1/kg.

About 1,3 kg greasy wool is needed as input to produce 1 kg washed wool as output. Data has been provided per 1 kg greasy wool which is why this is presented in the table below.

Table 11 LCI Data from wool scouring facility

Process for washed wool			
Output/Products			
Name	Amount	Unit	Allocation factor
Washed wool for yarn	0,70	kg	94%
Lanolin	0,050	kg	6%
Shoddy	0,0060	kg	0%
Inputs: Materials			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Greasy wool	1,0	See section 4.4.1	
Inputs: Electricity/heat			
Type of energy	Amount (kWh/kg)	LCI data representation	Comment
Electricity – residual mix	0,2	Electricity, low voltage {GB}| electricity, low voltage, residual mix | Cut-off, U	
Natural gas	0,7	Heat, district or industrial, natural gas {GB}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U	
Inputs: Consumables			
Type of consumable	Amount (kg/kg)	LCI data representation	Comment
Water	4,2	Tap water {Europe without Switzerland}| market for tap water | Cut-off, U	
Washing agent	0,006	Cleaning consumables, without water, in 13.6% solution state {GLO}| market for cleaning consumables, without water, in 13.6% solution state | Cut-off, U	
Outputs: Waste materials			
Type of waste	Amount (kg/kg)	LCI data representation	Comment
Waste water	4,2	Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, wastewater treatment | Cut-off, U	Added to match water input
Effluent sludge, composting	0,14	Sewage sludge, 75% water, WWT, WW, average {Europe without Switzerland}| market for sewage sludge, 75% water, WWT, WW, average | Cut-off, U	Spread to land after composting. Transported 45 km.
Dirt	0,006	-	Pellet formation for resale - spread onto land as fertiliser. Transported 100 km.

Raw material packaging waste, Hdpe - Jute – Polyprop, recycling	0,0051	Mixed plastics (waste treatment) {GLO}| recycling of mixed plastics | Cut-off, U	Transported 100 km to waste treatment.
Inputs: Packaging			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Packaging material, HDPE Bags	0,0019	Polyethylene, high density, granulate {GLO}| market for polyethylene, high density, granulate | Cut-off, U + Extrusion, plastic film {GLO}| market for extrusion, plastic film | Cut-off, U	Partly made from recycled material, but virgin is used as a conservative assumption.
Inputs: Internal transports			
Type	Amount (kg/kg)	LCI data representation	Comment
Gas propane used for internal transport	-	-	No data, excluded

4.4.3 Combing, England

Data was collected from the combing facilities as seen in Table 13 below. During combing, a short-filter material, so called wool noils and second wool noils are formed. The former can be used in the spinning process, while the second wool noils are discarded. This creates a spillage of approximately 1.4% from the carding process. To produce 1 kg of carded wool fibre, 1.014 kg washed wool is thus needed.

Table 12 LCI Data from wool combing facility

Process for combed wool			
Output/Products			
Name	Amount	Unit	Allocation factor
Combed wool	1	kg	100%
Inputs: Materials			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Washed wool	1,01	See section 4.4.2	
Inputs: Electricity/heat			
Type of energy	Amount (kWh/kg)	LCI data representation	Comment
Electricity – residual mix	0,2	Electricity, low voltage {GB}| electricity, low voltage, residual mix | Cut-off, U	
Inputs: Consumables			
Type of consumable	Amount (kg/kg)	LCI data representation	Comment
Lubricating oil	0,02	Lubricating oil {RER}| market for lubricating oil | Cut-off, U	

Outputs: Waste materials			
Type of waste	Amount (kg/kg)	LCI data representation	Comment
Spillage of wool	0,01	Biowaste {GLO}| treatment of biowaste, municipal incineration | Cut-off, U	See 4.2 for modelling of transport of the waste, 100 km assumed.
Packaging material, HDPE Bags	0,0019	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration FAE | Cut-off, U	Packaging of raw material - incineration assumed as a conservative assumption. See 4.2 for modelling of transport of the waste, 100 km assumed.
Inputs: Packaging			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Bales	0,006	Packaging film, low density polyethylene {GLO}| market for packaging film, low density polyethylene | Cut-off, U	250 kg wool per bale
Straps	0,002	Polyethylene, low density, granulate {GLO}| market for polyethylene, low density, granulate | Cut-off, U + Extrusion, co-extrusion {GLO}| market for extrusion, co-extrusion | Cut-off, U	250 kg wool per bale
Inputs: Internal transports (none reported)			

4.4.4 Yarn spinning, Lithuania

Data from the spinning facility was collected about electricity consumption, spillage, lubricant consumption and packaging of material for downstream distribution of the yarn. See the modelling for this below.

Table 13 Data for yarn spinning

Process for yarn spinning			
Output/Products			
Name	Amount	Unit	Allocation factor
Yarn	1	kg	100%
Inputs: Materials			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Carded wool	1,03	See section 4.4.3	
Inputs: Electricity/heat			
Type of energy	Amount (kWh/kg)	LCI data representation	Comment
Electricity – residual mix	3,58	Electricity, low voltage {LT}| electricity, low voltage, residual mix | Cut-off, U	Source of electricity is changed
Inputs: Consumables			
Type of consumable	Amount (kg/kg)	LCI data representation	Comment
Lubricating oil	0,0042	Lubricating oil {RER}| market for lubricating oil | Cut-off, U	
Outputs: Waste materials			
Type of waste	Amount (kg/kg)	LCI data representation	Comment
Spillage of wool	0,03	Waste yarn and waste textile {RoW}| market for waste yarn and waste textile | Cut-off, U	See 4.2 for modelling of transport of the waste, 100 km assumed.
Packaging of raw material – Bales and straps	0,008	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration FAE | Cut-off, U	Packaging of raw material - incineration assumed as a conservative assumption. See 4.2 for modelling of transport of the waste, 100 km assumed.
Inputs: Packaging			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Paper-based packaging	0,08	Corrugated board box {RER}| market for corrugated board box | Cut-off, U	
Inputs: Internal transports (none reported)			

4.4.5 Transports between the supply-chain steps

See the transport means and distances in the table below. See 4.2 for modelling of transports.

Table 14 Transports in the supply-chain

Supply-chain step	From → To	Truck transport distance (km)	Boat transport distance (km)
Farmer → Sorting	Many locations → Skottorp (Sweden). Average transport distance applied	360	-
Sorting → Scouring	Sweden → England	1820	40
Scouring → Combing	England → England	70	-
Combing → Spinning	England → Lithuania	2 270	40

4.5 Supply-chain of fabric from VERK

This section describes all supply-chain steps required to produce 1 m2 fabric from VERK and the data collected for these steps.

What supply-chain steps are included is shown in the figure below. Following subsection in this chapter describe these supply-chain steps and the data collected for them.

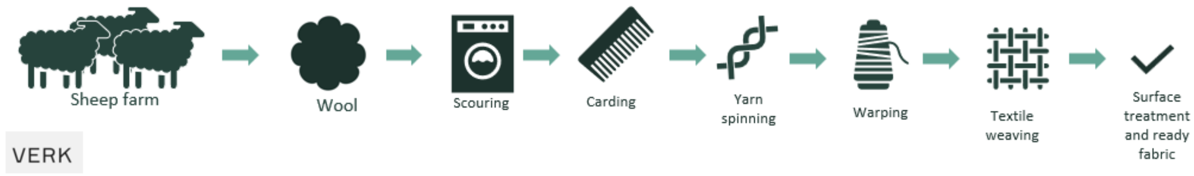


Figure 9 Supply-chain steps for VERK's fabric

4.5.1 Raw wool from Ullkontoret, Endre, Sweden

The majority of the wool used in VERK's supply chain is of the sheep "Gotlandsfår". There can also be a small amount of the Leicester breed used but this is considered negligible in this study. In the Gotland region, Gotlandsfår makes up the majority of the sheep population, but there are also farms in mainland Sweden who keep this breed. Ullkontoret collects most of its wool from Gotlandsfår from Gotland. Some farmers come with their wool to Ullkontoret, and some wool is collected by Ullkontoret at the farms.

When Ullkontoret retrieves wool, sorting on quality and suitable application is done. Ullkontoret aims for maximizing the use of the wool they collect which is why little wool goes wasted. Wool of the finest quality – long fibres – are suitable for yarn, whereas shorter fibres are suitable for needle felted wool, and if none of these are suitable for the wool, the unwashed wool is pressed to fertilizing pellets for gardening. A small fraction of the wool falls out in the drying process. It is mainly short fibres mixed with vegetable matters and sand or dust. It is currently stored until an application is found.

The sorting of the wool is manually done which is why any impact from this fall under cut-off.
The farmers are paid 15 SEK/kg for high-quality wool for yarn. They don't receive any payment for low-quality wool. According to Ullkontoret, from all wool they retrieve, farmers get paid for about 90%.

Ullkontoret also washes, cards and spins the wool.

Sheep farming, Gotland region

Key data from Ahlgren et al. (2022) for the Gotland region is presented in section 4.3 Greasy wool production. Please note that this data is collected for the region of Gotland, and not specifically for the breed Gotlandsfår. However, Gotlandsfår makes up a large part of the sheep population on Gotland. Therefore, it was deemed reasonable to use the data for the Gotland region to represent the wool used in VERK's supply chain.

Transport to Ullkontoret and sorting of greasy wool

Energy consumption and other inputs during sorting at Ullkontoret (before scouring) is assumed to fall under the cut-off rule.

Ullkontoret has explained that transport of the wool from the farmer can occur in three different ways described in the table below. Normally the wool is collected in metal cages or frames used for IBC tanks (with the plastic inner container removed) by Ullkontoret. These are reused which is why any impact from these are assumed to fall under cut-off and are excluded. Furthermore, it is explained that farmers may leave the wool in bigbags, these are returned to the farmer by Ullkontoret for reuse. This is why these are also assumed to fall under cut-off and are excluded.

Table 15 Data for transport of the wool to Ullkontoret

Description of collection	% of collected wool estimation	Transport type and distance
Fetched on mainland	25%	Diesel truck 5ton, and ferry – about 1000 km. Of these, it is assumed that 140 km occur with ferry.
Fetched on Gotland	50%	Diesel truck 4ton – about 100 km
Farmer leaves the wool	25%	No data, but diesel truck 50 km is assumed

4.5.2 Scouring, Ullkontoret, Endre, Sweden

Once the wool that is suitable for yarn is sorted out, it is washed. Ullkontoret has stated that 1,5 greasy wool becomes 1 kg wool after washed. Greasy wool contains grease and dirt which is separated from the wool in the scouring process and hence 1/3 of the weight of the greasy wool is washed out. Most of the mass that is washed out is currently discarded with the wastewater from the scouring process. Since this water contains allot of nutrients, it is collected in a sewage pond and used for nutrient irrigation.

In general, 1 tonne of wool is produced in one day and over a year's period 24/25 Ullkontoret had 46 days of wool scouring, producing 38 783 kg of washed wool. See the data collected for this process in the table below.

Table 16 Data for scouring at Ullkontoret

Process for washed wool			
Output/Products			
Name	Amount	Unit	Allocation factor
Washed wool for yarn	1	kg	100%
Inputs: Materials			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Greasy wool	1,5	See section 4.5.1	
Inputs: Electricity/heat			
Type of energy	Amount (kWh/kg)	LCI data representation	Comment

Electricity – wind power	0,19	Electricity, high voltage {SE}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, U	Facilities and operations, yearly production 7519 kWh. 38 783 kg wool produced with this consumption. See invoice stating windpower for electricity in Appendix 5.
Electricity – own production with solar power	-	-	Electricity consumption includes pumping water from the pond to the washing facility, lighting in the washing facility, electricity for operating the wood chip boiler, and the electricity required for the machine that presses bales of the washed wool. Additional electricity is used for charging the forklifts that transport the wool. All of this electricity comes from the subscription that also covers solar power production. Ullkontoret were not able to provide the data per kg wool for this as also other operations (not just wool handling) falls under this, they assume that the electricity consumption per kg wool is significantly small which is why this is excluded by cut-off.
Electricity – other	-	-	
Heat – from wood chips	16,9	Heat, central or small-scale, other than natural gas {CH}| heat production, hardwood chips from forest, at furnace 50kW | Cut-off, U	Heating of water and drying of wool. 6 m3 wood chips from their own wood is consumed per day. About 1 ton of wool is washed in one day. According to the dataset: Dry wood density 650kg/m3; Energy content (LHV, oven-dry) 18.3 MJ/kg. 15% moisture content in wood assumed.
Inputs: Consumables			
Type of consumable	Amount (kg/kg)	LCI data representation	Comment
Water	15	Inputs from nature: Water, lake, SE	15 m3 is used on average per day when doing 3 days of washing. Assumed density of water is 1 kg/l.
Washing agent	0,0011	Cleaning consumables, without water, in 13.6% solution state {GLO}| market for cleaning consumables, without water, in 13.6% solution state | Cut-off, U	In total 11 dl/day is consumed. No density provided, assumed density is 1 kg/l.
Potassium carbonate	0,016	Potassium carbonate {GLO}| market for potassium carbonate | Cut-off, U	
Outputs: Waste materials			
Type of waste	Amount (kg/kg)	LCI data representation	Comment
Water with grease and dirt	Water 15 + grease & dirt 0,5	Emissions to water: Water, SE	Sent to their own sewage pond which is used as nutrient irrigation at their fields.

			Treatment of grease and dirt waste is assumed to have no impact.
Inputs: Packaging			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Jute cloth	0,015	Textile, jute {GLO}| market for textile, jute | Cut-off, U	3 kg of jute cloth is used to package 200-300kg of wool. Returning customers gives back this packaging, the cloth can normally be reused 3 times.
Inputs: Internal transports (electrical trucks, included in electricity consumption)			

4.5.3 Carding and yarn spinning, Ullkontoret, Visby, Sweden

The washed wool is sent to Visby where it is carded and spun into yarn. This facility is newly established which is why full production has not been reached jet, but currently 12 ton yarn/year is produced.

See the data collected for this process in the table below.

Table 17 Data for carding and yarn spinning at Ullkontoret

Process for carding and spinning wool yarn			
Output/Products			
Name	Amount	Unit	Allocation factor
Wool yarn	1	kg	100%
Inputs: Materials			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Washed wool	1,01	See section 4.5.2	About 1% spillage occurs that cannot be close-looped recycled.
Inputs: Electricity/heat			
Type of energy	Amount (kWh/kg)	LCI data representation	Comment
Electricity – residual mix	2,00	Electricity, low voltage {SE}| electricity, low voltage, residual mix | Cut-off, U	No certificate for electricity - which is why Swedish residual mix is used.
Inputs: Consumables			
Type of consumable	Amount (kg/kg)	LCI data representation	Comment
Spinning oil 1 + 2	0,017	Lubricating oil {RER}| market for lubricating oil | Cut-off, U	700 ml oil 1 + 350 ml oil 2 per 60 kg wool. No density provided, assumed density is 1 kg/l.
Antistat	0,006	Chemical, organic {GLO}| chemical production, organic | Cut-off, U	Antistatic / ESD (electrostatic discharge) clothing fabrics.

			350 ml/60 kg wool No density provided, assumed density is 1 kg/l.
Outputs: Waste materials			
Wool spillage	0,01	Waste yarn and waste textile {RoW}| market for waste yarn and waste textile | Cut-off, U	Dataset used as a proxy. Stored on site.
Packaging of wool, jute	0,015/3	Biowaste {GLO}| treatment of biowaste, municipal incineration | Cut-off, U	Reused 3 times before disposed See 4.2 for modelling of transport of the waste, 100 km assumed.
Inputs: Packaging			
Type of material	Amount (kg/kg)	LCI data representation	Comment
Paper cone	0,035	Kraft paper {RER}| market for kraft paper | Cut-off, U	1 kg yarn is rolled onto a cone of 35g paper.
Plastic bag	0,015	Packaging film, low density polyethylene {GLO}| market for packaging film, low density polyethylene | Cut-off, U	Bag is "Insatspåse HD Blå 630/4470x700x0,02mm" were 250st has the weight 30kg. 8kg yarn is packaged in one bag.
Cardboard box	0,063	(Reused)	The cardboard boxes are reused banana boxes that are collected from the store close by. Therefore, they come burden-free. No weight for the box is given, an assumption of 0,5 kg/box has been made.
Inputs: Internal transports (none reported)			

4.5.4 Warping – Textilhögskolan, Borås, Sweden

Some of the yarn is sent to Textilhögskolan, Borås for a production of warp that is used in the weaving of VERK's fabric. No information about the production of the warp could be collected.

According to the weaver, 1 m2 warp has the weight of 0,28kg and no spillage occurs in this production process.

To estimate an electricity consumption for making the warp, the generic dataset "Textile, woven cotton {BD}| textile production, cotton, weaving | Cut-off, U" from ecoinvent were used as a proxy, this is probably an overestimation. Other aspects are assumed to fall under cut-off.

Process for warping			
Output/Products			
Name	Amount	Unit	Allocation factor
Warp	1	m2	100%
Inputs: Materials			

Type of material	Amount (kg/m2)	LCI data representation	Comment
Wool yarn	0,28	See section 4.5.3	
Inputs: Electricity/heat			
Type of energy	Amount (kWh/m2)	LCI data representation	Comment
Electricity – residual mix	2,2	Electricity, low voltage {SE}| electricity, low voltage, residual mix | Cut-off, U	
Outputs: Waste materials			
Type of waste	Amount (kg/m2)	LCI data representation	Comment
Paper cone + cardboard box	0,03	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration FAE | Cut-off, U	Packaging of raw material - incineration assumed as a conservative assumption. See 4.2 for modelling of transport of the waste, 100 km assumed.
Plastic bag	0,004	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration FAE | Cut-off, U	
Inputs: Packaging			
	Amount (kg/m2)	LCI data representation	Comment
Plastic film	0,005	Packaging film, low density polyethylene {GLO}| market for packaging film, low density polyethylene | Cut-off, U	10x1 meter of plastic film is used for a warp that is 100m, it is assumed that 10m2 plastic film weights 0,5 kg.

4.5.5 Weaving, Väveriet i Bollnäs, Bollnäs, Sweden

Yarn and warp are sent to Bollnäs where it is weaved into fabric. The weaving facility in Bollnäs can weave 30 meters per day for VERK, but it is not woven every day. In total, weaving for VERK is estimated to amount to 300-500 meters per year.

In the weaving process, it is calculated how much yarn is needed and the warp beam is sent a roundtrip to Borås. Furthermore, punch cards are created and when everything is in place, the machine is set up and test weaved before the fabric is woven and finished.

See the data provided from Väveriet in Bollnäs in the table below. The textile has the weight 0,56 kg/m2.

Table 18 Data for weaving of the fabric at Väveriet I Bollnäs

Process for weaving of fabric			
Output/Products			
Name	Amount	Unit	Allocation factor
Wool fabric	1	m2	100%
Inputs: Materials			

Type of material	Amount (kg/m2)	LCI data representation	Comment
Weft yarn	0,29	See section 4.5.3	About 50% of the yarn is used as weft. 0,01 kg yarn becomes spillage.
Warp yarn	0,28	See section 4.5.4	About 50% of the yarn is used as warp.
Inputs: Electricity/heat			
Type of energy	Amount (kWh/m2)	LCI data representation	Comment
Electricity – residual mix	0,4	Electricity, low voltage {SE}| electricity, low voltage, residual mix | Cut-off, U	No certificate for electricity -which is why Swedish residual mix is used.
Inputs: Consumables			
Type of consumable	Amount (kg/m2)	LCI data representation	Comment
Lubricating oil	-	-	About 3 liters are consumed yearly for the weaving machine, no information about the total yearly production of fabric in this machine so an average consumption per m2 cannot be calculated. But this is assumed to fall under cut-off.
Outputs: Waste materials			
Type of waste	Amount (kg/m2)	LCI data representation	Comment
Paper cone + cardboard box	0,03	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration FAE | Cut-off, U	Packaging of raw material - incineration assumed as a conservative assumption. See 4.2 for modelling of transport of the waste, 100 km assumed.
Plastic bag	0,004	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration FAE | Cut-off, U	
Plastic film	0,005		
Weft yarn	0,01	(recycled, no burden)	This is sold and reused, but no information about the price could be given so the fabric is allocated all impact as a conservative assumption. See 4.2 for modelling of transport of the waste, 100 km assumed.
Warp	-	-	There is 0.00666 meters of waste in 300 meters of warp. Hence, 0.0000222 m for 1 m2 of fabric. This falls under cut-off.
Inputs: Packaging			
Type of material	Amount (kg/m2)	LCI data representation	Comment
Corrugated cardboard	0,0001	Corrugated board box {RER}| market for corrugated board box | Cut-off, U	0,0002 m2 cardboard is required per m2 fabric, assumed density 0,5kg/m2.
Paper	0,00002	Paper, melamine impregnated {RER}| market for paper, melamine impregnated | Cut-off, U	0,0002 m2 paper is required per m2 fabric, assumed density 0,08 kg/m2.
Inputs: Internal transports			

Type of transport	km	LCI data representation	Comment
Truck transport of warp beam	1180	Transport, freight, lorry, 3.5-7.5 metric ton, diesel, EURO 5 {RER}| transport, freight, lorry, 3.5-7.5 metric ton, diesel, EURO 5 | Cut-off, U	The warp beam is sent to- and back from Borås, single trip is 590 km. No information about the weight of the beam is provided, the fabric is 1,5 meter wide, and it is assumed that the beam has the weight 20 kg and that it contains 30 meter warp.

4.5.6 Surface treatment, 7H - Sjuhäradsbygdens färgeri, Kinnahult, Sweden

At the surface treatment the fabric goes though following processes:

- A light wash in a foulard with water and then the fabric dry in a tenter frame.
- Then the fabric passes through a decatizing machine (steam press), which gives it a finer appearance, a softer “hand/feel,” and improved Martindale values.
- Finally, the fabric is inspected and rolled onto a roll.

Process for obtaining 1 m2 surface treated fabric			
Output/Products			
Name	Amount	Unit	Allocation factor
Surface treated fabric	1	m2	100%
Inputs: Materials			
Type of material	Amount (m2/m2)	LCI data representation	Comment
Woven textile	1	See section 4.5.5	
Inputs: Electricity/heat			
Type of energy	Amount (kWh/m2)	LCI data representation	Comment
Electricity – residual mix	0,064	Electricity, low voltage {SE}| electricity, low voltage, residual mix | Cut-off, U	
Steam	-	-	Supplier could not estimate the amount of steam per m2 fabric but according to them the amount of steam per m2 is minimal which is why it is assumed to fall under cut-off.
Inputs: Consumables			
Type of consumable	Amount (kg/m2)	LCI data representation	Comment
Water	0,30	Tap water {Europe without Switzerland}| market for tap water | Cut-off, U	
Oil	0,044	Lubricating oil {RER}| market for lubricating oil | Cut-off, U	0,044 liter oil per m2 is consumed for the tenter frame.
Outputs: Waste materials			

Type of waste	Amount (kg/m2)	LCI data representation	Comment
Waste water	0,3	Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, U	
Corrugated cardboard + paper	0,00012	Waste paperboard {CH}| treatment of waste paperboard, municipal incineration FAE | Cut-off, U	Packaging of raw material - incineration assumed as a conservative assumption. See 4.2 for modelling of transport of the waste, 100 km assumed.
Inputs: Packaging			
Type of material	Amount (kg/m2)	LCI data representation	Comment
Well	0,0076	Corrugated board box {RER}| market for corrugated board box | Cut-off, U	One piece of well is required for 50 meter fabric, and has the dimension 155cm broad, 5cm diameter, 2mm thick. Weight 380g/piece is estimated by Miljögiraff.
Plastic	0,0016	Packaging film, low density polyethylene {GLO}| market for packaging film, low density polyethylene | Cut-off, U	1,7m2 PE, thickness 0,05mm per 50 m2 fabric, weight 80g estimated by Miljögiraff.
Inputs: Internal transports			
Type of transport	m	LCI data representation	Comment
Truck	200	-	Manually dragged, no impact.

4.5.7 Transports between the supply-chain steps

See the transport means and distances in the table below. See 4.2 for modelling of transports.

Table 19 Transports in the supply-chain

Supply-chain step	From → To (all in Sweden)	Truck transport distance (km)	Boat transport distance (km)
Collection → Sorting, Scouring	Farmer → Endre	See 4.5.1 for information. Between 100-1000 km with truck and ferry.	
Scouring → Carding, Spinning	Endre → Visby	12	-
Spinning → Warping	Visby → Borås	270	120
Spinning → Weaving	Visby → Bollnäs	330	150
Warping → Weaving	Borås → Bollnäs	590	-
Weaving → Surface treatment	Bollnäs → Kinnahult	610	-

5 Result and discussion of the impact assessment of Swedish wool with different allocation methods

The two supply-chain assessed for Klippan's yarn and VERK's fabric uses Swedish wool from the West coast region and Gotland region.

Data in Ahlgren et al. (2022) presents that the total climate impact for Swedish sheep populations is:
- **538 tons CO2 equivalents/year** in the Gotland region
- 500 tones CO2 eq/year in the West coast region

According to Ahlgren et al. (2022), the largest climate impact is caused by methane emissions from enteric formation, emissions from organic soil and emissions from manure storage. The results include soil carbon sequestration and emissions from organic soils.

The sheep farms in these regions produce different products yearly - these were presented in detail in chapter *4.3 Greasy wool production,* and are around:
- 18 tons meat
- 2-3 tons other by-products from slaughter
- 1 ton wool
- Gotland region: 190 pieces of skin

As described in chapter *2.5 Challenge of quantifying the environmental impact of wool with Life Cycle Assessment* – the main question for making an LCA of wool is how the impact is allocated between these products from the sheep farm.

The ISO 14044 standard on LCA recommends the following three-step procedure when allocating environmental burdens in multi-output systems (ISO, 2006b):

- Allocation should be avoided if feasible.
- If allocation is necessary, physical relationships should be used.
- If no valid physical allocation basis exists, economic or other proxy relationships should be applied.

Allocation based on physical relationship
The standard for LCA – ISO 14040/44 along with product category rules (PCR) for EPD[1] recommends that allocation should be based on a physical relationship in the first hand.

This study applies an allocation method based on the protein content of wool compared to live weight. The reasoning behind this choice is presented in *3.3.3.2 Allocation of co-products*, where it was concluded that this approach is a simplified physical allocation between wool and live weight that can provide similar results to more advanced biophysical allocation methods were protein requirement is regarded.

Looking at the climate impact result for 1 kg greasy wool and 1 kg live weight from the Gotland and West coast region, the result becomes as indicated in Figure 10.

[1] According to EPD International

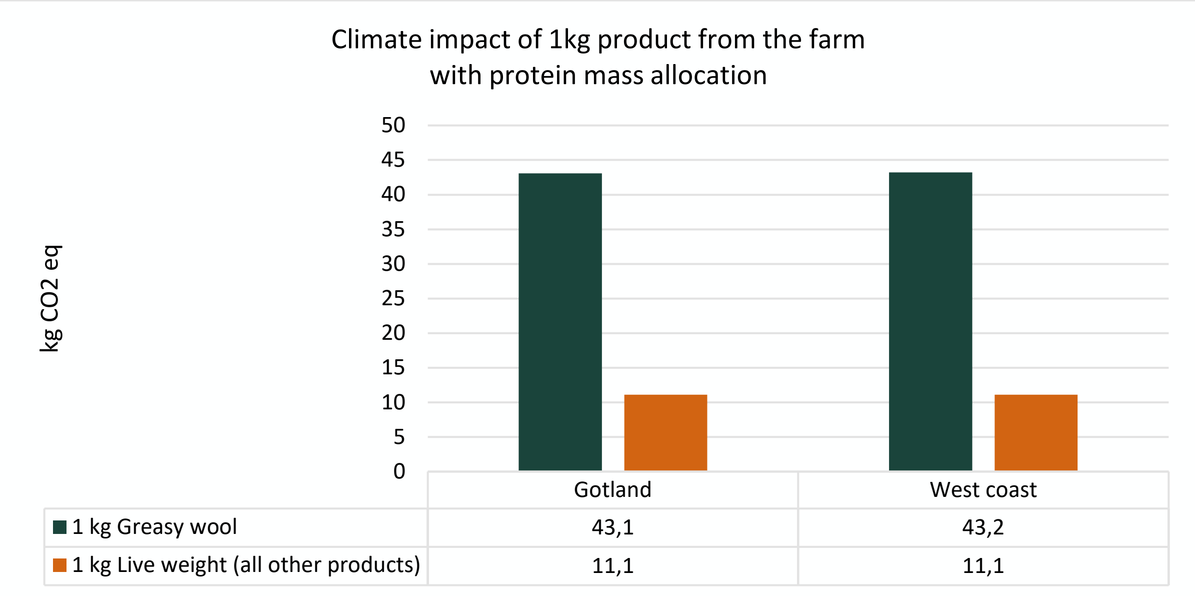


Figure 10 Climate impact of the products from the farm with PMA

The reason why wool obtains the higher result is that it contains relatively much more protein. Clean wool has about 100% protein content whereas greasy wool has about 68%. The protein content for live weight is about 18%. Data sources behind these amounts are presented in chapter *4.3.2 Data for biophysical allocation – protein content for co-production from sheep farm.* The protein mass allocation allocates the most impact to the product that has the highest protein content.

The allocation factor to wool vs live weight becomes about 9% vs 91%. But since it is 1 ton of wool carrying 9% of the impact from the farm, and 41-44 ton of liveweight carrying 91% of the impact - the normalized result to 1 kg gives wool a higher result.

Looking at the division of the climate impact per product of the 538 tons CO2 equivalents/year in the Gotland region and 500 tones CO2 eq/year in the West coast region, the result becomes as indicated below.

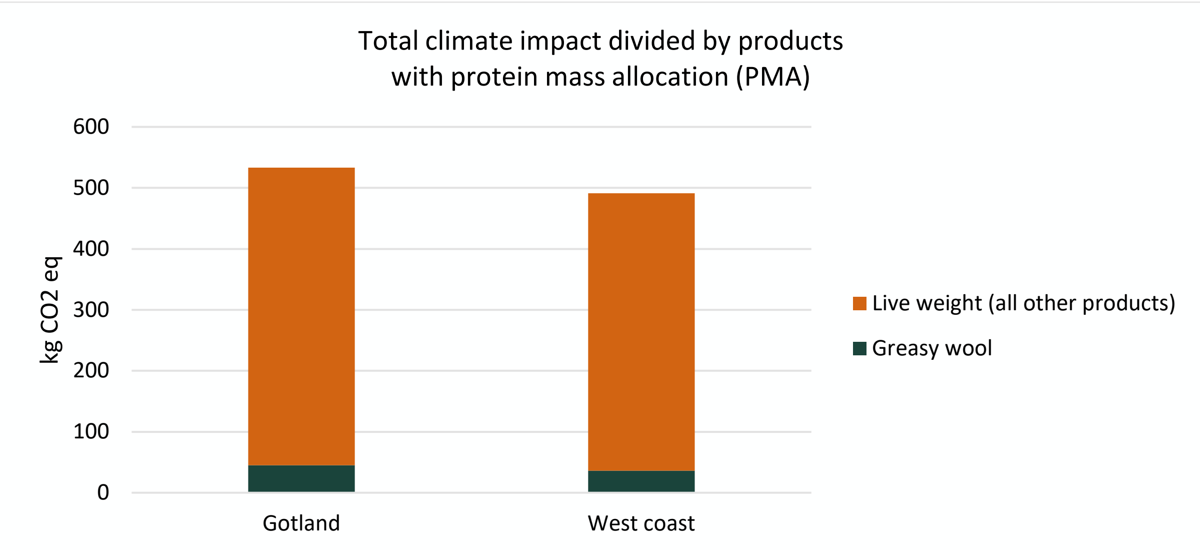


Figure 11 Total climate impact from sheep farms in each region divided by products produced with PMA

The allocation method that is not assessed in this study but that is recommended by standards like the PCR for fabrics (PCR 2022:04, version 1.0.1) within the EPD International system and the International Wool Textile Organisation (see chapter *2.5.2 Guidelines to allocation in standards*) is biophysical allocation based on protein requirement. As discussed in the allocation chapter *3.3.3.2 Allocation of co-products*, this allocation were too complex to conduct within the scope of this study. Although, it has been assessed in other studies like Wiedemann et al. (2015) who concludes that PMA as a simplified form of biophysical allocation. PMA avoids complex modelling of protein metabolism and maintenance, but produced results close to a method that allocates lamb maintenance fully to meat and were flock (ewe) maintenance Is split between wool and live weight by protein requirement ratio. Wiedemann et al. (2015) conclude that PMA a useful proxy as a biophysical allocation method.

Allocation based on economic relationship
Another allocation method that is applied in the context of wool is economic allocation, this is also the method applied in the established background database ecoinvent.

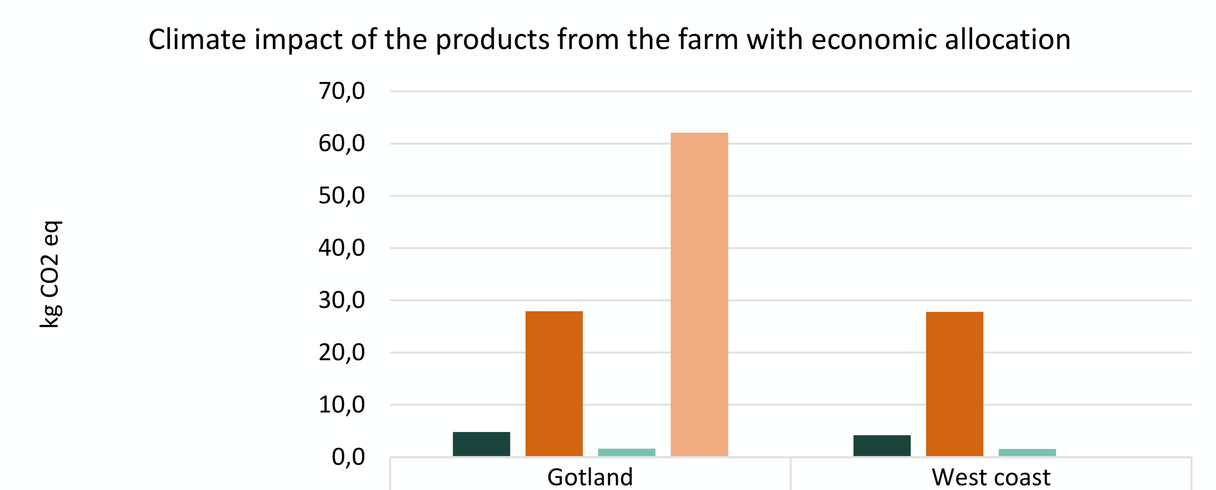
Looking at the recommendation for allocation procedure according to ISO 14040-44:
"If no valid physical allocation basis exists, economic or other proxy relationships should be applied."

The recommendation begs the question if wool and meat have a viable physical relationship since the products have very separate functions. It makes sense to use protein requirement/content for products that end up like food - like meat and milk.

This reasoning could explain why economic allocation can be motivated for co-products at the sheep farm. Furthermore, economic allocation better reflects if one product is much more valuable (economically) than the other. Using economic allocation then may better reflect the economic driver of the system. For example, if meat is relatively high value compared to wool (or vice versa) then allocating by economic value can align the environmental burden with the value chain.

Lastly, economic allocation is relatively simple to implement (once you have price data) compared to complex biophysical allocation based on protein requirement.

The economic allocation preformed in this study gives the result as indicated in Figure 12 below. It shows the climate impact result for 1 kg greasy wool, meat, other products from the slaughter, and skins (OBS skins are presented as pieces) from the Gotland and West coast region.



	Gotland	West coast
1 kg Greasy wool	4,8	4,2
1 kg Slaughter weight	27,9	27,8
1 kg Other by-products from slaughter	1,6	1,6
1 pcs Skin	62,1	0,0

Figure 12 Climate impact of the products from the farm with EA

Looking at the result, the wool is only allocated 0,9-1% of the impact from the farm since the economic value and the amount of wool produced is significantly lower than e.g meat that is allocated most of the impact. Hence, the economic allocation allocates the impact to the products that has the highest output amount and highest price.

Looking at the division of the climate impact per product of the 538 tons CO2 equivalents/year in the Gotland region and 500 tones CO2 eq/year in the West coast region, the result becomes as indicated below.

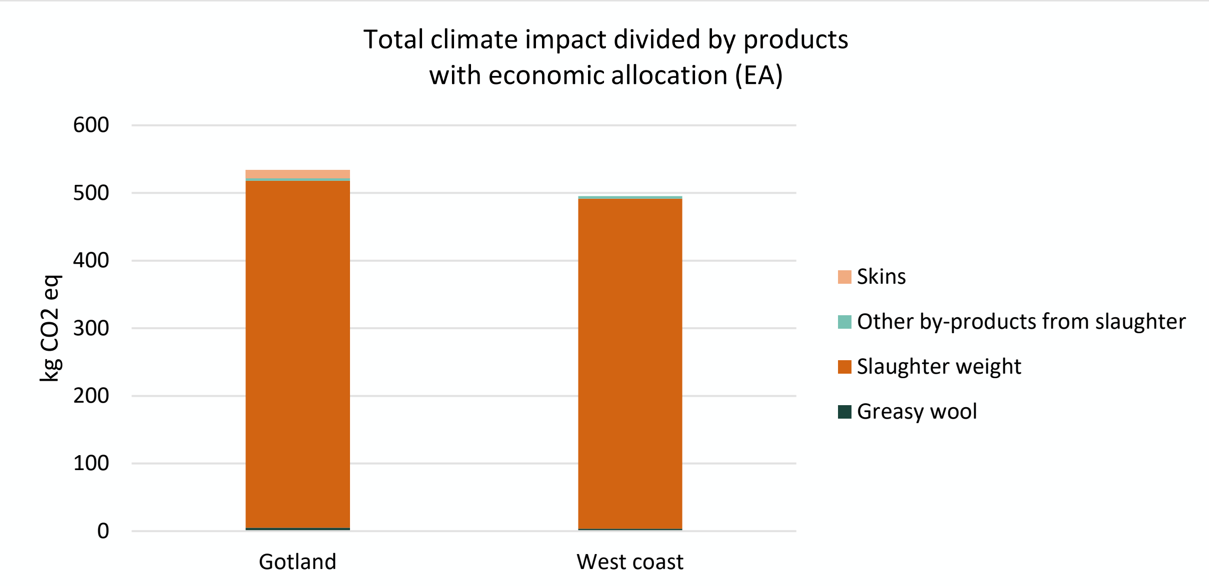


Figure 13 Total climate impact from sheep farms in each region divided by products produced with EA

Comparing the result for PMA and EA
Economic allocation gives the lowest impact while protein mass allocation gives significantly higher impact.

Table 20 Climate impact of 1 kg greasy wool used in the study

	Gotland		**West coast**	
Allocation method	**Calculated allocation factor to wool**	**Climate impact kg CO2 eq / kg wool**	**Calculated allocation factor to wool**	**Climate impact kg CO2 eq / kg wool**
Economic allocation (EA)	1,0%	4,8	0,9%	4,2
Biophysical - protein mass allocation (PMA)	9,3%	43,1	9,0%	43,2

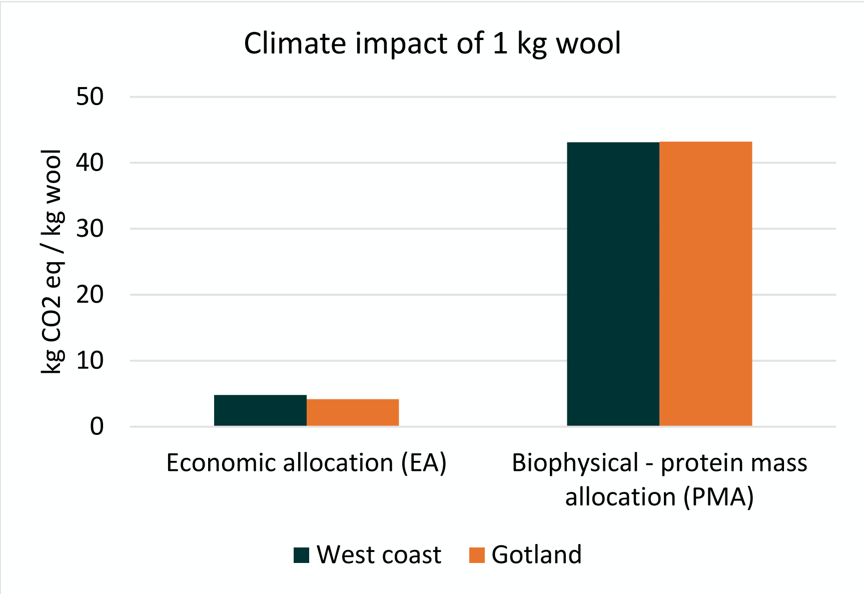


Figure 14 Comparison of the climate impact of greasy wool with the different allocation method EA and PMA

Please note that there is uncertainty in all the calculations presented in this chapter. All results should be interpreted with caution and viewed as first steps towards deriving reliable climate impact values for Swedish wool based on different allocation approaches.

5.1 Interpretation of the result

As highlighted in this study, the allocation of environmental impacts between wool and meat at the farm level is the key methodological choice for conducting an LCA of wool products. The chosen allocation method should reflect both the purpose of the production system and the function and market reality of the products being assessed.

When it comes to Swedish wool, the context differs substantially from that of more established wool-producing countries. Most sheep farms in Sweden have sheep since they keep landscapes open with grazing, after that it is meat production that is in focus, and wool has historically been regarded as a by-product with relatively low output and economic value. This dynamic is exemplified in the RISE study by Ahlgren et al. (2022) where the yearly outputs of wool and meat in Swedish regions were reported as about 1 tonne and 18 tonnes, respectively.

Arguments for using economic allocation for wool

Looking at the result for the physical allocation (PMA) and economic allocation (EA) preformed in this study for Swedish wool - and given that wool production plays a minor role at the sheep farms - this study argues for economic allocation for assessing wool with LCA.

As presented in the result, EA provides the result of about **4-5 kg CO2 eq/kg for greasy wool** and about **28 kg CO2 eq/kg meat**. Whereas PMA provides the result of about **43 kg CO2 eq/kg for greasy wool** and about **11 kg CO2 eq/kg live weight** (weight of animal before sent to slaughter).

Economic allocation simply reflects the reality best in terms of what is driving the system. In a production system where a product has a low yield and value relative to the other products produced – the PMA result it is not reasonable, but the EA is.

Further arguments for EA in this study are:

- Does wool and meat have a viable physical relationship since the products have separate functions? It makes sense to use protein requirement/content for products that end up being food - like meat and milk. If physical allocation is applied – it should reflect physical relationship between the functions of end-products at the sheep farm rather than the physical relationship between what can be grown from feeding a sheep population. In this regard, there is no physical relationship between wool and meat.

- Economic allocation is relatively simple to implement (once you have price data) compared to complex biophysical allocations based on protein requirement.

5.1.1 Sensitivity analysis of the economic allocation

Economic allocation has important benefits, but also limitations. Two important drawbacks for economic allocation are:
1) that the impact increases if the value of the by-product increases, possibly creating an incentive for keeping the value low (contrary to the project goals of the Swedish Wool Intiative), and
2) that the impact values become sensitive to price fluctuations.

This sensitivity check assesses what would happen to the result for the economic allocation if some of the project goals of the Swedish Wool Initiative were to be in place, mainly:

- Making sure that all wool is used instead of wasted
- Increase the economic value of Swedish wool

Sensitivity in amount of wool from the farm that have economic value
Since the Swedish Wool Initiative aims for making use of all wool collected, the share of the greasy wool that have value has hopefully increased or will increase in the future. The assessed wool collectors are aiming for maximising the use of the collected wool and 80-90% of collected wool is used.

In dialogue with the wool collectors, the share of wool that is used in Sweden normally is estimated to be about 50%. According to Ahgren et al (2022), about 25% of the greasy wool from the farm was sold.

Sensitivity in market prices for wool
As can be understood, the economic allocation method builds on market prices for products. Today, wool is usually considered a low-value by-product and is thus have a relatively low economic value compared to e.g. lamb meat in the Swedish case.

According to the wool collectors, the wool collected can vary in price depending on quality. For example, the farmers are paid 5-15 sek/kg for the wool depending on quality according to Västkustens ullingsamling (West coast). As no data were retrieved about how much wool had which price, a conservative assumption was made in this study were 15 sek/kg per all type of wool was used.

In reality there are different wool qualities that can be prices differently, this sensitivity check gives an intuition for what would happen when prices are changed.

Result of sensitivity check
This sensitivity check assessed what would happen to the economic allocation if farmers can be compensated for 25%, 50% and 100% of the greasy wool collected instead of 80-90% that has been used in the baseline calculation. This sensitivity check also assesses what will happen to the result when the kilogram price of the wool is changed to 5 sek and 30 sek instead of 15 sek used in this study.

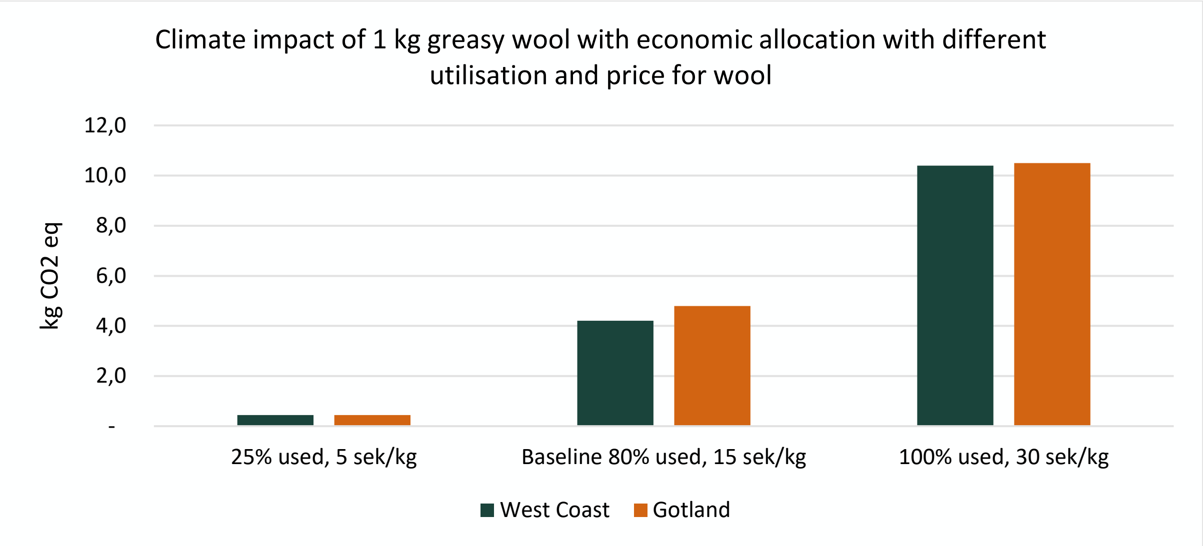


Figure 15 Sensitivity check of economic allocation to wool when the utilization and price of wool is changed

The sensitivity check highlights the time aspect of economic allocation, as long as market prices are fixed and the production system is steady, economic allocation will provide similar result. But for a market that is evolving and were utilisation rate of collected wool and prices are hoping to increase, the result with economic allocation risks being outdated and would need revision more frequent. Some rules suggest that economic allocation should be preform of market prices during a period.

Another conclusion that can be drawn from the sensitivity check is that if more of the wool can be utilized into valuable products, the environmental impact per SEK created value is reduced. It should also be mentioned here that if more wool is utilized, then bigger part of the sheep farming impact is allocated to the wool and thereby the impact per kg meat is reduced.

5.1.2 Is the current LCA method fair for Swedish wool?

Having sheep in Sweden offers numerous environmental advantages, many of which cannot be measured properly with the LCA methodology currently.

Do we capture all value that sheep in Sweden provide?

Swedish sheep farming provides important environmental and cultural benefits that are not fully captured in the conventional life cycle assessment methodology. Grazing maintains open landscapes, preserves semi-natural pastures, and supports biodiversity in species-rich ecosystems that would otherwise become overgrown. Sheep also utilize land that is unsuitable for other types of food production, thereby contributing to the maintenance of cultural landscapes and ecological values. Taken together, this highlights the dual role of sheep farming: it exerts certain environmental pressures but also delivers ecosystem services of significant importance.

In the case of wool, positive contributions such as maintaining biodiversity, keeping landscapes open, and preserving cultural values are not fully reflected in standard LCA indicators. These benefits are difficult to integrate into conventional LCA categories, which points to a methodological limitation. Therefore, an LCA of a wool product should be viewed as one of several complementary tools needed to evaluate the overall environmental performance of wool.

Swedish farmers can receive financial support practices that maintain biodiversity and manage semi-natural grasslands (Glimskär et al., 2023; SEPA, 2025). These payments aim to reward farmers for delivering ecosystem services in addition to food and fibre production.

Given these schemes, one could argue that part of the environmental impact of sheep farming should be attributed to its role in providing public environmental goods, such as biodiversity and landscape management. Since these ecosystem services are already partially recognized economically through subsidy payments, there is a rationale to consider including such revenues in economic allocation within LCA studies.

Doing so could better reflect the multifunctionality of sheep farming — acknowledging that not all environmental burdens are incurred solely for product output (e.g., wool or meat), but also in the delivery of ecosystem services that are compensated through public funding.

Maximize the use of resources

When evaluating the environmental impact of Swedish wool, it is essential to place the results in a broader sustainability context. Resource efficiency is a central principle, large volumes of wool are still discarded, and greater utilization of this resource would clearly improve the environmental performance for having sheep.

Ultimately, the aim is for every output from sheep farming to reach its highest potential value. However, in practice, this is challenging. Different sheep breeds are better suited to different purposes, and farming systems are often optimized either for wool or for meat. As a result, it remains a challenge to fully maximize the value of both purposes simultaneously within the current production structures.

Beyond environmental considerations, there are strong social and economic arguments for making better use of Swedish wool. Neglecting local resources undermines national self-sufficiency and wastes economic potential. At the same time, wool carries important cultural and social value through craft traditions and skilled local workmanship. Supporting these dimensions strengthens rural livelihoods and preserves cultural heritage, while also aligning with sustainable production goals.

From an LCA perspective, both quantitative and qualitative assessments are needed. Quantitative results provide measurable outcomes, but they often fail to capture local conditions and social contexts. Qualitative evaluations can complement these insights by highlighting aspects such as biodiversity, resource efficiency, cultural values, and socio-economic impacts. A balanced approach is therefore essential.

6 Result of the impact assessment of the supply-chains for Klippan yarn and VERK's fabric

In this section, the results from the environmental impact assessment method IPCC 2021 GWP100 for Klippan's yarn and VERK's fabric will be presented. The LCIA method follows the standard for carbon footprint according to ISO 14067. Here, the biogenic carbon dioxide uptake is calculated as 0 and biogenic carbon dioxide emissions as 0[2]. For further details on the LCIA method, see Appendix 3.

The results are presented in the following order:

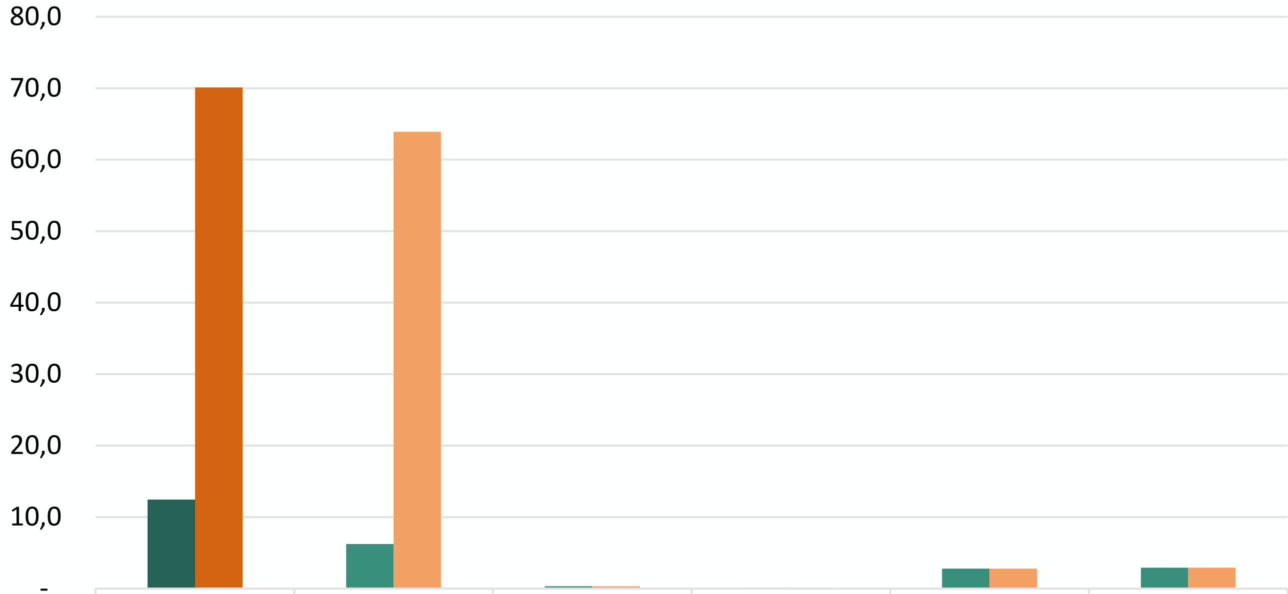
1. Climate impact of the supply-chain of wool yarn from Klippan Yllefabrik
2. Climate impact of the supply-chain of wool fabric from VERK
3. Biogenic carbon content of the products

Note that the LCIA results are relative expressions, which means that they do not predict impacts on category endpoints or the exceeding of thresholds, safety margins or risk.

[2] Note that there are methods using the factors -1/+1 for biogenic carbon uptake/emissions.

6.1 Climate impact of the supply-chain of wool yarn from Klippan Yllefabrik

The result is shown for 1 kg of yarn and is divided into the different supply-chain steps required to produce the yarn. The result Is shown for both EA and PMA allocation of wool - which Is why there are two totals provided.



	Total	Sorted greasy wool	Scouring	Combing	Yarn spinning	All transport between supply-chain steps
% of total EA		50%	3%	1%	22%	23%
% of total PMA		91%	0%	0%	4%	4%
Economic allocation (EA) of wool	12,4	6,2	0,3	0,2	2,8	3
Protein mass allocation (PMA) of wool	70,1	63,9	0,3	0,2	2,8	3

Figure 16 Climate impact for 1 kg yarn cradle-to-gate with different allocation methods

Below is the detailed result for the supply-chain steps provided as a total (GWP-total), and also divided into the its sources: fossil, biogenic, and luluc. Since the data for the wool did not contain this information, the division into sources are not sown for the wool.

Table 21 Result for 1 kg Klippan yarn with EA

Impact category	Unit	Total	Sorted greasy wool	Trasport farmer -> collection	Transport collection -> scouring	Scouring	Transport scouring -> Combing	Combing	Transport Combing-> spinning	Yarn spinning
GWP-total	kg CO2-eq	**12,4**	**6,2**	**0,3**	**1,3**	**0,3**	**0,0**	**0,2**	**1,3**	**2,8**
GWP-fossil	kg CO2-eq	-	-	0,3	1,3	0,2	0,0	0,2	1,3	2,8
GWP-biogenic	kg CO2-eq	-	-	0,0	0,0	0,1	0,0	0,0	0,0	0,0
GWP-luluc	kg CO2-eq	-	-	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 22 Result for 1 kg Klippan yarn with PMA

Impact category	Unit	Total	Sorted greasy wool	Trasport farmer -> collection	Transport collection -> scouring	Scouring	Transport scouring -> Combing	Combing	Transport Combing-> spinning	Yarn spinning
GWP-total	kg CO2-eq	**70,1**	**63,9**	**0,3**	**1,3**	**0,3**	**0,0**	**0,2**	**1,3**	**2,8**
GWP-fossil	kg CO2-eq	-	-	0,3	1,3	0,2	0,0	0,2	1,3	2,8
GWP-biogenic	kg CO2-eq	-	-	0,0	0,0	0,1	0,0	0,0	0,0	0,0
GWP-luluc	kg CO2-eq	-	-	0,0	0,0	0,0	0,0	0,0	0,0	0,0

6.2 Climate impact of the supply-chain of wool fabric from VERK

The result is shown for 1 m2 of fabric with the weight 0,56 kg/m2 and is divided into the different supply-chain steps required to produce the fabric. The result is shown for both EA and PMA allocation of wool - which Is why there are two totals provided.

	Total	Greasy wool	Scouring	Yarn spinning	Warping	Weaving	Surface treatment	All transport between supply-chain steps
% of total EA		69%	5%	3%	4%	9%	1%	9%
% of total PMA		95%	1%	0%	1%	1%	0%	1%
Economic allocation (EA) of wool	6,0	4,1	0,3	0,2	0,2	0,5	0,1	0,5
Protein mass allocation (PMA) of wool	39,0	37,2	0,3	0,2	0,2	0,5	0,1	0,5

Figure 17 Climate impact of 1 m2 fabric (0,56 kg/m2) cradle-to-gate with different allocation methods

Below is the detailed result for the supply-chain steps provided as a total (GWP-total), and also divided into the its sources: fossil, biogenic, and luluc. Since the data for the wool did not contain this information, the division into sources are not sown for the wool.

Table 23 Result for 1 m2 VERK fabric with EA

Impact category	Unit	Total	Greasy wool	Transport farm -> collection	Scouring	Yarn spinning	Transport yarn -> warp + weaving	Warping	Weaving	Transport weaving -> surface treatment	Surface treatment
GWP-total	kg CO2-eq	**6,0**	**4,1**	**0,1**	**0,3**	**0,2**	**0,2**	**0,2**	**0,5**	**0,2**	**0,1**
GWP-fossil	kg CO2-eq	-	-	0,1	0,3	0,2	0,2	0,2	0,5	0,2	0,1
GWP-biogenic	kg CO2-eq	-	-	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
GWP-luluc	kg CO2-eq	-	-	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Table 24 Result for 1 m2 VERK fabric with PMA

Impact category	Unit	Total	Greasy wool	Transport farm -> collection	Scouring	Yarn spinning	Transport yarn -> warp + weaving	Warping	Weaving	Transport weaving -> surface treatment	Surface treatment
GWP-total	kg CO2-eq	**39,0**	**37,2**	**0,1**	**0,3**	**0,2**	**0,2**	**0,2**	**0,5**	**0,2**	**0,1**
GWP-fossil	kg CO2-eq	-	-	0,1	0,3	0,2	0,2	0,2	0,5	0,2	0,1
GWP-biogenic	kg CO2-eq	-	-	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
GWP-luluc	kg CO2-eq	-	-	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

6.3 Biogenic carbon content

The biogenic carbon content is mandatory to report for a cradle-to-gate carbon footprint study according to ISO 14067. This information may be relevant for the remaining value chain (CEN, 2020).

See below how the biogenic carbon content is calculated and standard values for wool:

Equation 1 Biogenic carbon content according to EN 16449.

$$\text{Biogenic carbon content} = \text{Biogenic carbon fraction} \bullet \frac{\text{Wet density of the biomass} \bullet \text{Wet volume of the biomass}}{1 + \frac{Moisture\ percentage}{100}}$$

Standard Values:
Moisture: 10-14% for raw wool according to ecoinvent.
Biogenic Carbon fraction: ca 50% for wool (IPCC, 2006).

Table 25: Shows the biogenic carbon content of the products

Share of biogenic carbon	Unit	Amount 1 kg yarn	Amount 1 m2 fabric (0,56 kg)
Biogenic carbon in the product	kg C	0,43-0,45	0,24-0,25

(1 kg Biogenic carbon content = 44/12 kg CO2)

6.4 Interpretation of the result

This section focuses on interpreting the results for Klippan's yarn and VERK's fabric. It covers the key aspects of the results, sensitivity analyses, scenario analyses and an evaluation of the model and underlying data. Furthermore, a scenario analysis assessing a future scenario were the supply-chain steps are integrated at one site is assessed.

6.4.1 Key aspects of results

The climate impact of assessed products when wool is allocated impact with economic allocation (EA) and protein mass allocation (PMA) is summarised in the table below.

Table 26 Climate impact results cradle-to-gate of assessed products

Impact category	Unit	1 kg yarn from Klippan		1 m2 fabric from VERK (0,56kg/m2)	
		Total with EA	Total with PMA	Total with EA	Total with PMA
GWP-total	kg CO2-eq	12,4	70,1	6,0	39,0

It is the raw material, greasy wool, that is the hot-spot for the cradle-to-gate result regardless allocation method. The wool stands for about 50-70% of the assessed supply chains with economic allocation and 90-95% with protein mass allocation. Regardless how allocation to the wool occur, a sheep farm will come with a climate cost. Conclusions from Ahlgren et al. (2022) state that the climate impact from sheep farms vary between rearing systems but that methane from enteric fermentation, emissions from organic soils and emissions from manure storage account for the largest emissions.

Looking at the yarn from Klippan's supply-chain, transports and the process for yarn spinning are the most contributing supply-chain steps. All transports during the supply-chain stands for about 4% (PMA)/23% (EA) of the climate impact of assessed supply-chain. The yarn spinning stands for about 4% (PMA)/22% (EA) of the climate impact of assessed supply-chain, and it is the electricity consumption in that process that mainly contributes to the result.

Looking at the fabric from VERK's supply-chain, it is mainly transports that are contributing to the result part from the wool. Transports between supply-chain steps stands for about 1% (PMA)/9% (EA) of the climate impact of assessed supply-chain. Furthermore, the weaving process includes a transport of the warp beam back-and-forth which stands for most of the impact from this supply-chain step which contributes to about 1% (PMA)/9% (EA) of the climate impact of assessed supply-chain.

6.4.2 Limitations with selection of system boundaries

Since the products assessed are intermediate products, the system boundary for the study is defined as cradle-to-gate. This approach aligns with how the results are typically used by customers, who rely on data at this stage in the value chain.

However, it is important to acknowledge that downstream life cycle stages, use and end-of-life, can significantly influence the overall environmental impact of wool products. Several studies assessing wool products using LCA have highlighted this, including the IWTO Guidelines for Wool LCA (2016) and Wiedemann et al. (2020).

Use phase considerations
Consumer behaviour plays a critical role during the use phase. For end-products of wool like a garment or furniture, factors such as lifespan, frequency of use, and maintenance practices (e.g. washing intervals and water temperature) affects the overall lifecycle impact. Wool is widely recognized for its durability and suitability for high-quality products. In that regard, the number uses and overall lifetime are most influential factors determining the environmental impact from a lifecycle perspective. This underscores the consumer's influence to reduce the environmental impact by maximizing the active lifespan of wool garments. Also, the producer’s responsibility to use the right material quality and design for the right function and use.

End-of-life considerations
End-of-life scenarios are also relevant. According to Russel et al. (2016), wool textiles are more likely to be reused or recycled than other textile types. Additionally, wool is a biogenic and biodegradable material, which generally results in lower environmental burdens compared to fossil-based textiles at the end of life (Russel et al., 2016).

In this study, the exclusion of end-of-life is not expected to significantly change the conclusions. But using recycled wool instead of virgin wool into production could further reduce impacts. Achieving this depends on effective collection systems and consumer behaviour that promotes reuse and recycling of wool products.

Dyeing of yarn or fabric
Note that the assessed yarn and fabric are undyed and if they were to be dyed, this is an important manufacturing step to collect data for as allot of water, energy and chemicals can be consumed in this process.

6.4.3 Data quality assessment

The data is valid for production of Klippan yarn and VERK fabric. An evaluation of the model and underlying data is made by a data quality assessment which includes a completeness check, assessing the validity of data and a consistency check. This data quality assessment has been made throughout the study and in reference to the goal and scope of the report, the LCA is judged to be complete.

Specific data were collected from suppliers about raw material consumption, energy consumption, consumables, waste, packaging, and internal transports. Furthermore, transport distances were collected between the supply chain steps. All specific data were collected in 2025 and represents 2024 years production.

Specific data for electricity consumption in yarn spinning for Klippan yarn could not be retrieved, this were represented with generic data in ecoinvent 3.11. Furthermore, some data were excluded due to cut-off rules and documentation for these can be found in 3.3.2.

6.5 Data gaps and methodological needs to improve assessment quality and adhere to EPD standards

This study, as well as much of the current data landscape in sustainability assessments, focuses narrowly on climate change. This is largely because climate change is the category we have become most comfortable quantifying. However, a sole focus on climate risks overlooking other important environmental aspects, such as land use, eutrophication, acidification, and resource depletion.

A crucial step towards improving the quality of the LCA presented in this study is therefore to obtain more comprehensive background data that would enable calculations across additional environmental impact categories. In this report, modelling for all supply-chain steps beyond greasy wool production has been carried out using such background data, which allowed results to be reported for several impact categories. However, as the results clearly indicate, the primary hotspot lies in the wool production itself. It is therefore essential to obtain detailed, high-quality data specific to Swedish wool. The work presented by RISE in Ahlgren et al. (2022) could serve as a valuable foundation for this effort. Some of the authors of the RISE study were contacted early in the project to explore whether data covering multiple impact categories could be accessed, but pursuing this further was ultimately beyond the scope of the present study. For this reason, only climate change has been regarded in the LCA calculations.

To increase the robustness of future assessments, it will be necessary to expand the scope beyond climate change and to include a broader set of impact categories. This is also required for making an Environmental Product Declaration (EPD) (see chapter 2.3 for an explanation of EPD).

For Swedish wool to be assessed and reported in compliance with EPD standards, detailed and representative inventory data is needed not only for climate change but also for the full range of mandatory impact categories.

In practical terms, the next steps to improve assessment quality and enable EPD-compliant reporting for Swedish wool products could be:

- **Best quality of LCA** - Expand the work conducted by RISE Ahlgren et al. (2022) where they have collected detailed life cycle inventory data at farm level. Make sure that the work is done and presented in a way that allows for it to be used in a LCA study that could serve as input data to an EPD. (E.g. include the full set of mandatory environmental impact categories specified by the relevant PCR's.)
- **Lesser quality of LCA** – Find more representative generic data. E.g. there are background data for meat-oriented production systems that can be motivated to use given the Swedish condition.

Specific allocation requirements for greasy wool in the PCR for yarn, fabrics and apparel

The product category rules (PCR) for yarn and apparel by the International EPD system do not specify any certain allocation procedure for animal farms but follows the ISO 14044 recommendation for allocation. By this, one could argue that e.g. wool and meat don't have a viable physical relationship and that economic allocation should be applied.

The PCR for fabric although state that biophysical allocation shall be used for wool. Furthermore, the fabric PCR specify that the share allocated to the wool shall be calculated using the ratio of its metabolizable protein requirement to the total protein requirement for making all products like meat and wool.

In more depth, the PCR for fabric within the EPD International system states that biophysical allocation shall be used for allocation between milk, meat, and fibre at farm and that economic allocation shall be used in the washing were clean fibre and lanolin are co-products. Economic allocation shall be based on a minimum of three years of recent average prices. See the detailed requirements cited from the PCR below:

"The allocation ratio for fibre, relative to fibre plus meat and milk shall be calculated from the ratio of the metabolizable protein requirement for fibre production to the metabolizable protein requirement for fibre, meat (the component for live weight sold for meat) and milk (if relevant) production using:

Allocation % to fibre = 100 x (protein req. for fibre/(protein req. for fibre + protein req. for meat + protein req. for milk))

Farm survey data should be used to define ruminant production systems and ruminant population.

The data should be used to determine the protein requirements with the recommended hierarchy:
1. Apply a published country-specific model such as stated in Australian Livestock Feeding Standards – Ruminants.
2. Apply another model that has been peer-reviewed and published and that is applicable to the region and country.
3. Apply NRC (2007) metabolizable protein requirement model.

For biophysical allocation, a sensitivity analysis shall be carried out to illustrate the effects of the choice of biophysical allocation The biophysical allocation approach, protein requirements calculation model, sensitivity analysis methodology and sensitivity analysis result shall be available to the verifier and shall be presented in the EPDs."

Plausibility in complying with allocation rules set by PCR for fabrics
In practice, it seems unlikely that the PCR requirements for allocating impacts to wool are consistently followed, given the substantial effort needed to perform the calculations as specified above. Instead, data from secondary databases – such as those discussed in chapter 2.5.1 Allocation factors and GWP results from literature - are typically used when developing EPDs for wool-based products. These databases apply different allocation methods.

The literature reviewed in this study shows that biophysical allocation based on protein requirements for wool is methodologically complex and data-intensive. As a result, many practitioners instead rely on economic allocation or protein mass allocation, which is also the approach applied in this study.

To demand that each producer of wool-based products individually perform full biophysical allocation, as prescribed in the PCR, does not appear reasonable. Moreover, this study highlights that allocation choices are highly sensitive and significantly affect results. If each EPD were based on producer-specific allocation models, results would vary widely, undermining one of the core purposes of EPDs - ensuring comparability. A more effective solution would be for industry stakeholders to jointly develop standardized allocation data and for PCR rules to be updated to reflect these realities.

How PCR rules can be influenced
PCRs are not fixed permanently, they are living documents that are revised periodically. Industry stakeholders, research institutions, and companies can propose changes when the PCR is up for review. This is typically done by submitting evidence, such as methodological studies or sector-wide data, during public consultation phases. If a critical mass of stakeholders agrees that certain requirements are impractical or reduce comparability, the PCR can be updated accordingly.

For wool products, this means that collective industry efforts to generate robust allocation data could directly inform future revisions of the PCR and make the requirements more feasible and harmonized.

Based on the outcome form this study, we think that PCR rules for wool products should follow the recommendation for allocation according to the ISO standard. Then according to the reasoning in this study, economic allocation is the viable allocation method between co-products at farm level.

To enhance comparability, the PCRs should include default values for economic allocation and environmental parameters, including those for meat and wool, when specific and verified data are not available.

Furthermore, we would like to see that following is declared in the EPDs assessing the environmental impact of wool products:

- Description of the wool sourcing – were does the wool come from and what are the premises on those farms?
- Clearly declaration of background data used to represent the wool.
- Clear description of the allocation method applied, and which co-products are included at farm level.
- Result GWP-GHG for 1 kg greasy wool.

Furthermore, the LCA report should contain a sensitivity check motivating and assessing the allocation method applied – preferably at farm level if this is possible. By farm level, we mean that all co-products from the farm should be described and how the total impact from the farm is divided between these.

7 Scenario analysis on integrated supply-chain at Holma-Helsingland

A future production scenario at Holma-Helsingland is assessed in this study. Holma-Helsingland traces its lineage to 1898, when local farmers founded Helsinglands Linspinneri AB; in 1907 it merged with a weaving concern in Holma to form Holma-Helsinglands Linspinneri & Väveri AB, and over subsequent decades the company operated in spinning, twisting, bleaching, dyeing and finishing yarns (linen, cotton, wool and blends) with in-house dyeing capacity. Today, large-scale spinning of raw linen no longer takes place in the original plant, but the facility still bleaches, dyes, twists and rolls yarns. The textile industry in Holma has decreased significantly compared to its peak, although facilities like Holma-Helsingland may offer a foothold for re-localization of parts of textile value chains in Sweden.

This scenario examines the Holma scenario – a scenario when the entire production process, from raw wool to finished fabric, is geographically located at the same place.

LCA modelling of the Holma scenario

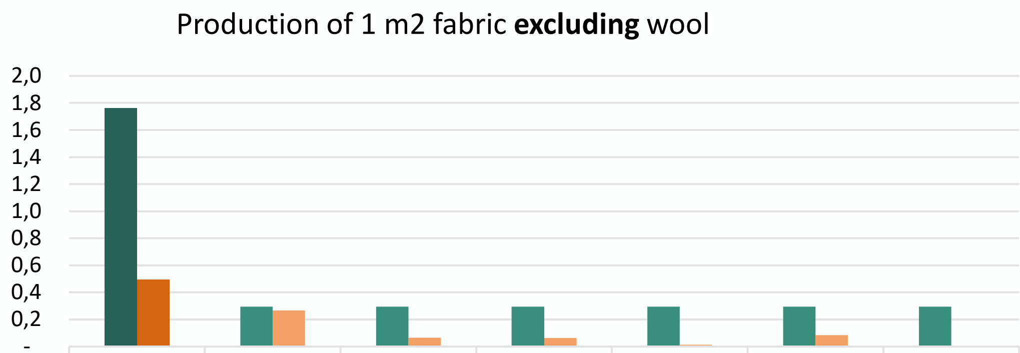
To do this scenario, Holma is based on the modelling of VERKs fabric - but were transports and packaging between supply-chain steps has been excluded. Packaging of finished textile is included. Furthermore, Holma has electricity mix that is fossil free, see certificate in Appendix 3. The electricity consumption is assumed to be the same as in VERKS supply-chain but the source is changed and modelled as: 50% Electricity, high voltage {SE}| electricity production, hydro, reservoir, non-alpine region | Cut-off, U + 50% Electricity, high voltage {SE}| electricity production, nuclear, boiling water reactor | Cut-off, U. An 8% transmission loss from high to low voltage is assumed.

Result with an integrated supply-chain

Since the impact from wool is the same for the scenario – the result is shown excluding and including wool. By this, it becomes easier to assess the effects of minimizing transports and having renewable electricity in production.

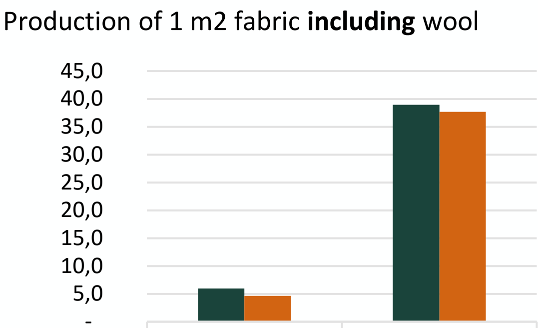
In Figure 18 and Figure 19 the result for the production of 1 m2 fabric with the weight 0,56 kg/m2 is presented. Looking at the supply-chain excluding the wool – there is a 72% reduction with having an integrated supply-chain that is powered with renewable electricity. Looking at the supply-chain including wool – this gives an 3% reduction with PMA and a 23% reduction with EA.

In Figure 20 and Figure 21 the result for the production of 1 kg yarn is presented. Looking at the supply-chain excluding the wool – there is a 46% reduction with having an integrated supply-chain that is powered with renewable electricity. Looking at the supply-chain including wool – this gives an 1% reduction with PMA and a 6% reduction with EA.



	Total for supply-chain exluding wool	Scouring	Yarn spinning	Warping	Weaving	Surface treatment	All transport between supply-chain steps
VERK	1,8	0,3	0,3	0,3	0,3	0,3	0,3
Holma scenario	0,5	0,3	0,1	0,1	0,0	0,1	
Reduction	-72%	-9%	-78%	-78%	-95%	-71%	-100%

Figure 18 Climate impact result for the Holma scenario 1m2 fabric excluding wool

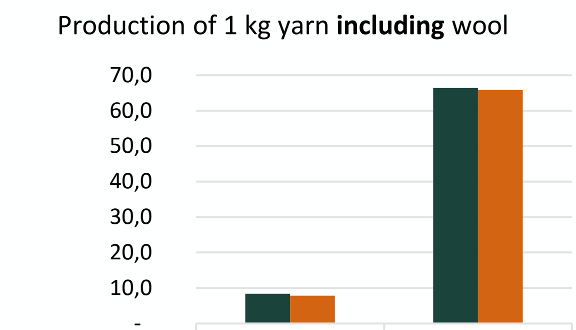


	EA total	PMA total
VERK	6,0	39,0
Holma scenario	4,6	37,7
Reduction	-23%	-3%

Figure 19 Climate impact result for the Holma scenario 1m2 fabric including wool

	Total for supply-chain exluding wool	Scouring	Yarn spinning	Transport wool collection
VERK	1,1	0,5	0,3	0,2
Holma scenario	0,6	0,5	0,1	
Reduction	-46%	-9%	-65%	-100%

Figure 20 Climate impact result for the Holma scenario 1 kg yarn excluding wool



	EA total	PMA total
VERK	8,3	66,4
Holma scenario	7,8	65,9
Reduction	-6%	-1%

Figure 21 Climate impact result for the Holma scenario 1 kg yarn including wool

8 Conclusions and recommendations

This section will summarise the conclusions from the study in terms of highlighting the most important outcomes.

What are hot spots for the climate impact of products made from Swedish wool

The results of this study confirm that wool production is the dominant contributor to the climate impact of Swedish wool products supply-chains. Sheep farming inherently entails greenhouse gas emissions, primarily from methane generated through enteric fermentation, as well as emissions from organic soils and manure management. Consequently, for both yarn and fabric, wool production at the farm stage accounts for the majority of emissions throughout the supply chain.

However, downstream processes such as transport, spinning, and weaving also play a relevant role in determining the total climate impact of producing products in Swedish wool. The scenario analysis conducted in this study indicates that a more integrated and regionally concentrated supply chain, characterized by shorter transport distances and the use of renewable electricity, has significant potential to reduce the overall climate impact of Swedish wool products.

How can LCA frameworks evolve to favour materials like wool

A crucial methodological finding is that allocation method strongly influences the result. Sheep farms always come with an environmental impact – the question is how this impact is allocated between co-products from the farm. Results vary substantially depending on the allocation method applied for co-products at the sheep farm. In this study economic allocation (EA) and biophysical allocation by protein mass (PMA) were done to demonstrate the difference in the result with different allocation methods.

Using economic allocation, the result is about **4-5 kg CO2 eq/kg for greasy wool** and **28 kg CO2 eq/kg meat**. Whereas protein mass allocation produces result of about **43 kg CO2 eq/kg for greasy wool** and about **11 kg CO2 eq/kg live weight.**

Most sheep farms in Sweden have sheep since they keep landscapes open with grazing, after that it is meat production that is in focus, and wool has historically been regarded as a by-product with relatively low output and economic value.

In Sweden, most sheep farms exist primarily to maintain open landscapes through grazing, with meat production as the main commercial driver. Wool has been considered a by-product with limited market value. Consequently, economic allocation - which assigns impacts based on the relative market value of co-products - better reflects the current Swedish context, where meat is the dominant output and wool plays only a minor economic role.

In contrast, biophysical methods such as PMA assign a larger share of the environmental burden to wool, often resulting in less realistic outcomes for Swedish conditions. These methods are more complex to apply and may not accurately represent the market dynamics or production drivers in sheep farming. Therefore, this study supports the use of economic allocation for wool in LCA studies, as it most accurately represents the system's underlying economic reality. When a co-product has low yield and value compared to the main product, results based on physical or biophysical allocation may be unreasonable in relation to how the system operates in practice. Furthermore, if an allocation method based on physical relationship is chosen, it should be based on the relationships between the end-products at the farm than the physical relationship between what can be grown from feeding a sheep population. In this regard, it is hard to find a physical relationship between wool and meat.

Economic allocation could also capture the broader multifunctionality of Swedish sheep farming. Farmers in Sweden may receive financial support for practices that maintain biodiversity and manage semi-natural grasslands. These payments compensate farmers for delivering ecosystem services. Given these schemes, it can be argued that part of the environmental impact of sheep farming should be attributed to the service they provide. This approach acknowledges that not all environmental burdens arise solely from product outputs like meat or wool, but also from the provision of ecosystem services that society actively rewards. In this way, economic allocation aligns more closely with Sweden's multifunctional agricultural policy and provides a fairer representation of how environmental burdens and benefits are distributed.

One limitation with economic allocation is that is has a temporal dimension. As long as market prices and production systems remain stable, results will be consistent. However, if wool utilization and prices increase over time - as is currently being encouraged in Sweden - the allocation results would shift, requiring periodic revision to remain valid. Some guidelines recommend using average market prices over a representative period to mitigate this effect.

However, if we maximise the value of having sheep in Sweden – with increased utilisation of wool and acknowledging the ecosystem services they provide – the economic allocation leads to a lower environmental impact per unit of economic value generated. This dynamic underlines the potential environmental - and economic benefits of developing the Swedish sheep farming further.

Readiness for Environmental Product Declarations

At present, data for Swedish wool in the preferable quality is not in place. The main barrier is the lack of representative and detailed farm-level data across the full set of mandatory impact categories specified in the Product Category Rules (PCRs). Current studies only provide robust data for climate change, which is insufficient for EPD compliance.

In practical terms, the next steps to improve assessment quality and enable EPD-compliant reporting for Swedish wool products could be:

- **Best quality of LCA** - Expand the work conducted by RISE Ahlgren et al. (2022) where they have collected detailed life cycle inventory data at farm level. Make sure that the work is done and presented in a way that allows for it to be used in a LCA study that could serve as input data to an EPD. (E.g. include the full set of mandatory environmental impact categories specified by the relevant PCR's.)
- **Lesser quality of LCA** – Find more representative generic data. E.g. there are background data for meat-oriented production systems that can be motivated to use given the Swedish condition.

Moreover, the current PCR for fabrics within the EPD International System (PCR 2022:04, version 1.0.1) prescribes biophysical allocation based on metabolizable protein requirements. As discussed, this approach is highly complex, data-intensive, and impractical for individual producers to implement. In practice, most industry actors rely on economic allocation or simplified protein mass allocation, which makes current practice inconsistent with PCR requirements. This situation undermines comparability between wool-based EPDs and highlights the need for sector-wide coordination.

PCRs are not fixed permanently, they are living documents that are revised periodically. Industry stakeholders, research institutions, and companies can propose changes when the PCR is up for review. This is typically done by submitting evidence, such as methodological studies or sector-wide data, during public consultation phases. If a critical mass of stakeholders agrees that certain requirements are impractical or reduce comparability, the PCR can be updated accordingly.

For wool products, this means that collective industry efforts to generate robust allocation data could directly inform future revisions of the PCR and make the requirements more feasible and harmonized.

Based on the outcome form this study, we think that PCR rules for wool products should follow the recommendation for allocation according to the ISO standard. Then according to the reasoning in this study, economic allocation is the viable allocation method between co-products at farm level. Furthermore, we would like to see that following is declared in the EPDs assessing the environmental impact of wool products:

- Description of the wool sourcing – were does the wool come from and what are the premises on those farms?
- Clearly declaration of background data used to represent the wool.
- Clear description of the allocation method applied, and which co-products are included in the allocation at farm level.
- Result GWP-GHG for 1 kg greasy wool.

Furthermore, the LCA report should contain a sensitivity check motivating and assessing the allocation method applied – preferably at farm level if this is possible. By farm level, we mean that all co-products from the farm should be described and how the total impact from the farm is divided between these.

8.1 Recommendations for future work

To advance towards EPD compliance and improve the robustness of future LCAs of products made from Swedish wool, several actions are required. Below are some recommendations divided by stakeholders to whom LCA results for wool could be relevant.

To researchers and developers of environmental data

Expand the work conducted by RISE Ahlgren et al. (2022) where they have collected detailed life cycle inventory data at farm level. Make sure that the work is done and presented in a way that allows for it to be used in a LCA study that could serve as input data to an EPD. (E.g. include the full set of mandatory environmental impact categories specified by the relevant PCR's.)

To policymakers and decision-makers

Evaluate the need for a certification system or equivalent incentive for sheep farming that acknowledges that one product form the sheep farm is the maintenance of open landscapes and ecological values, not only producing meat and wool. Life cycle assessments in these cases should consider this function in the analysis.

To all that wants to assess wool products with LCA

Clearly communicate the purpose of sheep farming and adjust life cycle assessments accordingly. According to ISO 14040–44, environmental impacts should be allocated among the functions or products generated. When these functions are not comparable in physical units, economic allocation

should be applied.
The value of maintaining open landscapes can be estimated through the cost of alternative methods achieving the same function, such as mechanical mowing or grazing subsidies.

To manufacturers of wool products
Use wool resource-efficiently and with a focus on product longevity.

- Prioritize recycled wool where possible.
- Provide users with clear care instructions and services or support that extend product life.
- Choose wool with lower environmental impact, based on transparent environmental data.
- Use wool in products where its unique properties are truly beneficial, such as flame resistance, water repellence, and antibacterial performance.

In this way, the value of wool can be maximized throughout its life cycle, while minimizing the overall use of resources.

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10 Appendix list

Appendix 1 Basics of Life Cycle Assessment

There are four phases in an LCA study; the goal and scope definition phase, the inventory analysis phase, the impact assessment phase and the interpretation phase. Below is a conceptual picture of this. In sections Appendix 1A - Appendix 1D further details on each life cycle phase are presented.

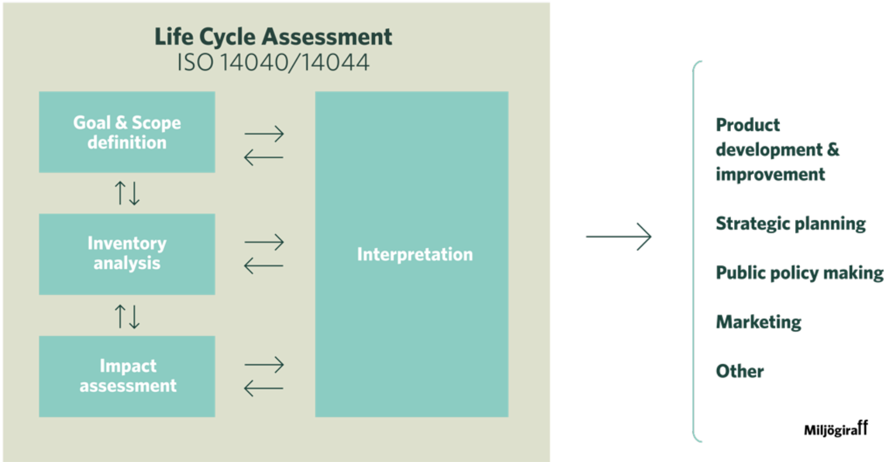

Figure 22. The four phases of the Life Cycle Assessment

A. Goal and scope definition

The first phase is the definition of goal and scope. The goal and scope, including system boundary and level of detail, of an LCA depend on the subject and the intended use of the study. The depth and breadth of LCA can differ considerably depending on the goal of a particular LCA. The goal also affects the choice of system boundaries and data requirements. See further details below.

i. System boundary

The system boundary determines which modules and activities are included within the LCA. The selection of the system boundary shall be consistent with the goal of the study. A system boundary chosen to include all contributing processes for the system while facilitating the modelling and analysis of the system. Therefore, there may be reasons to exclude activities that contribute insignificantly to the environmental effects (so-called "cut-off"). However, the omission of life cycle stages, processes, inputs, or outputs is permitted only if it does not significantly change the study's overall conclusions. It should be clearly stated if life cycle stages, processes, inputs, or outputs are not included; and the reasons and implications for their exclusion must be explained.

When the life cycle is defined by the system boundary, the environmental aspects included, and the data used to represent the different aspects is in detail described under the LCI part.

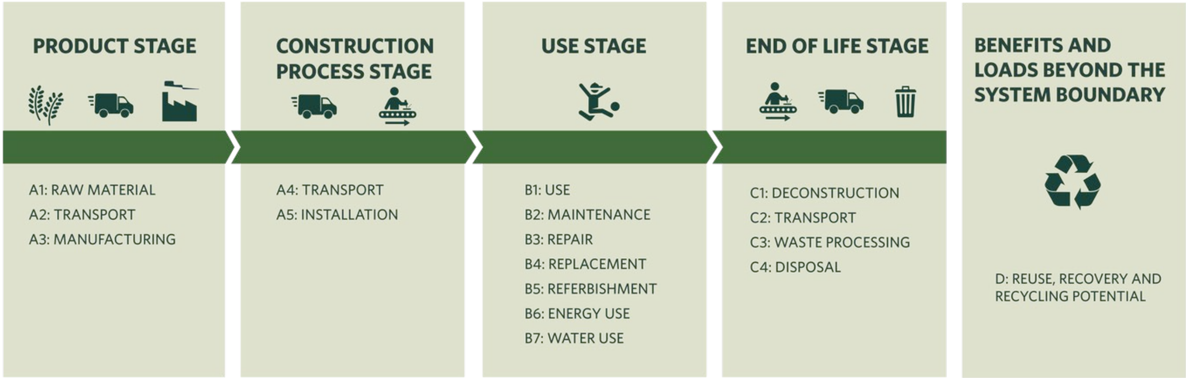

Figure 23: General summary of the modules included in an LCA, based on EN 15804.

In this LCA, boundaries with other systems, and the allocation of environmental burdens between them, are based on the recommendations of the international EPD system[3], which are also in line with the requirements and guidelines of the ISO14040/14044 standards. Following these recommendations, the Polluter Pays (PP) allocation method is applied (see figure below). For the allocation of environmental burdens when incinerating waste, all processes in the waste treatment phase, including emissions from the incineration, are allocated to the life cycle in which the waste is generated. Subsequent procedures for refining energy or materials to be used as input in a following/receiving process are allocated to the next life cycle.

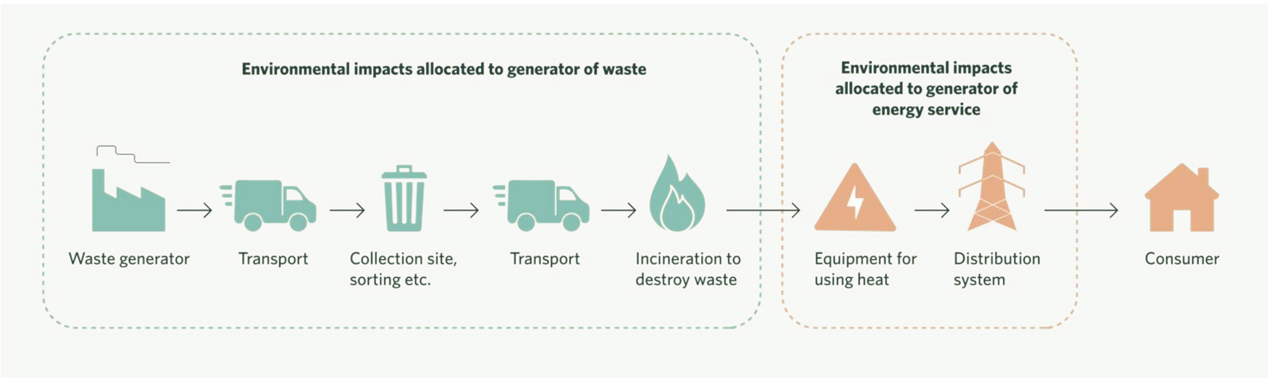

Figure 24: Allocation of environmental impacts between two life cycles according to the PP allocation method. Here in regard to the incineration of waste and resulting energy products.

In the case of recycling, environmental burdens are accounted for outside of the generating life cycle. They have thus been allocated to the subsequent life cycle, which uses the recycled materials as input.

Avoided materials due to recycling are typically not considered in the main scenario, per the International EPD system's recommendation of the Polluter Pays Principle. In other words, only if the generating life cycle uses recycled material as input material will it account for the benefits of recycling.

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[3] EPD (Environmental Product Declarations) by EPD International®

ii. Cut-off

It is common to scan for the most important factors (a “cut off” of 95% is a minimum) to avoid putting time and effort into irrelevant parts of the life cycle. In general, LCA focuses on the essential material and energy flows, while the flows that can be considered negligible are excluded. By setting cut-off criteria, a lower limit is defined for the flows to be included. Flows below the limit can be assumed to have a negligible impact and are thus excluded from the study. For example, cut-off criteria can be determined for inflows concerning mass, energy, or outflows, e.g., waste.

iii. Allocation

The study shall identify the processes shared with other product systems as co-products, and deal with them according to the stepwise procedure presented below:

- **Step 1**: Wherever possible, the allocation should be avoided by dividing the unit process into two or more sub-processes and collecting the input and output data related to these sub-processes or expanding the product system to include the additional functions related to the co-products.
- **Step 2**: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e., they should reflect how the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.
- **Step 3**: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

When other allocation methods are used, it should be documented and assessed whether it may be significant to the results.

iv. Data requirements (DQR)

General LCI databases contain a large amount of third-party reviewed LCI data compiled according to the ISO 14048 standard. Certified LCI data forms a basis for a robust and transparent study. However, it is crucial to understand that specific producers may differ considerably from general practice and average data.

The LCI data can be either specific or general. Specific data means that all data concerning material, energy and waste are specifically modelled for the conditions at the manufacturing facility and the technology used. Generic data means that material or energy are represented using LCI data from ecoinvent or other databases.

Specific data
1. Environmental Product Declarations (type III)
2. Collected data (web format, site visits and interviews).
3. Reported data (EMS, Internal data systems or spreadsheets)

Selected generic data
1. Close proxy with data on a similar product
2. Statistics
3. Public documents

Generic data
1. Public and verified libraries with LCI data

2. Trade organisations' libraries with LCI data
Sector-based IO data, national

B. Inventory analysis (LCI)

The life cycle inventory analysis phase (LCI phase) is the second phase of LCA. It is an inventory of input/output data with regard to the system being studied. It involves the collection of the data necessary to meet the goals of the defined study.

C. Impact assessment (LCIA)

The life cycle impact assessment phase (LCIA) is the third phase of the LCA. The purpose of LCIA is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance. Mandatory steps in the lifecycle impact assessment are classification and characterisation. An optional step is weighting.

Readymade methods for classification, characterisation and weighting have been used to evaluate environmental effects (either from a broad perspective or for a single issue) and find the categories or parts of a system with the most potential impact. Some of the most common LCIA methods are presented in Appendix 2 - Appendix 4.

Classification, characterisation and weighting will here be briefly explained.

i. Classification and characterisation

The process of determining what effects an environmental aspect can contribute to is called classification, e.g. that the use of water contributes to the environmental effect of water depletion, see figure below for an illustration. The characterisation, in turn, means defining how much an environmental aspect contributes to the environmental impact category to which it is classified, e.g. the use of 1 tonne of river water contributes a factor of 0.5 to water depletion. Evaluating how critical it is in a specific area depends on the current environmental impact, the pressure from resource consumption and the ecosystem's carrying capacity. This is done through normalisation.

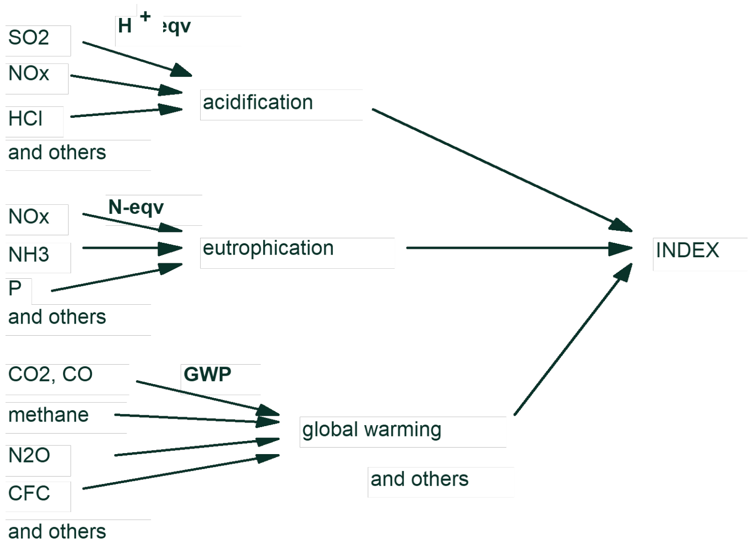

Figure 25: An illustration of the Impact Assessment of an LCA.

ii. Weighting

To compare different environmental effects and to identify "hot spots", so-called *weighting* is applied. The calculated environmental effects are weighted together to form an index called a "*single score*" which describes the total environmental impact.

Because weighting involves subjective weighting (e.g. by an expert panel), it is recommended for internal communication only. Otherwise, there is a risk of mistrust if the choice of weighting method used leads to results that emphasise the "upsides" and hide the "downsides" of the analysed product. For external communication, only *Single issues* should be communicated.

D. Interpretation

The life cycle interpretation phase of an LCA or an LCI study comprises several elements:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA
- an evaluation that considers completeness, sensitivity and consistency checks
- conclusions, limitations, and recommendations.

The interpretation of the results in this study is carried out by first identifying the aspects that contribute the most to each individual environmental effect category. After that, the sensitivity of these aspects is evaluated, and the completeness and consistency of the study are assessed. Conclusions and recommendations are then based on the results and a clear understanding of how the LCA was conducted with any subsequent limitations.

i. Evaluation of the results

The objectives of the evaluation element are to establish and enhance confidence and the reliability of the results of the LCA or the LCI study, including the significant issues identified in the first element of the interpretation. The evaluation should use the following three techniques:

- Completeness check
  The objective of the completeness check is to ensure that all relevant information and data needed for the interpretation are available and complete. If any relevant information is missing or incomplete, the necessity of such information for satisfying the goal and scope of the LCA shall be considered. This finding and its justification shall be recorded.
- Sensitivity check
  The objective of the sensitivity check is to assess the reliability of the final results and conclusions by determining how they are affected by uncertainties in the data, allocation methods or calculation of category indicator results, etc.
- Consistency check
  The objective of the consistency check is to determine whether the assumptions, methods and data are consistent with the goal and scope.
- Uncertainty check
  Is a systematic procedure to quantify the uncertainty introduced in the results of a life cycle inventory analysis due to the cumulative effects of model imprecision, input uncertainty and data variability

Appendix 2 IPCC 2021 GWP100 methodology

Climate change is defined as the warming of the climate system due to human activities. Human activities emitting greenhouse gases (GHG) are the leading cause of global warming. GHG emissions have the property of absorbing radiation, resulting in a net warming effect called the greenhouse effect. These will then perturb the Earth's natural balance, increasing temperature and affecting the climate with disturbances in rainfall, extreme climate events and rising sea levels. Climate change is an impact affecting the environment on a global scale.

GHG sources can be classified of three main types: fossil sources, biogenic sources, and land use change. Fossil sources are formed from the decomposition of buried carbon-based organisms that died millions of years ago. Burning fossil sources leads to an increase in GHG in the atmosphere. Biogenic sources are often considered natural and refer to carbon taken up during the cultivation of a crop, considering that there is no net increase of carbon dioxide in the atmosphere. Another source of carbon dioxide emissions is the effect of land use on plant and soil carbon. For example, carbon is stored naturally in nature, and by changing the characteristics of a land area, this carbon is then released. Land use change hence measures the GHGs emissions that occur when changing the vegetation or other characteristics of the land used for a product's lifecycle.

The potential impact on the climate is calculated using the IPCC 2021 GWP 100 v.1.0 model for Global Warming Potential, GWP. The impact of climate gases is expressed as carbon dioxide equivalents, CO2 eq. It is the most established scientific method and has been implemented (with adaptations) in other methods, such as the GHG protocol and EF 3.1.

Appendix 3 Guarantees of Origin and other certificates

Electricity invoice Ullkontoret

GEAB
Gotlands Energi

Faktura

Fakturadatum	2025-05-07
Fakturanr	0649361805
Kundnr	213041

Mallas Stenstugu AB
Endre Stenstugu 424
621 77 Visby

Vid kontakt: gotlandsenergi.se eller ring vår
kundtjänst tel: 0498-285000

Anläggningsadress
Se specifikation

Kod Mitt GEAB u2pt

Faktureringsperiod 2025-04-01 - 2025-04-30

		Exkl moms	Moms	Totalt
Gotlands Elförsäljning AB ELHANDEL	SE556528415401	869,76	217,45	1 087,21
Gotlands Elnät AB ELNÄT, NÄT3525730	SE5565374724	3 499,72	874,93	4 374,65

Moms 25%: 4 369,48

Netto	Moms total	Öresutjämning	Förfallodag	Att betala, SEK
4 369,48	1 092,38	0,14	2025-05-30	5 462,00

Läs om konsumentens rättigheter och hur du går tillväga vid klagomål eller skadestånd samt användarrådgivning och tvistelösning på vår hemsida gotlandsenergi.se eller via vår Kundtjänst 0498-28 50 00.
Specifikation finns på fakturans baksida. Sker ej betalning i rätt tid debiteras ränta (referensränta plus åtta procentenheter) och ersättning för de kostnader som är förenade med dröjsmålet. Nätavgifter debiteras på uppdrag av Gotlands Elnät AB -
orgnr 556537-4724 Box 1095 - 621 21 VISBY - IBAN Nr:SE1295000099604201894005 - BIC (SWIFT): NDEASESS

GOTLANDS ELFÖRSÄLJNING AB

	VÄXEL	PLUSGIRO	BANKGIRO	MOMSREG NR	E-POST
Box 1095 621 21 VISBY	0498-285000	4143304-6	5796-5402	SE556528415401	kundtjanst@geab.vattenfall.se

Fakturadatum	2025-05-07
Fakturanr	0649361805
Kundnr	213041

Specifikation för: Endre Stenstugu , Stenstugu Egendom Endre 62177 Visby
Anl nr: 08647386
Anl id: 735 999 103 000 100 889
Områdesid: GTL
Kontraktnr: 10108113

	Förbrukning	Á pris	Summa
ELNÄT (N4 reaktiv effekt) 2025-04-01 - 2025-04-30			
Effektabonnemang N4	30 Dygn		276,16 SEK
Elöverföring (förbrukning) låglasttid konsumtion N4	1 440 kWh	0,260 SEK	374,40 SEK
Elöverföring (förbrukning) höglasttid konsumtion N4		0,460 SEK	0,00 SEK
Månadseffekt (konsumtion)	25 kW	59,0000 SEK	1 475,00 SEK
Reaktiv effekt konsumtion	26,5 kVar	28,0000 SEK	742,00 SEK
Energiskatt		0,4390 SEK	0,00 SEK
Energiskatt	1 440 kWh	0,4390 SEK	632,16 SEK
Moms 25,00 %			874,93 SEK
Totalt, NÄT3525730			4 374,65 SEK
Summa: 08647386			4 374,65 SEK

Specifikation för: Endre Stenstugu; Stenstugu Egendom Endre; 62177 Visby; Sverige
Anl snr: 10020289
Anl id: 735 999 103 000 100 889
Områdesid: GTL
Kontraktnr: 10201000

	Förbrukning	Á pris	Summa
ELHANDEL (Rörligt elpris) 2025-04-01 - 2025-04-30			
Rörligt pris	1 440 kWh	0,3871 SEK	557,42 SEK
Elcertifikatsavgift	1 440 kWh	0,0120 SEK	17,28 SEK
Månadsavgift	1 Mån	36 SEK	36,00 SEK
Fast påslag	1 440 kWh	0,060 SEK	86,40 SEK
Rörlig kostnad	1 440 kWh	0,0449 SEK	64,66 SEK
Energikälla vindkraft	1 440 kWh	0,075 SEK	108,00 SEK
Moms 25,00 %			217,45 SEK
Totalt			1 087,21 SEK
Summa: 10020289			1 087,21 SEK

Electricity certificate Holma

Ursprungsgaranti

VENI Energy Group garanterar 100% CO_2 fri energi
till **Holma-Helsinglands AB**

Certifikattyp	**Ursprungsgaranti (GoO)**
Period	**2025**
Ursprungsgaranti	**Europeisk**
Energikälla	**Vatten och kärnkraft (inget från fossila energikällor)***

*Vår ursprungsmärkta elleverans för 2025 är inte baserad på en enskild specifik energikälla, men Nordel garanterar CO_2-fritt eller förnybart ursprung i förhållande till internationella GHG-standardens scope 2.

Christian Zivlak
Platschef

Nordel Energi