Basis for conducting Life Cycle Assessment of Brazilian silk yarn manufacturing

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Abstract. There has been a growing concern around environmental impacts worldwide, and the implications of the production of silk yarn should not be disregarded. On that note, this study presents the basis for conducting a Life Cycle Assessment (LCA) of the silk yarn production system in Brazil. The result is a qualitative inventory for the silk yarn production process, with an overview of the most relevant input and output. The product system of this work can be considered gate-to-gate and comprised from the receipt of the fresh silk cocoons to the sale of the silk yarn in skeins, which is one phase of the silk yarn production system. Brazil is one of the world's largest producers of silk, but in the yarn manufacturing phase, there is only one spinning company. To the best of our knowledge, there are no studies on silk yarn manufacturing phase under Brazilian conditions in the existing literature until the time this research is being written.

1 Introduction

Silk is a continuous filament of great commercial importance, in addition to its naturalness, different from all other fibers. It is possible to mention its natural brightness, inherent affinity to rich colours, high absorption, light weight, strong resistance, low heat conduction (warm in the winter and cool in the summer), low static current generation, and resilience. Its applications are present in the fashion market, upholstered furniture, carpets and ribbons, and it is also mixed with other fibers in the manufacturing of fabrics. It is also present in the sectors of sewing, knitting, and embroidery, among others. To produce a kilogram of raw silk, about 2,500 cocoons are required [1, 2].

China, India, Uzbekistan, Brazil, Japan, the Republic of Korea, Thailand, Vietnam, North Korea, and Iran, are among the world's leading silk producers. The main silk consumers are: USA, Italy, Japan, India, France, China, United Kingdom, Switzerland, Germany, the United Arab Emirates, Korea, and Vietnam [3]. Although the sericulture requires much work, it contributes to maintaining the employment of rural populations and prevents the rural exodus guaranteeing remunerated employment, besides requiring little investment [2, 4].

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From a social point of view, sericulture plays a vital role in the lives of small farming families, where they see the opportunity to reap more benefits from agriculture. Another relevant point in this scenario is that it not only prevents rural exodus, but also adds to the advantage of low investment, for a return guaranteed in a short period. The sericulture industry is considered an excellent job opportunity, allowing for entrepreneurial development for farmers.

Previous works have assessed impacts and identified opportunities for improving the environmental profile of raw silk cocoon production [5, 6]. However, it is important to consider not only the possible impacts of silk farm systems, but also, impacts in other stages of the silk supply chain. Thus, life cycle assessment (LCA) is often used as a decision support tool to compare production systems as well as to understand the impact of fibre production and to analyze the advantages and disadvantages of synthetic fibers in relation to natural fibers and vice versa.

In this sense, this study continues the initiative for conducting a Life Cycle Assessment (LCA) of the silk yarn production system in Brazil, as the first steps reported in [5, 6]. As a result, this paper accomplishes a qualitative inventory of the silk yarn manufacturing phase. To this end, this first section presents the study context and aim. The next section provides a brief background on LCA and the Methods used in this research, and then a few major issues on LCA of silk yarn under Brazilian conditions are brought to light; thereafter, a few Discussions and Final Considerations are drawn.

2 Methods

2.1 Life Cycle Assessment

Life Cycle Assessment is a tool that allows assessing potential environmental impacts of goods and services [7] to find opportunities for improving the environmental performance of the system under study [8] by informed decision-making [9, 10], as LCA has repeatedly been highlighted as the most complete and robust tool for environmental profiling [11, 12]. The four phases of an LCA are depicted in Figure 1 and the characteristics of each one applied to this study are detailed thereafter.

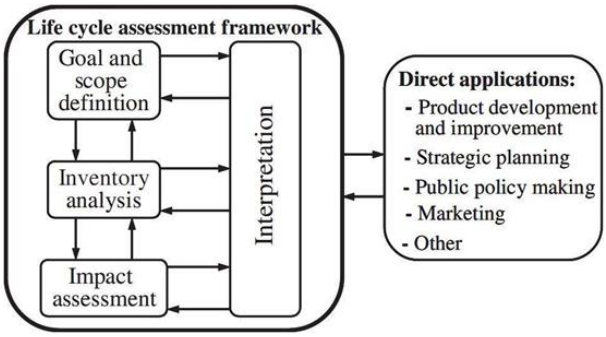

Figure 1 - Phases of an LCA and their relationships. Source: ISO (2006a)

This study was designed for the agroindustry in the State of Paraná (Brazil), specifically for the spinning industry. It comprises phases one and two (partially) of an LCA study according to ISO 14040 and 14044 [9, 10], up to the qualitative inventory of the production of silk yarn.

Goal and scope definition. The objective of this study involved building a qualitative inventory for the manufacturing phase of Brazilian silk yarn. In order to accomplish this, scientific and technical literature were analysed. The boundaries of the system were defined,

and the production system was mapped according to [13]. The boundaries of the system under study, as depicted in Table 1, can be considered "gate-to-gate", since they address from the receiving of the fresh cocoons until the sale of the silk yarn. Figure 2 highlights where in the life cycle of silk our study focuses (process in bold in Figure 2). It focuses only on the manufacturing phase of the silk yarn, not involving previous processes such as mulberry cultivation or the rearing of silkworms, neither posterior phases such as use and end-of-life. No functional unit has been defined as this study comprises an initial assessment to identify the possibility to conduct a complete LCA of the referred system.

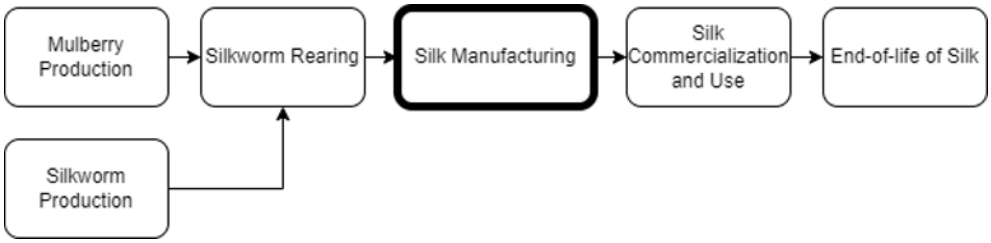

Figure 2 - Life cycle of silk.

Life Cycle Inventory Analysis (LCI). The processes (Figure 3) for the scope of the study (manufacturing phase of the silk production) were modelled using the OpenLCA 1.10.3 software tool. The Ecoinvent database v3.7.1 was used for modelling processes that needed secondary data. A qualitative inventory for the processes that comprise the manufacturing phase of the silk production can be seen in Table 1.

Life Cycle Impact Assessment (LCIA). In the LCIA phase, the input and output of the set of LCIs is used to quantify the impacts according to impact assessment methods. At this stage, one needs to decide on assessing midpoint or endpoint impacts, and indicate what categories need to be assessed. At this point, software tools are usually used to calculate the impacts. In this study no LCIA was conducted, as the study was based on a qualitative inventory.

Interpretation. After mapping and investigating the processes, and building the qualitative inventory, a few limitations and challenges were identified for conducting a comprehensive LCA study of the silk yarn production in Brazil. They are presented later in sections 3 and 4.

3 Major issues on Life Cycle Assessment of the production of silk yarn in Brazil

The qualitative inventory, including the survey carried out in Teruya's [13] diagnosis, and the mapping of the production processes of the silk yarn in Brazil, allowed having a systemic view of the silk yarn production process as well as pointing out the main difficulties and limitations for carrying out an LCA study of the said system. The qualitative inventory for the production of Brazilian silk yarn is presented in Table 1, and the modelling of the processes is illustrated in Figure 3.

As presented in the methods section, the system comprises from the receipt of fresh cocoons until the sale of raw silk yarn. There are many challenges identified to conduct a comprehensive LCA of silk yarn production in Brazil, as presented below.

Table 1 - Qualitative inventory of silk yarn manufacturing

Process	**Inputs (material/energy)**	**Outputs (material/energy)**
Vapor/boiler	Water	Vapor
	Wood	Emissions of carbon monoxide (CO)
		Emissions of nitrogen oxides (NOx)
Drying	Fresh cocoons	Dry and packaged cocoons
	Raffia sack	BR 09 (cut cocoons)
		Pupae
Sorting	Dry and packaged cocoons	Sorted dry cocoons
	Electricity	BR 10 (anafaia)
		Non-usable cocoon
Cooking	Sorted dry cocoons	1 quality cooked cocoons
	Water	2 quality cooked cocoons
		Non-usable cocoon
		Wastewater
Automatic spinning (a.s.)	1st quality cooked cocoons	Silk yarn in plastic reel (a.s.)
	Water	Wastewater
		BR 03 (waste)
		BR 06 (pieces of silk yarn)
		BR 15 (silk tow)
		Frison (saste / master yarn)
		Non-usable part of cocoon
Semiautomatic spinning (Dupion)	2nd quality cooked cocoons	Silk yarn in plastic reel (dupion)
	Water	Wastewater
		BR 01 (waste)
		BR 07 (pieces of silk yarn)
		Non-usable part of cocoon
Transference	Silk yarn in plastic reel (a.s.)	Silk yarn skein (sewn)
	Silk yarn in plastic reel (dupion)	Wastewater
	Water	BR 05 (pieces of silk yarn)
Finishing	Silk yarn skein (sewn)	Packaged silk yarn
	Electricity	
	Plastic bag	
	Carton boxboard	

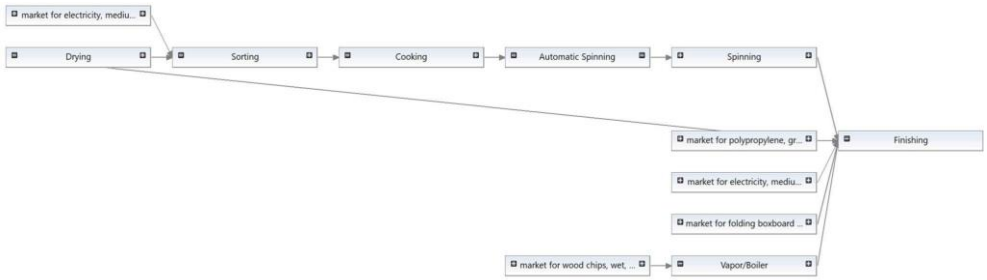

Figure 3 – Process modelling of the silk yarn production system. Source: Authors (2021)

Lack of specific data. One of the main challenges is collecting all quantitative data needed for most processes. Many upstream and downstream processes can be found in the Ecoinvent database (for example); however, there are few inventories (even for general processes) under Brazilian conditions, thus, they are generally not regional inventories. Among those identified in the inventory in Figure 1, only the inventories for electricity and water are specific for Brazil, all remaining processes are from existing inventories under other (general/generic) geographic conditions. Nonetheless, it should be highlighted that it is possible to obtain primary data for all processes within the system boundaries, as they are controlled by the organization.

Obtaining representative data. For a range of the processes in which specific data are possible to be collected, data are not measured separately. For instance, electricity or water consumption might be disclosed as the sum of monthly consumption, which renders a detailed accounting of the resources consumed by a specific process to become a hurdle.

Company openness. As there is only one company in the country who manufactures silk yarn, it is decisive that they acknowledge the need for conducting an LCA of silk and that they express their openness to embark on this endeavor, providing the necessary data to build a complete inventory of the manufacturing process of silk yarn.

4 Discussions and Final Considerations

This study presents an initial mapping of the system being the first step to analyze the environmental issues related to the production of silk thread in Brazil.

Despite Brazil being the fifth silk producer in the world, there is only one spinning company, which still does not have specific input and output data available for some of the processes, for such mapping. However, it is possible to organize such data for future control and availability, because the organization controls all processes. These data include material, energy, effluent treatment and boiler, which makes a quality inventory difficult.

The next step to achieving the complete LCA study of silk will be to carry out a quantitative inventory of the silk yarn production with good quality using the present process map as a starting point. Quantitative data will be used to quantify impacts. To prepare the quantitative inventory, the primary data must be collected directly from the spinning company, the only one in Brazil, and the secondary data from the Ecoinvent database. The categories of impacts considered for assessment at this stage are: Freshwater Ecotoxicity (FETP), Human Toxicity (HTP), Terrestrial Ecotoxicity (TETP), Climate Change (GWP), Freshwater Eutrophication (FEP), Agricultural Land Occupation (ALOP), Water Depletion (WDP), Terrestrial Acidification (TAP), and Natural Land Transformation (NLTP).

Another limitation for conducting an LCA of such a system in Brazilian conditions at this point, is the scarcity of secondary data available for background process with high representativeness. In addition, the opening of the silk yarn manufacturer and the availability of the necessary data are essential for carrying out an LCA of the Brazilian silk yarn

manufacturing process.

So, the main particularity identified as a Brazilian condition in the yarn manufacturing phase is the concentration in one single company, differently from the mulberry and cocoon production phases where there are more relevant technological and practices differences. Other limitations are not yarn manufacturing phase specific.

In future studies it is suggested that a quantitative inventory of the production of silk yarn be carried out, using the present mapping as a starting point. It is also suggested to evaluate the environmental performance of the silk yarn production, from a complete LCA study.

This study conducted a bibliographical analysis on the textile context, specifically the silk, making perceptible the importance of the silk for the agroindustrial sector represented by its producers, as well as for the Brazilian economy. Thus, there has been an increasing concern towards a sustainable silk production chain.

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