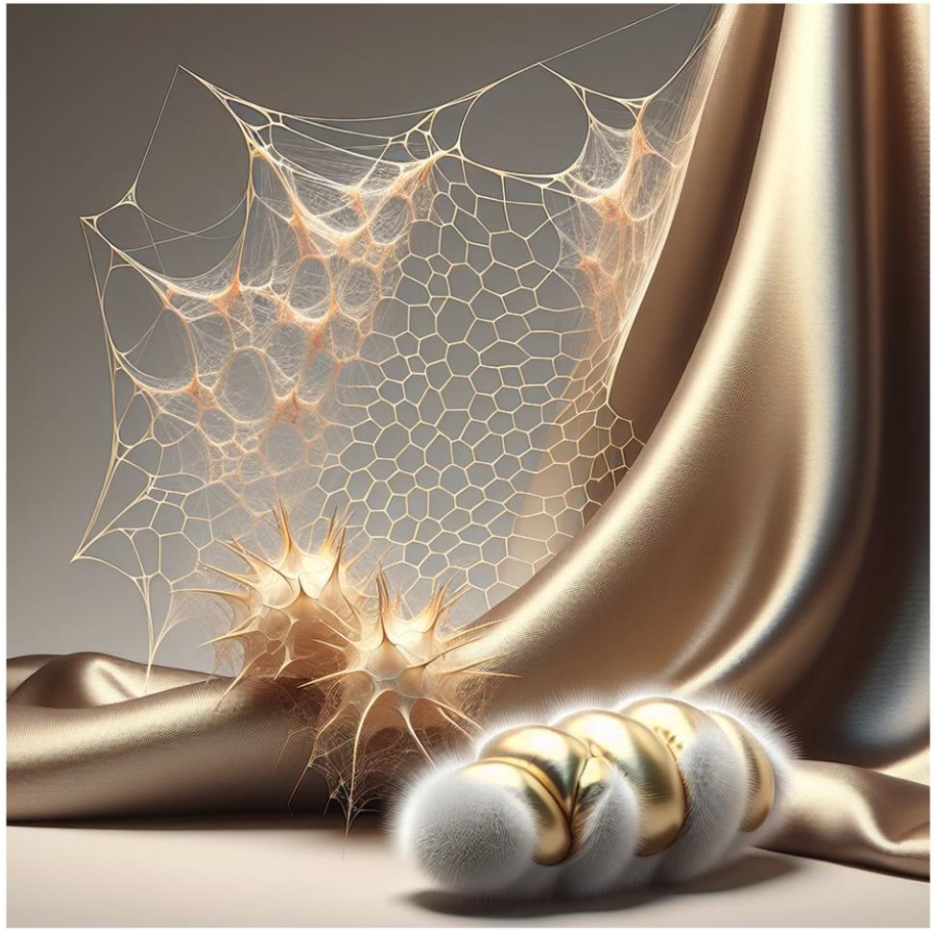
AMSilk

CRADLE-TO-GATE LCA OF LUXURY TEXTILE FIBERS

Essentials 2024



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About Silk

Legend has it that almost 5,000 years ago, the Chinese empress Si Ling Chi discovered a caterpillar wrapped in a shiny thread in the branches of a mulberry tree while out walking with her ladies-in-waiting. It must be nice, thought the empress, to wrap herself in such a thread. She had the thread unwound from the cocoons and wove fabrics from it. Thus began the long, fascinating history of silk. For three thousand years, the Chinese guarded the art of silk production like a state secret. Bringing the cocoons and eggs of the silkworm across the borders of the giant empire was forbidden under penalty of death. The coveted silk reached Europe via the Silk Road and is still a valuable commodity today.

Caterpillars of the mulberry moth (Bombyx mori) have long been the only known suppliers of silk. However, there are many other animals in nature that are also able to produce silk. These silks differ in terms of their intended use, but from a structural point of view, silks can be described as structural proteins that are made up of highly repetitive amino acid sequences and are present in liquid form inside an arthropod.

For the founders of AMSilk, the dragline silk of the European garden cross spider (Araneus diadematus) was the most interesting silk, as its combination of tensile strength and extensibility and the resulting toughness is superior to most natural and synthetic fibers. AMSilk started to find a way to produce these high-performance proteins biotechnologically to overcome the negative aspects of production by insects.

About AMSilk

AMSilk is a frontrunner in advanced biomaterials made from spider silk-based proteins. Using a technology platform, protected by a best-in-class patent portfolio, we are pushing boundaries in the field of bio-based materials. At AMSilk, we turn man-made proteins into formulations, including fibers and yarns, hydrogels and silk powder. The high-performance qualities of our material enable a wide range of applications in the textile, homecare, biomedical, and automobile industries and bring breakthrough benefits for products and customers.

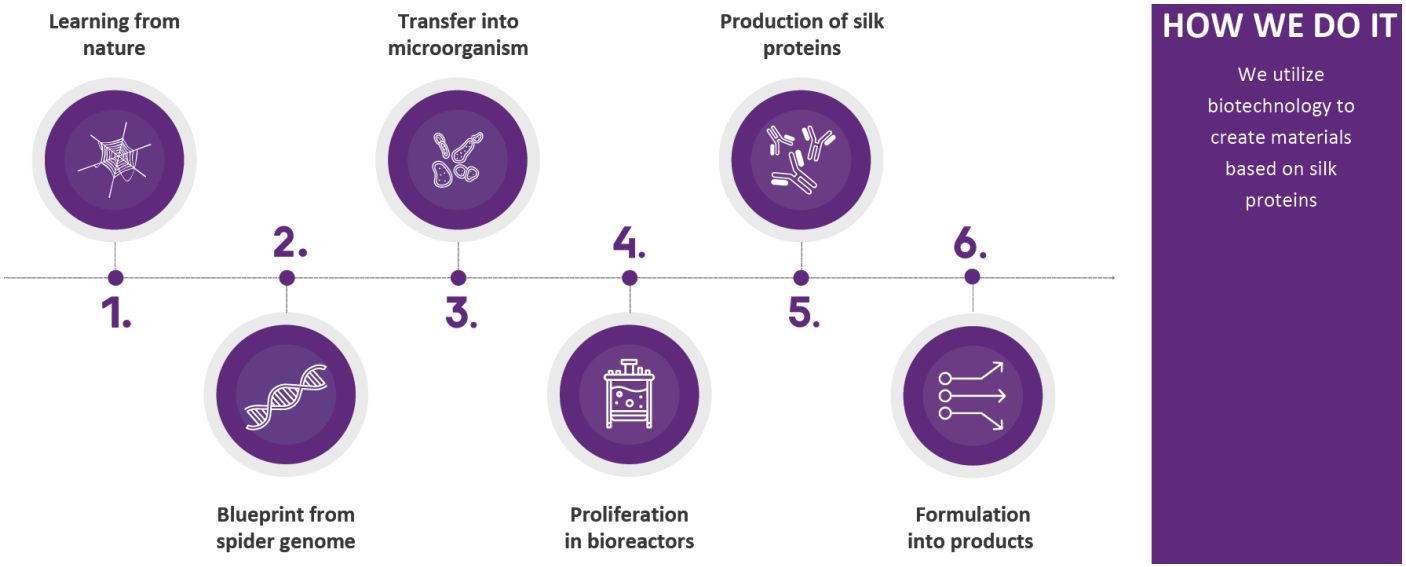

Figure 1: How AMSilk is utilizing biotechnology

AMSilk's materials go beyond earlier bio replacements; they can be tailored to specific market or product requirements and are biodegradable according to international standards. AMSilk has already collaborated with industry-leading global companies and plans to continue partnering with enterprises worldwide to pursue the vision of enabling true change through intelligent biotech materials.

Goal and Scope of the Life Cycle Assessment

Together with Quantis, a BCG company and leading environmental sustainability consultancy, we conducted a cradle-to-gate Life Cycle Assessment (LCA) that complies with ISO standard 14040/14044:2006 and was externally reviewed by a panel of three experts from the fields of LCA, biotechnology and textile.

We wanted to identify the environmental hotspots in the production of AMSilk Ultrafine fibers to improve our processes and compare the results with other luxury textile fibers such as mulberry silk. The resulting LCA report helps us to communicate with various stakeholders, especially B2B partners, shareholders and investors, to demonstrate the positive impact of AMSilk Ultrafine fibers.

An LCA typically relies on a Functional Unit (FU) for comparison of alternative products that may substitute each other in fulfilling a certain function for the user. The FU describes this function in quantitative terms and serves as an anchor point of the comparison ensuring that the compared alternatives do indeed fulfil the same function. It is therefore critical that this parameter is clearly defined and measurable. The Functional Unit in this LCA study was defined as:

“1 kilogram of fiber with approximately the same fineness and linear density to provide the same durability”.

To fulfil the functional unit some quantities of material are required and known as reference flows. The reference flows in this study are “1 kg of AMSilk Ultrafine fiber” and “1 kg of mulberry silk fiber”.

Product system and boundaries

To compare products with the same function, the product system and boundaries must be defined. The system boundary identifies the life cycle stages, processes and flows that are considered in the LCA and includes all activities that are relevant for the fulfilment of the functional unit. The following graphic illustrates the product system and boundaries for mulberry silk and AMSilk Ultrafine fiber.

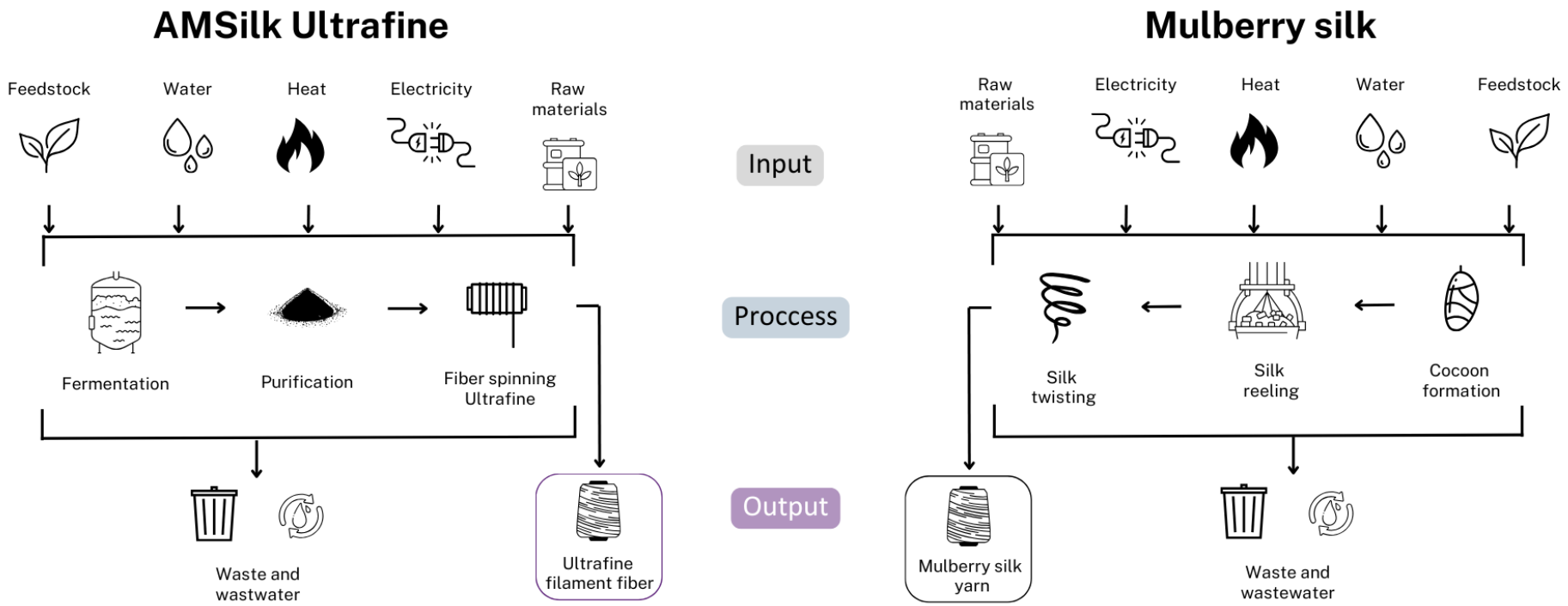

Figure 2: Illustration of AMSilk Ultrafine and Mulberry silk product system and boundaries

The system boundaries of both fibers include the energy, water and utilities to produce the fibers, feedstock and raw materials as well as the waste and wastewater treatment and all necessary transport services.

This LCA study excludes packaging and distribution, application/use phase and end of life and recycling and focusing solely on the cradle-to-gate impacts. This means that only the raw material and fiber production processes and all necessary inputs and outputs of the processes are considered. This exclusion is in line with the ISO 14044:2006 standard and is justified by the perceived similarity in these stages across both fibers. The rationale for the 'cradle-to-gate' approach is the availability of data and the complexity of modeling end of-life and use scenarios, especially in the case of AMSilk fibers, which can be used in numerous and diverse ways. In addition, a cradle-to-gate approach is primarily desired by the manufacturers of textile products, as the fibers themselves are only a preliminary product in the supply chain.

*Figure 3: Illustration of the process steps of a complete product life cycle. Included stages of this LCA study are highlighted in black. *Excluded stages.*

Cutt-off criteria

In the process of building a life cycle inventory (LCI), it is an accepted practice to exclude items considered to have a negligible contribution to results. To do this in a consistent and robust manner, there must be confidence that the exclusion is fair and reasonable. To this end, cut-off criteria are defined, which allow items to be neglected if they meet the criteria. In this study, exclusions could be made if they were expected to be within the criteria below:

- Mass: if a flow is anticipated to be less than 1 % of the mass of the product it may be neglected
- Energy: if a flow is anticipated to be less than 1 % of the cumulative energy within the lifecycle of the individual product it may be neglected
- Environmental significance: if a flow is anticipated to be less than 1 % for all impact categories it may be excluded
- The total of all flows excluded must not exceed 5 % of the total energy usage, mass, or environmental significance of the product life cycle

If an item meets one of the criteria but is expected to be significant to any of the other criteria, it is not neglected. For example, if a substance is small in mass but is expected to make a notable contribution to the environmental results (e.g., use of a highly hazardous chemical), then it may not be excluded.

Allocation

In LCAs, situations often arise where the life cycles of different production systems intersect, or where multiple co-products emerge from a single system. As per ISO 14044, it is recommended to avoid the allocation of process inputs by expanding the system boundaries. However, when allocation is unavoidable, it should be based on physical relationships such as mass or energy content, or other criteria such as economic value, as suggested in ISO 14044.

For the AMSilk fiber, no allocation is performed in the **foreground system** as there are no multi-output processes. When collecting primary data, the annual data for energy consumption of representative machines has been measured and allocated (based on mass) to the studied product. For animal-derived fiber mulberry silk no allocation is considered as, typically, these fibers are the primary desired product obtained from the Mulberry silkworm.

In the **background system**, various allocation approaches are used as implemented in the different databases (e.g. allocation by mass, economic value, heating value). Descriptions of the allocation approaches can be found in the documentation of the respective *ecoinvent* database. Many datasets in the ecoinvent database (the primary database used in this study) provide multiple functions, and allocation is required to provide inventory data per function (or per process). The allocation process used is cut-off by classification.

This study accepts the allocation method used by this database for those processes. It should be noted that the allocation methods used in ecoinvent for the background system (i.e. upstream activities for which generic information is used in the model, such as the production of energy and raw materials or emissions from transport), such as mass or economic allocation, may be inconsistent with the approaches used to model the foreground (i.e. modeled specifically for this study) system. Continuing a single allocation methodology into the background datasets would add substantial complexity without necessarily improving the quality of the study (i.e. ISO does not require that all multi-output processes be handled with the same allocation methodology).

Additionally, the allocation approach used for recycled materials is cut-off by classification. The allocation methodology used in the background datasets is considered appropriate to the context of those processes.

Impact assessment

The selected impact assessment method is Environmental Footprint (EF) developed by the European Commission to measure and communicate the environmental performance of products and organizations. EF is a political consensus and is considered state-of-the-art as it is updated regularly, e.g. with the new IPCC factors. It is mandatory for PEF compliant or aligned studies, which will become more and more important with the upcoming PEFCR for apparel and footwear.

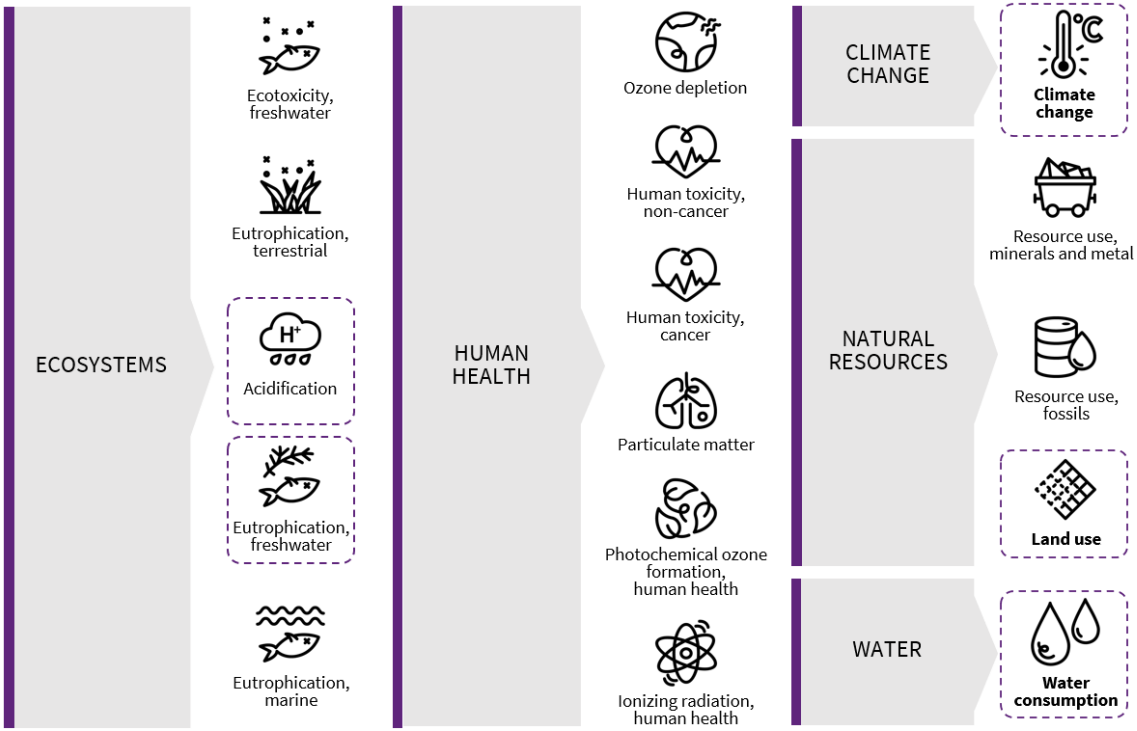

Figure 4: The 16 environmental impact categories of the Environmental Footprint (EF 3.1) methodology with the selected categories (outlined with a dashed line)

The EF 3.1 impact assessment offers 16 well-defined environmental impact categories. Five categories are selected as focal assessment indicators in this study based on normalized and weighted results for each fiber following the EF 3.1 methods. The following indicators are considered in the assessment section:

1. **Climate Change (kg CO_2 eq.):** Assess the impact of all greenhouse gas emissions emitted, including carbon dioxide (CO_2), methane (CH_4), or nitrous oxide (N_2O).

2. **Acidification (mol H+ -eq.):** Assess impacts due to acidifying substances (NOx, NH_3, SOx) in the environment.

3. **Eutrophication, freshwater (kg P eq.):** Assess the consequences of excess nutrients, primarily P and N, leading to an overgrowth of algae and aquatic plants.

4. **Land use (Pt.):** Evaluating habitat loss, deforestation, and overgrazing.

5. **Water Use (m^3 depriv.):** Understanding agricultural and processing water demands, including potential pollution.

Additionally, the single score of the EF methodology is applied. The single score provides an aggregated score for all 16 EF indicators and is calculated with the PEF normalization and weighing approach. Due to the limitations of this approach, it should not be used as a single impact value. We provide the single score as additional information to provide an aggregated overview of the impacts in the other 11 impact categories of the EF 3.1 methodology.

Limitations

The focus of the LCA on the cradle-to-gate processes means that potential environmental benefits or impacts associated with the use and end-of-life phase, such as recyclability, biodegradability or toxicity of disposed materials, are not included.

The data sources used for modelling the two fibers have different levels of data quality and granularity. The AMSilk fibers are modelled based on primary data from AMSilk based on current production processes and projections for semi-up scaled production. A generic model is used for mulberry silk fibers. It cannot be ruled out that the model used for silk fiber corresponds to the properties defined in the functional unit.

Different levels of technological maturity. Differences in technological progress can affect the environmental impact, efficiency and resource consumption of individual fibers, which makes a direct comparison difficult and can lead to inaccuracies in the assessment. This study does not consider the potential impacts or benefits of scaling up production. This may lead to over- or underestimation or overlook the environmental impacts associated with changes in production volumes.

According to ISO 14044:2006, LCA results are relative expressions that do not predict impacts on category endpoints, exceeding thresholds, safety margins or risks. The precision among impact categories varies, which causes certain limitations on an overall environmental impact assessment. Additionally, these categories do not cover all the environmental impacts associated with human activities. Impacts such as noise, odors, electromagnetic fields and others are not included in the present assessment. Other impacts, such as potential benefits or adverse effects on biodiversity, are also only partly covered by current impact categories.

Life Cycle Inventory

The quality of LCA results is dependent on the quality of data used in the evaluation. Every effort has been made for this investigation to implement the most credible and representative information available. LCI data collection mainly concerns the materials used, the energy consumed, and the waste and emissions generated by each process included in the system boundaries.

AMSilk Ultrafine

Two different production processes are required to manufacture the AMSilk Ultrafine fiber. Protein production with the fermentation and purification steps and the processing of the AMSilk protein into a fiber with the spinning process. The production processes of the year 2023 were the basis of the models created for this LCA study. The production of all process steps is in Europe and local energy mixes were used when no specific data was available.

To enable an adequate comparison with industrialized mulberry silk production, the processes were modelled in a partially scaled-up scenario due to the pilot nature of current production. The modelled protein production can be regarded as a highly scaled process. In contrast, the fiber spinning process was modelled based on the process parameters of the pilot plant, and it is very likely that improvements will still be made.

Mulberry Silk

For the inventory for the conventional fiber silk, the ecoinvent 3.9 dataset “Yarn, silk {IN}| yarn production, silk, long fibre | Cut-off, U“ is applied as it considers both the reeled raw silk hank production and its subsequent processing into yarn. This dataset thoroughly includes all necessary input and output flows for the gate-to-gate unit process in the silk yarn production.

Primarily based on industry data, it represents the regional average process for producing silk yarn. In this process, silk thread, or yarn, is produced through throwing or twisting, where silk filaments are reeled onto bobbins and twisted to achieve a specific yarn texture. The dataset’s data are obtained from a silk reeling and spinning plant in Hoshangabad, in the state of Madhya Pradesh (Central India), chosen due to its use of technology that is representative of current industry practices.

When choosing datasets, the following database hierarchy is applied:

1) ecoinvent v3.9.1.2

2) WALDB 2.5

3) WFLDB 3.9.1

The database ecoinvent is recognized as one of the most complete background LCI databases available, from both quantitative (number of included processes) and qualitative (quality of the validation processes, data completeness, etc.) perspectives. Historically focused on European production activities, it has reached a global coverage of thousands of commodities and industrial processes. It is believed that the credibility and transparency of this database make it a suitable option for representing the systems under study. The data's geographic representativeness is one aspect evaluated as part of the data quality assessment.

The WALDB is built with ecoinvent datasets in the background and focuses specifically on apparel and textile products. It complements ecoinvent with a more comprehensive coverage of the textile value chains and by developing datasets that reflect the mainstream production systems in main producing countries. WALDB is developed by Quantis in partnership with leaders in the fashion sector.

The WFLDB is a database of emission factors for agricultural and food products. This database has been developed over more than 12 years in partnership with some of the most important brands in the food and beverage sector.

Life Cycle Impact Assessment

Results of the fiber comparison

The LCA model is created using the SimaPro 9.3 software. The environmental exchanges are translated into the specific impacts, by using the characterization model for each impact indicator. The methods are selected according to the goal and scope of the study.

All impact results are given in units per 1 kg of fiber. When interpreting these results, it must be kept in mind that LCIA indicators are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. Thus, the results of LCIA shall be seen as environmentally relevant indicators of potential impact, rather than predictions of actual environmental effects (e.g., damage to human health and damage to ecosystem diversity). In this section, the EF 3.1 results for the indicators acidification, climate change, freshwater eutrophication in addition to land use and water use for the AMSilk Ultrafine fiber and Mulberry silk fiber are evaluated. The results show the cradle-to-gate environmental impact results for both fibers covering their raw materials, their production energy and utilities as well as their production waste, its treatment and finally internal transport.

The absolute results for the focused EF 3.1 impact indicators as well as the single score are presented in the following table.

	Climate Change	Acidification	Freshwater Eutrophication	Land Use	Water Use	Single Score
Mulberry Silk	149 kg CO_2 eq.	2,46 mol H^+ eq.	0,06 kg P eq.	8035 Pt	1123 m^3 deprived	32 Points
AMSilk Ultrafine	28 kg CO_2 eq.	0,24 mol H^+ eq.	0,01 kg P eq.	629 Pt	34 m^3 deprived	5 Points
Difference in Impact	-81%	-90%	-75%	-92%	-97%	-85%

Table 1: Comparison of the LCIA results of AMSilk Ultrafine and Mulberry silk in the 5 focussed impact categories and the EF single score

"AMSilk Ultrafine performs better than Silk in all indicators studied"

The LCA results demonstrate that AMSilk Ultrafine exhibits a reduction in the range from 75-97% lower environmental impact compared to silk. Key factors contributing to this difference include AMSilk's potential to reduce water and land use impacts by significantly reducing deforestation and land use alterations from mulberry tree cultivation. The reduction potential of the relative impact is illustrated in following figure.

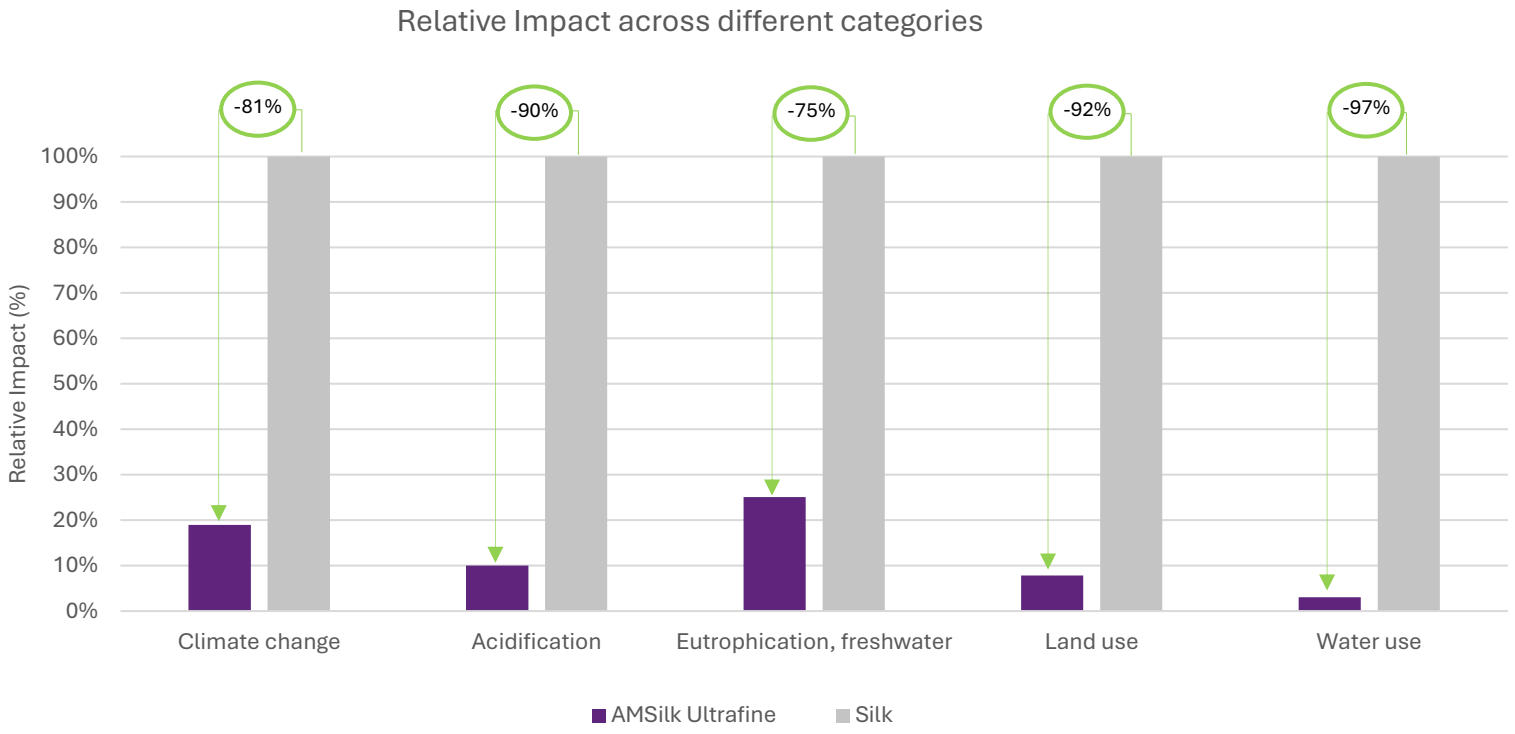

Figure 5: Relative impact of AMSilk Ultrafine and Mulberry silk fiber with the resulting reduction potential

Contribution analysis

The focus of the contribution analysis is on examining the distribution of environmental impacts across the process stages of both compared fibers. The aim is to understand the allocation of the environmental footprint to each stage. Due to the different methods of producing the fibers, the allocation to the individual process steps differs significantly when comparing both fibers. AMSilk's biotechnological method, combined with the artificial spinning of the fibers, has different impact distributions in the EF impact categories, with a focus on the spinning process due to the pilot-scale nature of the modeled process. In contrast, the impact of the mulberry silk process is mainly driven by the animal-based fiber processing in the cocoon formation stage, which has the highest impact in all categories.

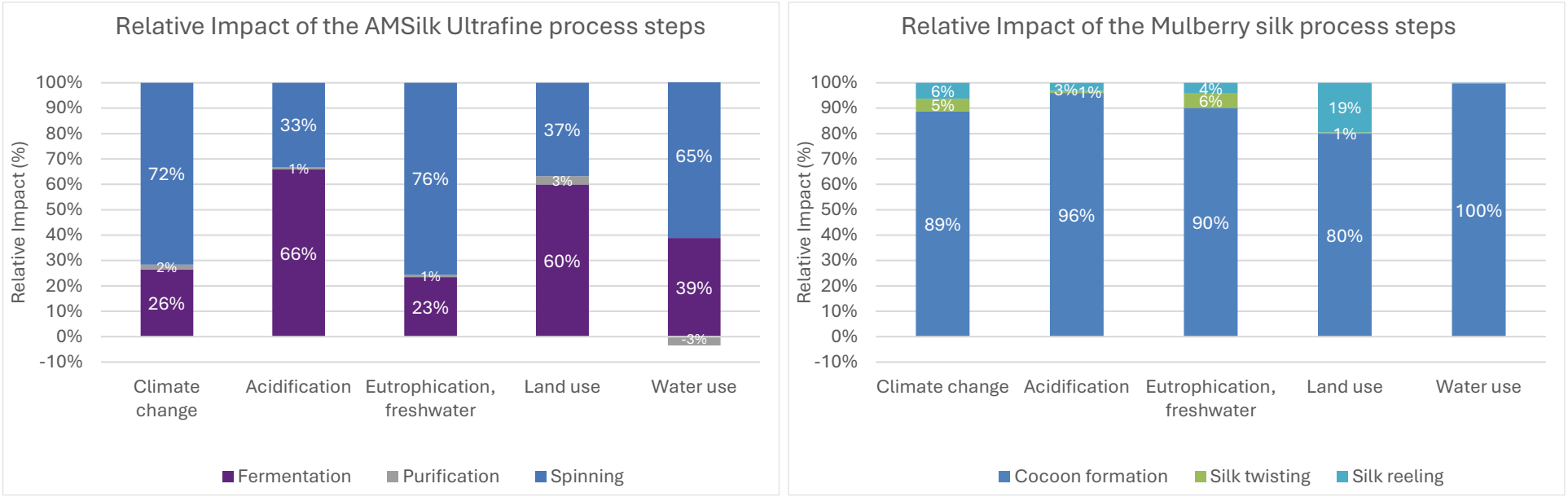

Figure 6: Relative Impact of the AMSilk Ultrafine and Mulberry silk process steps in the focussed impact categories

In Figure 6, the water impact observed during the purification process in the AMSilk Ultrafine production appears negative, as a consequence of the data assessment approach in this section where each stage is evaluated independently. The analysis of the contribution of the mulberry silk process steps shows a distribution that concentrates the effects in all categories on cocoon formation. The reason for this is the large number of mulberry leaves used to produce the cocoons. To produce 1 kg of reeled raw silk, 8 kg of cocoons and 184 kg of mulberry leaves are required. Many mulberry trees are needed to produce this number of leaves, which leads to a high environmental impact due to the agricultural practices used.

To determine the sources of influence in the various environmental impact categories, further analyses were conducted for both fibers. The results were divided into groups: raw materials, energy, water, waste and wastewater and building to identify the origin of the individual influencing factors.

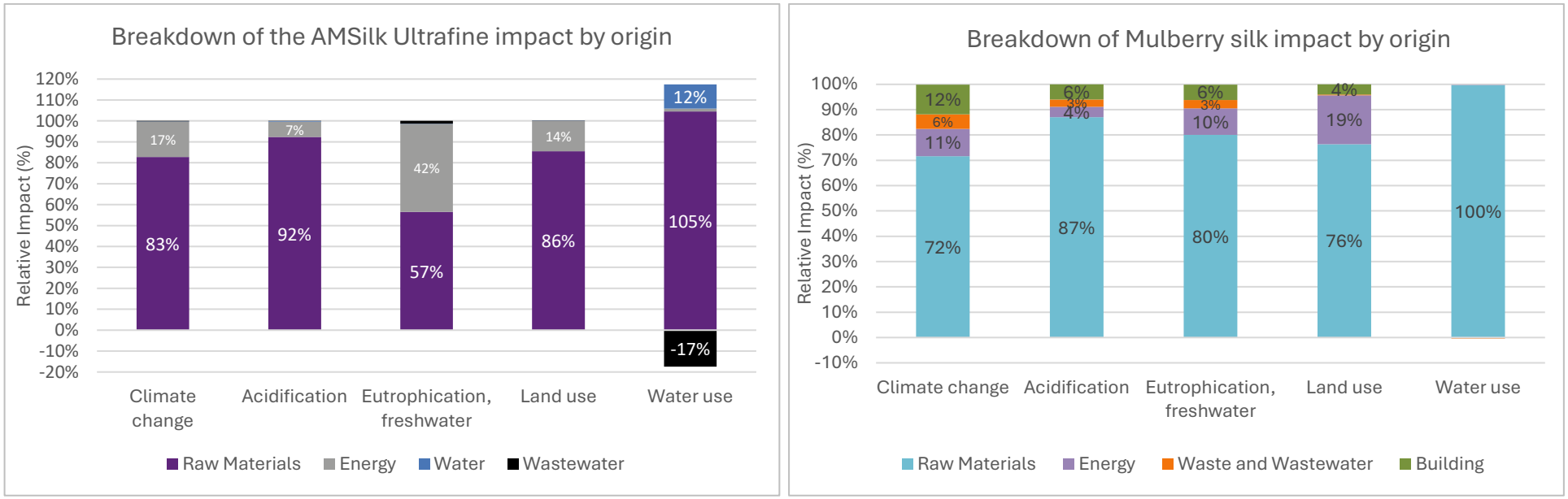

Figure 7: Breakdown of the AMSilk Ultrafine and Mulberry silk impacts by origin

The breakdown of the impacts in figure 7 shows the important role of the raw materials used for both fibers. In AMSilk Ultrafine production, the raw materials in the fermentation and spinning process are primarily responsible for 57% to 100% of the impact, with electricity and heat supply being the second most important source at 7% to 42%. The high impact of raw materials from the spinning process is related to the pilot scale of the modelled spinning process, in which not all materials are reused now. The high impacts of energy are related to the German electricity mix, which is still based on coal and gas and leads to high impacts. Except for the water use category, water, waste and wastewater play no role in the other impact categories for the AMSilk Ultrafine production.

The breakdown of mulberry silk process in figure 7 again shows the focal point of cocoon production, where cocoons as raw material has the highest impact in all categories. The use of water in silk production has a negligible impact below 1%, so the origin group “Water” was replaced by “Building”. Silkworm rearing is carried out by many smallholders, and each has a silkworm shed whose building has a significant impact score in 4 of the 5 categories. Biowaste generated by silkworm rearing also has a significant impact in some categories, as shown in figure 7.

Scenario analysis for further impact mitigation in AMSilk Ultrafine production

The contribution analysis clearly shows that the hot spots in the focused impact categories originate from the raw materials used and the German electricity mix. For further possible improvements in the process development of AMSilk Ultrafine fiber, these hot spots were discussed with our process experts, and mitigation strategies were developed. Improvement possibilities were identified primarily in the purification and spinning processes as key factors for reducing environmental impact.

The impact from protein production is mainly related to the feedstock used for the bacteria. The conversion rate of sugar to protein is limited due to the metabolism of the production strain, but efficiency can be further improved by enhancing purification efficiency in the purification steps.

The modelled spinning process is based on pilot line data, with improvements expected mainly in the recirculation of raw materials used in the spinning process. Additional improvements will involve using renewable energy in the individual process steps of fermentation, purification, and spinning. The following two scenarios are further investigated:

Scenario 1: Improved purification efficiency and recovery of all media for the spinning process

Scenario 2: Additional to scenario 1, renewable energy mix for fermentation, purification, spinning and recovery processes

	Climate Change	Acidification	Freshwater Eutrophication	Land Use	Water Use
Basis scenario	28 kg CO_2 eq.	0,24 mol H^+ eq.	0,015 kg P eq.	629 Pt	34 m^3 deprived
Scenario 1	15 kg CO_2 eq.	0,17 mol H^+ eq.	0,010 kg P eq.	387 Pt	13 m^3 deprived
Scenario 2	9 kg CO_2 eq.	0,16 mol H^+ eq.	0,004 kg P eq.	420 Pt	13 m^3 deprived

Table 2: Results of the scenarios for further impact mitigation in AMSilk Ultrafine production

The identified paths for further impact mitigation can decrease the environmental impact in all focussed impact categories.

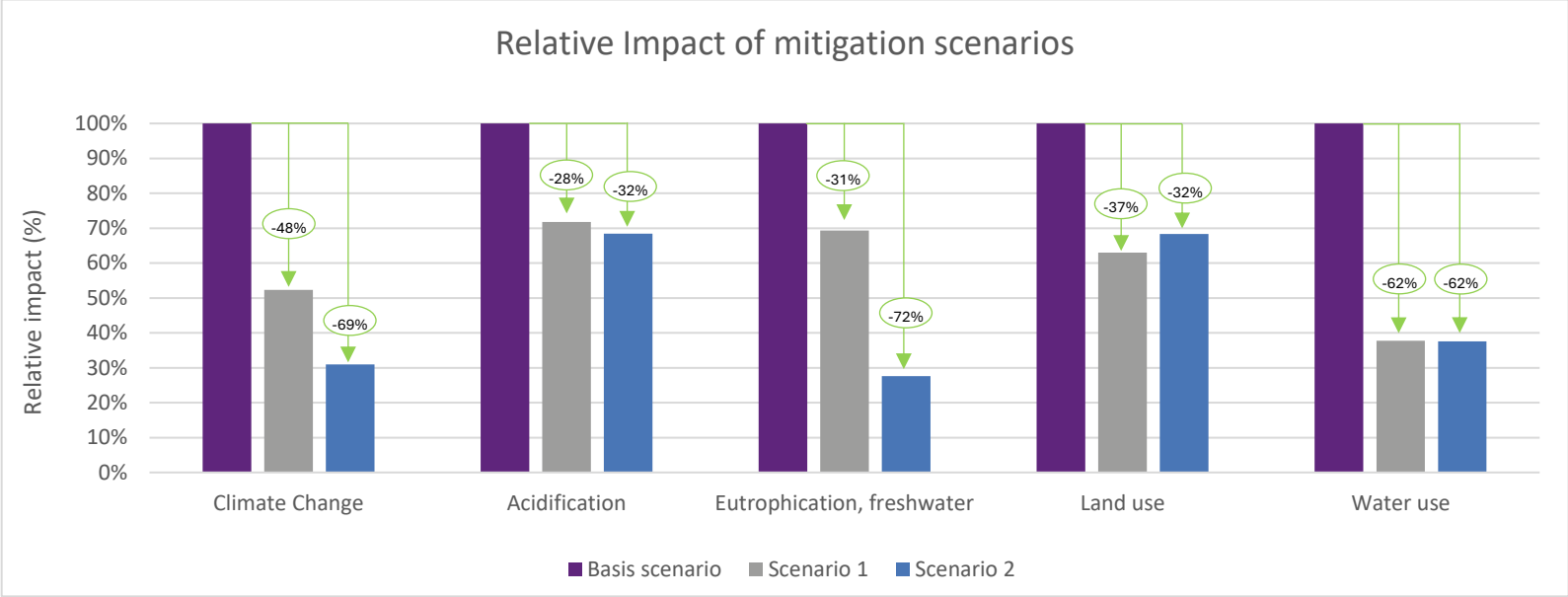

Figure 8: Scenario analysis of further impact mitigation in AMSilk Ultrafine production

As seen in figure 8, the circulation of the used media in spinning process has a significant impact on all categories, with a decrease in values by -28% to -62%. A further reduction using 100 % renewable energy can be achieved in the categories of climate change and eutrophication, freshwater but does not affect water use and leads to only a small reduction in the acidification category. In this scenario, the heat for the process is based on a heat and power co-generation and thus land use increases due to the use of wood as agricultural mass.

Conclusion

In conclusion, this study highlights the improved environmental performance of AMSilk Ultrafine fiber compared to mulberry silk, demonstrating a reduction range of 81-97 % across the indicator’s climate change, acidification, freshwater eutrophication as well as land and water use. A notable aspect of AMSilk’s environmental benefit is its mitigation of water and land use impacts by bypassing the need for mulberry tree cultivation. This factor significantly addresses issues related to water scarcity, deforestation, and land use changes.

AMSilk Ultrafine fiber offers a more sustainable alternative to traditional mulberry silk, with a markedly lower environmental footprint. The company's ongoing process improvements and commitment to renewable energy use are expected to further enhance the sustainability of its products.

The LCA results underscore the potential of AMSilk's technology to contribute to a more sustainable textile industry, aligning with the growing demand for eco-friendly products. As AMSilk continues to innovate and scale its production, the environmental benefits are likely to increase.

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