SUSTAINABILITY ASSESSMENT OF THE PRODUCTION OF SISAL FIBER IN BRAZIL

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ABSTRACT

Natural fibers are increasingly researched and applied in fiber reinforced polymer car parts. Compared to synthetic reinforcing fibers such as glass fiber, natural fibers offer several advantages such as lower weight, lower price and renewability. To assess whether these natural fibers are also more sustainable, all three dimensions of sustainability must be investigated; environmental, social and economic sustainability. This study aims to assess the sustainability of Brazilian sisal fiber production. The Life Cycle Sustainability Assessment method is used to address sustainability aspects from all three dimensions and considering all steps from the farm to the port. Data was collected from literature, technical reports and a questionnaire. The non-renewable energy use of sisal fiber production is ca. 4.2 GJ/t fiber and the greenhouse gas emissions are ca. 270 kg CO_2-eq./t fiber. These impacts are approximately 93% lower compared to glass fiber production and ca. 41%-61% lower compared to the production of Tanzanian sisal fiber. The largest environmental impacts occur during fiber extraction (54%-56%) and transportation to the port (32%-36%). In the economic assessment, the breakdown of sisal fiber production costs is investigated. Labor costs are the largest cost factor (ca. 82%), whereas fiber extraction is the most costly process during production. These results can be explained by the extensive use of manual labor in the Brazilian sisal sector. In the social assessment, positive and negative social impacts relating to the sisal sector are investigated. There are significant social problems such as gender discrimination and the possible use of child labor. Furthermore, wages in the sisal sector are significantly below the minimum wage and the occupational accident rate is high. There are also positive social aspects; workers are free to organize in the rural labor unions and the social security scheme provides benefits for illness, disability, retirement etc. Furthermore, the sisal sector contributes to local socio-economic development through providing jobs and income to many unskilled workers. Finally, the Brazilian government, local organizations, scientific institutions and labor unions are actively addressing sustainability issues through projects and programs. Preferred solutions are those that relieve problems from all dimensions of sustainability, such as improved machinery that can reduce the number of accidents, energy costs and environmental impacts. For car manufacturers considering to implement sisal, it is important to carefully select fiber suppliers to ensure that international labor standards are safeguarded. Furthermore, contributing to existing sustainability programs can help solve problems relating to the sisal sector.

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1. INTRODUCTION

1.1. Background

Over the past decades, humanity has become increasingly aware of a growing environmental crisis on this planet. Transportation, housing and the production of food and other materials are the primary drivers behind issues such as anthropogenic climate change, ecosystem destruction, biodiversity loss, the depletion of non-renewable resources and reduced capabilities to provide renewable resources. Aside from the environmental significance of these issues, they are also a great threat to human wellbeing and prosperity (DESA, 2013; UNEP, 2010). Considering the worldwide contribution of transportation to environmental pressures (e.g. 13% of global greenhouse gas emissions), end-of-life and fuel efficiency regulations for the automotive industry are becoming increasingly stringent (UNEP, 2010). For example, European regulation demands that, by 2015, at least 95% of the vehicle (by weight) is reused or recycled (EC, 2005). In response, car manufacturers have aimed to lower fuel consumption and increase the share of renewable and recycled material in their cars. Through material innovation, many car parts traditionally made of metal have been replaced by polymer car parts. This has caused the use of polymers in cars to double over the last 25 years (Zah et al., 2007). Compared to metals, polymers are cheaper, lighter and easier to mold in complex shapes, whilst using much less processing energy during production. To increase their strength, polymer car parts are typically reinforced with glass fiber (Zah et al., 2007).

Since the 1990s, natural fibers are increasingly studied and applied as replacement of glass fiber in fiber reinforced polymer (FRP) car parts (Joshi et al., 2004; Zah et al., 2007). Natural fibers have comparable mechanical properties to glass fiber, but offer several advantages such as lower costs and lower weight (Müssig, 2010; Wambua et al., 2003). Additionally, studies have reported numerous environmental advantages of natural fibers. The Nova Institut found that the cumulative energy demand of production was up to ten times higher for glass fiber than for natural fibers (Carus et al., 2008). Corbiere-Nicollier et al. (2001) come to a similar conclusion in a comparison of glass fiber and China reed fibers. Furthermore, the lighter weight of natural fibers can also improve fuel efficiency of vehicles (Joshi et al., 2004). Finally, at the end-of-life of the material, natural fiber reinforced polymers (NFRP's) have superior recyclability characteristics over glass fiber reinforced polymers (GFRP's). NFRP's lose less strength during recycling than GFRP's and can, in contrast to the latter, be successfully incinerated for energy recovery (Bourmaud & Baley, 2007; Zah et al., 2007).

The use of natural fibers has suffered a long period of decline caused mainly by competition with synthetic fibers. However, modern applications provide prospects for growing demand and production of natural fibers (CFC/FAO, 2008). One natural fiber, studied for its potential for polymer reinforcement, is the sisal fiber. Sisal fiber is harnessed from the leaves of the sisal plant, a species of Agave, and is most commonly used for making cordage such as agricultural baler twine. Other uses are in the making of bags, floor coverings and specialty paper (Müssig, 2010). Global sisal fiber production was ca. 241,300 metric tons (t) in 2011 (FAO, 2012a). The cultivation of sisal is concentrated mainly in Brazil, Tanzania, Kenya, Mexico and China. The sisal plant can grow on marginal lands in semi-arid regions where few other crops can grow. Therefore, there is little to no competition for land with food production in these places (Müssig, 2010). The cultivation and processing of sisal is labor intensive and provides a livelihood for some of the poorest people in these countries (CFC, 2000). Brazil is the main producer and exporter of sisal, with a global market share of ca. 46% in 2011 (FAO, 2012a). Approximately 850,000 people are directly or indirectly employed in the Brazilian sisal sector (CFC, 2012). Almost 95% of Brazilian sisal production takes place in the province of Bahia. The average income in the sisal producing regions lies significantly below the average income in Brazil (Sindifibras, 2012).

Sisal fibers are considered a renewable resource with several environmental advantages over glass fiber. However, worldwide agricultural production contributes significantly to greenhouse gas (GHG) emissions, eutrophication, land use and water use. Therefore, renewability does not mean that sisal fibers are necessarily (more) sustainable (UNEP, 2010). Sustainability is generally considered to consist of three 'pillars';

environmental, social and economic sustainability (UNEP/SETAC, 2011). The environment, in this context, refers to the biophysical environment. To assess the sustainability of sisal fibers, the environmental, social and economic aspects of sisal fiber production must be investigated. No integrated and quantitative analysis of these sustainability aspects of sisal fiber production in Brazil exists at the moment. Such an analysis could provide the basis for informed decision making on the use and choice of sisal fibers for producing FRP's. Additionally, it could guide improvements of the environmental, social and economic performance of sisal fiber production in Brazil.

1.2. Research aim and questions

The aim of this study is (1) to perform a comprehensive, quantitative sustainability assessment of the production of sisal fiber in Brazil. Subsequently, (2) to formulate recommendations regarding the sourcing of sisal fiber from Brazil by car manufacturers.

The main research question reads: How does the production of sisal fiber in Brazil perform in a quantitative sustainability assessment and which recommendations can be drawn with regard to the sourcing of sisal fiber from Brazil by car manufacturers?

The sub questions read:

- What are the main characteristics of the production of sisal fiber in Brazil?
- What are the environmental impacts related to the production of sisal fiber in Brazil?
- How do the environmental impact of the production of sisal fiber in Brazil compare to the environmental impacts of the production of sisal fiber in Tanzania and the production of glass fiber?
- What is the breakdown of the production costs of Brazilian sisal fiber?
- What are the most important social impacts related to the production of sisal fiber in Brazil?
- What interrelationships can be identified between the three pillars of sustainability for the production of sisal fiber in Brazil?
- Which recommendations can be drawn with regard to the sourcing of sisal fiber from Brazil by car manufacturers?

1.3. Relevance

This study is part of a University Research Program (URP), signed by Ford Research and Advanced Engineering with Utrecht University. The main goals of the project are (1) to generate and further improve the Life Cycle Assessment (LCA) database of natural fiber composites and recycled polymers, and (2) to conduct an LCA comparing the impact of those materials to conventional materials for selected car components. Various natural fibers are considered for use in several applications of their cars. Within this project, environmental LCA studies have been performed on coir fibers from Sri Lanka and sisal fibers from Tanzania. The focus of this study is on the sisal fiber production in Brazil. To ensure consistency, the functional unit and system boundary of this study are aligned with the earlier studies.

From a scientific perspective, the relevance of this study lies in producing LCA data on the production of sisal fiber in Brazil to fill the existing data gap. Furthermore, the application of a semi-quantitative social sustainability assessment provides new insights into the social characteristics of sisal fiber production in Brazil and into the use of the social LCA method in general. Finally, this study adds to the currently limited number of case studies that use integrated quantitative sustainability assessments following the guidelines of UNEP and SETAC.

The societal relevance of this study lies in providing recent and quantitative data on the environmental impacts related to the production of sisal fiber in Brazil. This gives car companies and other manufacturers the ability to compare sisal fiber from Brazil with other materials according to several environmental sustainability measures and thus make an informed choice on the use of materials. Furthermore, the results of this study can be used by actors involved in the sisal fiber production system in Brazil to improve the sustainability performance by reducing the environmental impacts, improving social conditions and economic performance.

1.4. Thesis structure

This thesis will continue with an introduction of the case study in chapter 2. The chapter discusses the sisal plant, its applications and the sisal fiber production systems in Brazil and Tanzania. Furthermore, the production and specifications of fibers and FRP's are explained. In chapter 3, the sustainability assessment method used for this study is explained and the goal and scope of the assessment are defined. In chapters 4, 5 and 6, the inventory analysis, results and interpretation are presented of respectively the environmental, economic and social assessment. In chapter 7, the results of the three assessments are integrated to identify interrelationships between the different sustainability aspects. In chapter 8, the methodology, methodological choices, data use and uncertainty are discussed. Finally, in chapter 9, the research questions are answered and recommendations for further research are provided.

2. CASE STUDY BACKGROUND

2.1. Sisal plant

The sisal plant (*Agave sisalana*) is a species of Agave, native to Mexico's Yucatan peninsula (CFC, 2012). It has been cultivated for several centuries in Central and South America, mainly to extract its leaf fiber for use in yarns, twine and cordages (Müssig, 2010). Sisal is a tropical plant that is resistant to heat and drought and can grow on a range of soils with very little nutrition (CFC, 2000). However, the plant grows best on fertile, well drained and aerated soils and with annual rainfall between 1,200 and 1,800 millimeter (mm) and temperatures between 16 and 27°C (CFC, 2001; Saxena et al., 2011).

The sisal plant, shown in Figure 1, has between 20 and 40 stiff, green leaves which grow from a plant bole. The leaves are between 1 and 1.5 meters (m) long and ca. 10 centimeters (cm) wide and have a sharp tip (Alvarenga Júnior, 2012). The mature sisal plant produces rhizomes called suckers near its base. These suckers can be transplanted and used as planting material. At the end of its life, the plant produces a flower stalk between six and nine meters long. Some 500 to 2,000 small plantlets called bulbils grow on the flower stalk. Bulbils and suckers constitute the main method for plant propagation (CFC, 2005; Saxena et al., 2011). The life cycle of the sisal plant is ca. 10 years. Over its lifetime, the sisal plant yields about 200-250 commercially usable leaves which weigh between 400 and 700 grams. Each leaf contains roughly 1000 fibers, ca. 4% of the leaf by weight (Alvarenga Júnior, 2012). The sisal fiber belongs to the category of hard fibers (CFC, 2012).

There exist several hybrid sisal varieties with distinct properties. The most important is Hybrid 11648, which was developed in east Africa and is considered more drought resistant and produces more leaves than *Agave sisalana*. However, the leaves of the hybrid plant are wider and thicker and therefore more difficult to process (Alvarenga Júnior, 2012). Furthermore, the hybrid is less resistant to water logging and more susceptible to pests and diseases (KSB, 2006).

FIGURE 1: AGAVE SISALANA (SOURCE: BOTURA, 2011)

2.2. Sisal applications

Fibers and other materials harnessed from the sisal plant can be used for a range of applications. Several of these applications are discussed below.

2.2.1. Traditional applications

Approximately 60% of the sisal fiber produced worldwide is used to make agricultural baler twine. Although increased use of synthetic fibers and new baling methods have significantly reduced the demand of sisal fiber in the past decades, this still remains the most important application (Embrapa, 2008; Leão et al., 2006). Other important traditional uses are in carpets, rugs, sacks, yarns, ropes and other cordage (Müssig, 2010).

2.2.2. Natural fiber reinforced polymers

When plastics were first developed, natural fibers were amongst the first materials to be added to create polymer composite materials. The purpose of the natural fibers was to increase impact resistance and reduce costs. Due to its higher strength, glass fiber became the most important fiber added to polymers for automotive applications. In recent years, however, natural fibers are again applied in these materials because of their low cost and environmental benefits (Taj et al., 2007; Zah et al., 2007).

2.2.3. Building materials

Sisal fiber can be applied in construction materials such as cement composites. Especially in Brazil, where the use of asbestos has still not been fully banned in all states, there may be large potential for sisal fiber reinforced cement to make products such as tiles, bricks, water tanks and roofing sheets. The advantage of sisal for these applications is that short and lower quality sisal fibers can be used, resulting in low costs (CFC, 2010; Leão et al., 2006).

2.2.4. Geotextiles

Geotextiles are permeable woven or non-woven fabrics that can be used in the construction of roads, rail, and other landscaping applications to improve soil stability and reduce erosion. Natural fiber based geotextiles offer the advantage of natural decomposition in applications such as natural stream bank restoration. Natural vegetation is able to grow through the geotextiles and can provide further ground stabilization (Müssig, 2010; Saxena et al., 2011).

2.2.5. Electricity production

Fibers constitute only 4% of the sisal leaves by weight, meaning that, for every ton of fiber, 24 tons of sisal pulp are produced during fiber extraction. Research into possible uses of this pulp is ongoing. In Tanzania, trial projects are investigating anaerobic digestion of sisal pulp and wastewater for the production of biogas, which can be used for decentralized power generation. Potential electricity production is between 1200-3000 kWh per ton pulp. Estimates for total potential electricity production from sisal pulp in Tanzania range from 25 to 67 gigawatt hours (GWh) per year (Terrapon-Pfaff et al., 2012).

2.2.6. Animal feed

In Brazil, sisal pulp distributed in the field is often eaten by goats or cattle. This may lead to health problems for the animals if short fibers (tow) and juice are not removed from the pulp. Cheap manual presses and rotary sieves are tested for the production of dry animal feed from the sisal pulp, shortly after fiber extraction. The extracted sisal juice may then be used for chemical applications (Sindifibras, 2012).

2.2.7. Chemicals

Sisal juice contains several types of chemical compounds that can be extracted and used commercially. The most important bioactive substances are saponins, which form ca. 0.01% of sisal juice. Saponins extracted from other plants have been used in the production of pharmaceuticals (hormones), pesticides and fungicides. The use of sisal juice for similar purposes is being investigated (SECTI, 2013; Sindifibras, 2012).

2.3. Sisal in Brazil

The sisal plant was brought to Brazil in 1903, but commercial cultivation only started in the late 1930's in the province of Bahia (SECTI, 2007). Most of the sisal cultivation and fiber production in Brazil currently takes place in the northeast, with the province of Bahia covering ca. 95% of national production. Within Bahia, the Sisal Territory, consisting of 20 municipalities, has the largest concentration of sisal farms and processing plants (Sindifibras, 2012). Figure 2 shows the map of Brazil with the northeast and the sisal territory in Bahia.

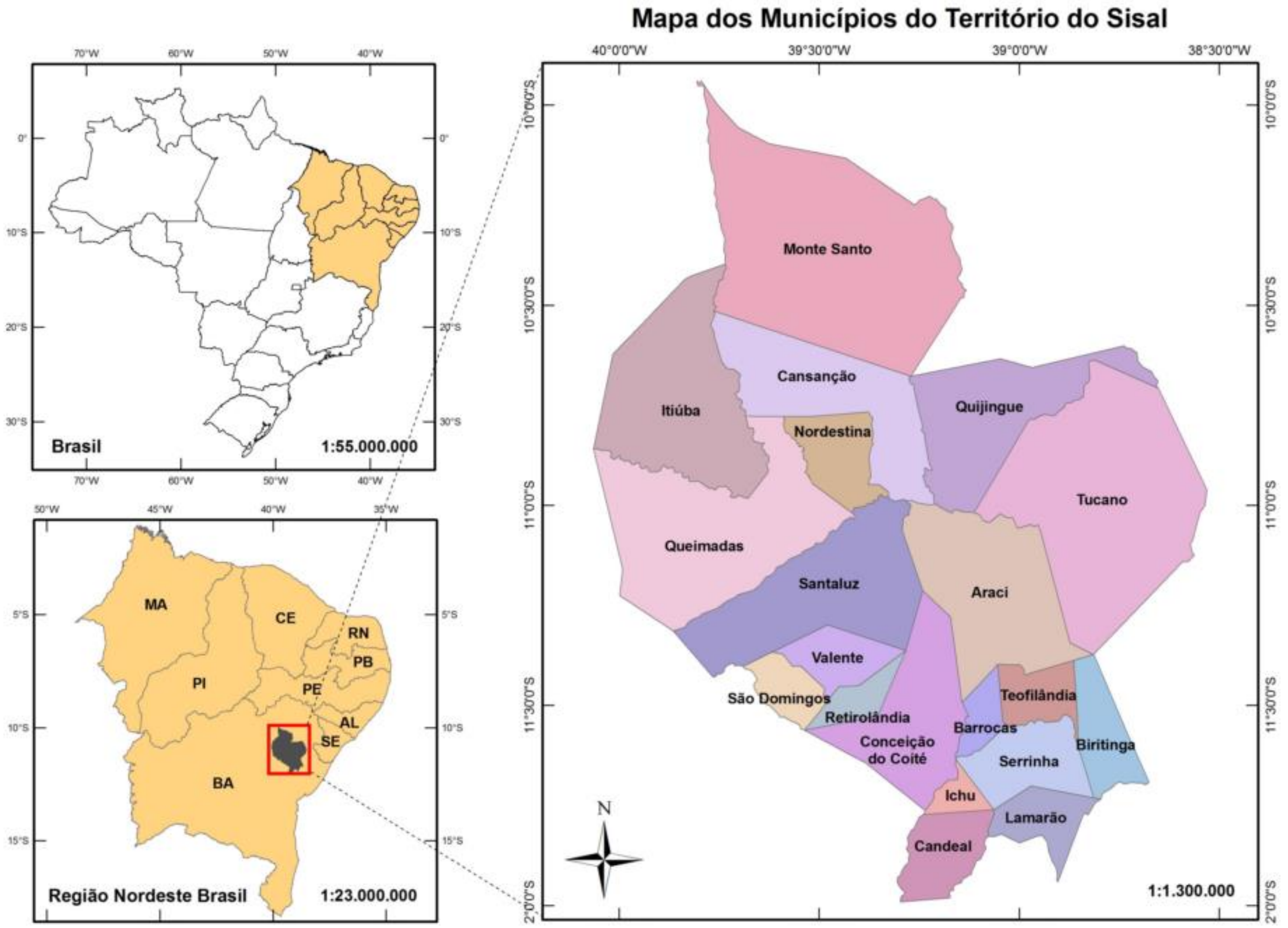

FIGURE 2: MAP OF BRAZIL, THE NORTH EAST OF BRAZIL AND THE SISAL TERRITORY IN BAHIA (SOURCE: MOREIRA, 2013)

2.3.1. CLIMATE

The northeast of Brazil is a semi-arid region with average temperatures exceeding 24°C. Since annual precipitation (between 500 and 1250 mm) is generally lower than evapotranspiration, the risk of drought is always present. Due to the climate, the drought resistant sisal plant is one of the few crops that can be successfully and commercially cultivated in the area (Silva et al., 2008).

Climate projections indicate that the northeast of Brazil will likely experience substantial effects of climate change. Forecasts for the region predict average temperature increases ranging between 2 and 5°C until the year 2100 and large reductions in precipitation. Furthermore, the intensity of weather extremes will increase, leading to more extreme heat and more frequent dry spells (Ambrizzi et al., 2007). These changes in the climate can result in large decreases in agricultural food production and biodiversity. This can have detrimental consequences for the northeast of Brazil, which is extremely vulnerable due to high levels of poverty and inequality (Lemos, 2007; Ventura & Andrade, 2013). The sisal plant is more resistant to drought and high temperature than most other crops cultivated in the area, which could make it more attractive for farmers to cultivate. However, increased temperatures and drought may also threaten the yield of sisal plants.

2.3.2. Production system

Sisal is mainly cultivated by smallholders on family farms (Brenters, 2000). Two-thirds of the farms in the region are smaller than 10 hectare (ha), while only 4% are larger than 100 ha (Peerboom, 2012; Sindifibras, 2012). There are generally no significant differences in the cultivation methods and technology used on small or larger sisal farms (Peerboom, 2012).

2.3.2.1. Land preparation

To prepare a field for use as mature sisal field, old plants, other vegetation, rocks and rubble need to be removed. The vegetative waste can be put on the edges of the sisal field to reduce soil erosion (Alvarenga Júnior, 2012). The land should be plowed and harrowed to increase aeration and water infiltration and ease the growth of plant roots. Finally, pits need to be prepared for planting the sisal (Embrapa, 2014).

2.3.2.2. Cultivation

Sisal plantlets come from either suckers or bulbils that were collected earlier from a mature sisal field. Bulbils need to be raised in a nursery field for about 24 months before they are large enough to be transplanted to the main field (CFC, 2001). In Brazil, farmers almost exclusively use the suckers for planting material and over 98% of the farmers plant directly on the mature field without using a nursery (Vale et al., 1998). Sisal plantlets are planted in single or double rows and oriented north-south to reduce shading between plants. Common plant densities are between 4,000 and 5,000 sisal plants per hectare, which allows enough space to maneuver between the rows. *Agave sisalana* is the main variety used for commercial cultivation in Brazil. However, Hybrid 11648 is also used at some farms (Embrapa, 2014).

The sisal field needs regular weeding operations, especially during the first years, to reduce competition for nutrients. From the second year of planting, suckers may appear near the base of the sisal plant. These small plantlets can be dug out and used for plant propagation. After about 10 years the sisal plant flowers and dies (Silva et al., 2008). The farmer is responsible for clearing the field of dead sisal plants and preparing the land for the plantation of new plantlets (Embrapa, 2014).

The level of mechanization in agriculture in the northeast of Brazil is low and the agricultural practices used are simple and traditional (Peerboom, 2012; SECTI, 2007). Given the scarcity of water in the semi-arid northeast of Brazil, no irrigation is used (Peerboom, 2012). Commercial fertilizers or pesticides are also not commonly applied (FAO, 2012b; Silva et al., 2008). However, sisal responds well to nitrogen, phosphorus and potassium (Saxena et al., 2011). Red rot is the only significant disease affecting sisal in Brazil. Although it cannot be treated, the risks and damages can be limited if the appropriate precautions are taken (Batista et al., 2010).

2.3.2.3. Decortication

Two years after planting, the sisal plant is ready for harvesting. Leaves are cut manually, usually once a year, by several cutters called *cortadoras* (Peerboom, 2012). With every cutting operation, a few leaves are left on the plant to allow sufficient photosynthesis and moisture capture (CFC, 2005). When the leaves are cut, they must be processed as soon as possible to avoid deterioration. The leaves are bound together and loaded on a donkey by the transporter or *botador,* to be transported to a mobile decorticator located near the field (Peerboom, 2012). Using a decorticator, the fibers are extracted from the leaves in a dry decortication process. The decorticator is driven by a small combustion engine and uses fast rotating knives to remove the leaf tissue, yielding wet fibers (see Figure 3) (Brenters, 2000). One person, called the *resideiro,* hands the leaves to the machine operator. The machine operator (*cevador)* inserts the leaves into the decorticator. The *resideiro* also removes the leaf tissue from the machine, binds together the fibers and weighs them (Peerboom, 2012). Sisal residues are commonly distributed on the field by the farmer to restore nutrients to the soil, inhibit the growth of weeds and prevent moisture evaporation from the soil. Residues are also frequently eaten by cattle, sheep and goats. However, if tow and juice are not removed, this can lead to health problems (Sindifibras, 2012).

FIGURE 3: BRAZILIAN MOBILE DECORTICATOR (SOURCE: CFC, 2001)

At this point, the fibers should be washed in tanks filled with clean water to remove mucilage and chlorophyll sap. However, due to water scarcity, this process is usually skipped (Vale et al., 1998). The dryer (*estendedeira)* is responsible for transporting the wet fibers to a drying yard and hanging them over drying wires. The fibers need to dry for approximately 72 hours to reduce the moisture content to ca. 13% and give the fibers their distinctive color (Müssig, 2010; Peerboom, 2012). The laborers responsible for the cutting and decortication process are hired by the owner of the decorticator, who often participates in the process himself. The owner of the decorticator stays at the same farm for several weeks until all sisal leaves are decorticated and then moves his machine to the next farm (Peerboom, 2012).

2.3.2.4. Brushing and baling

The dried sisal fiber is often bought by a middleman (*atravessador*), who visits the farm and transports the fibers to the brushing and baling facility (*batedeira*). The middleman sells the fibers to the owner of the *batedeira* (Peerboom, 2012). In the *batedeira*, the sisal fiber is brushed using a large brushing machine to remove the last impurities and make the fibers soft and shiny (Brenters & Romijn, 2002; CFC, 2001). The fibers are then sorted by quality and baled using a baling press (Peerboom, 2012). The baled sisal fiber can be stored or transported to other facilities for further processing or export.

2.3.3. Fiber grading

Sisal fibers are graded both on their quality and length. The four length classes are (1) extra-long (length over 1.10 m), (2) long (length between 0.90 and 1.10 m), (3) medium (length between 0.70 and 0.90 m) and (4) short (length between 0.60 and 0.70 m). The quality of the fibers is graded along the following categories:

- Type 1: Dry and well-brushed fiber. Cream or clear yellowish colored. Soft, shiny and normal strenght. Free from impurities.
- Type 2: Dry and brushed fiber. Yellowish to brownish in color. Average shine and slightly rough.
- Type 3: Dry and brushed fiber. Yellowish, brownish or greenisch in color. Average shine, rough and some color difference allowed.

For all fiber grades above, the maximum moisture content permitted is 13.5%. Sisal fiber that does not meet these quality levels or is shorter than 0.60 m, is graded as type 4 or *refugo* (scrap) (Müssig, 2010; Silva et al., 2008). Sisal fiber from Brazil is generally regarded to be of lower quality than east-African sisal fiber, which can be partly attributed to the less efficient decortication machinery used (Brenters, 2000). Fiber quality can also be impacted by weather conditions such as long lasting drought (WGC, 2012).

2.3.4. Productivity

The productivity of sisal plants depends on several factors; local weather and soil conditions, agricultural practices and the variety of sisal used. Furthermore, sisal fiber production may also be influenced by the efficiency of the machinery used for decortication and brushing (Peerboom, 2012). The productivity of the Brazilian sisal sector is generally low; between 0.5 and 1.2 tons of dry sisal fiber per hectare per year (Andrade et al., 2009; Sindifibras, 2012). Sisal productivity in India and Tanzania are generally higher and can get up to 2.5 tons of sisal fiber per hectare per year (CFC, 2005; Saxena et al., 2011).

Since fertilizers are seldom used in sisal cultivation, many soils are increasingly depleted of nitrogen, potassium, phosphorous, calcium and magnesium (Hartemink, 1997). Despite the sisal plants' ability to survive on poor soils, plant growth and fiber yield decline when soils are depleted. Both in east Africa and Brazil, historic fiber yields were higher. The sisal sector in Brazil has seen virtually no technological innovations over the past decades and there has been little research into the calibration of soil nutrients or use of sisal varieties (Ferreira, 2002; Müssig, 2010).

2.3.5. Recent developments

From the beginning of 2012, the northeast of Brazil suffered one of the worst droughts in 30 years. In certain areas no rain had fallen in 18 months. Sisal production declined by 40-50% compared to 2011, leading to a shortage of sisal fiber. Shortages were initially buffered by stocks of sisal fiber in warehouses belonging to the Brazilian Ministry of Agriculture. Over half of the exported sisal fiber in 2012 originated from these warehouses (WGC, 2013a). Rainfall in the second half of 2013 has made some recuperation of sisal plants possible, although the impacts of the drought were still clearly present at the end of 2013 and supply remained tight (WGC, 2013b). The sisal fiber production in 2013 is estimated to have been between 82,300 and 127,500 t, a notable increase from 2012 (CONAB, 2014). Figure 4 shows the price of raw sisal fiber in three Brazilian provinces and the minimum price offered by the government. At several moments, the price paid by local merchants exceeded the minimum price offered by the government. Three reasons were identified for the high prices: (1) the decline in sisal production caused by the drought in 2012/2013, (2) the rising prices for sisal by-products in international markets, and (3) the increased minimum price of 1.41 $R/kg, effective since July 2013 (CONAB, 2014).

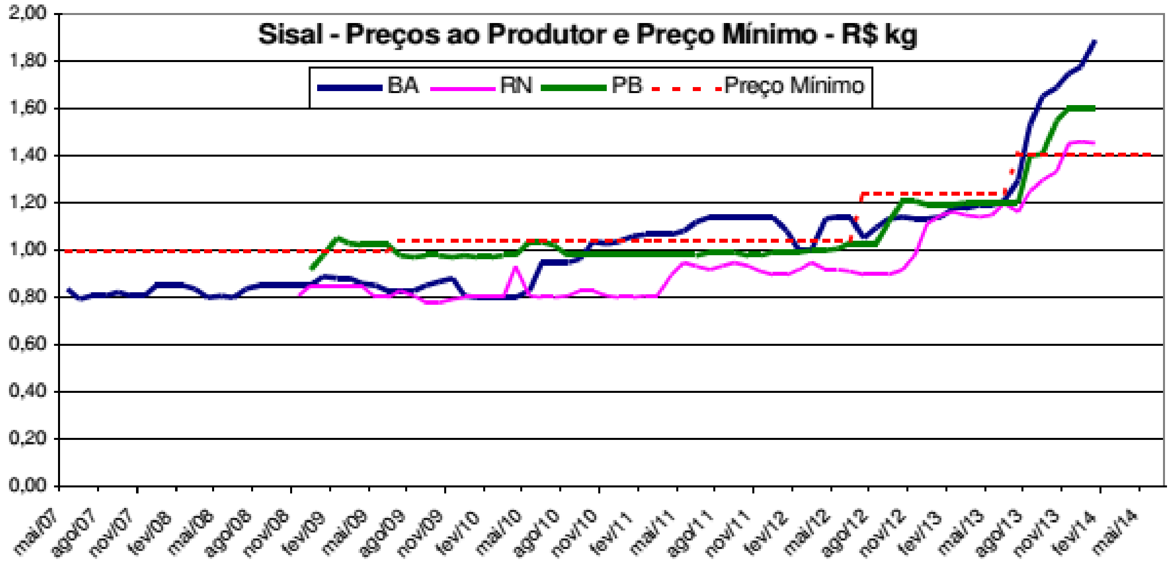

Figure 4: Sisal type 2 fiber producer price (source: CONAB, 2014)

2.4. Sisal in Tanzania

In Tanzania, sisal is predominantly cultivated at large estates, covering several hundreds of hectares. There is a higher level of mechanization and more advanced agricultural techniques are used. Furthermore, several hybrid sisal varieties are used which are adapted to the local climate and soil conditions and may produce higher yields than in Brazil (Kimaro et al., 1994). Furthermore, the quality of Tanzanian sisal fiber is generally higher than Brazilian sisal fiber, caused by different climate and soil conditions and more advanced cultivation and processing methods (SECTI, 2007).

At most estates in Tanzania, the sisal bulbils are used for planting material. The bulbils are raised in a nursery field for 2 years before they are transplanted to the main field. To prepare the fields, large vegetation is removed with a brush cutter and herbicides are used to eradicate weeds. Then, the land is plowed and harrowed using agricultural machines, after which the sisal plantlets are planted manually. During sisal cultivation, commercial fertilizers are applied at some estates. Before the sisal leaves are manually cut, a mowing machine mows the grass between the plants. Because of the large size of the sisal estates in Tanzania, large stationary decorticators are used, located in a central building. This necessitates the use of tractors and trailers to transport the sisal leaves from the field to the decorticator building. In contrast with the small mobile decorticators used in Brazil, the machines in Tanzania use a wet decortication process, in which large volumes of water are used to wash away sisal waste. The sisal pulp and wastewater are disposed of in nearby ponds or rivers, causing methane emissions through anaerobic digestion of plant material. After decortication, sisal fibers are dried and subsequently brushed. The brushed fibers are baled using a baling press and transported by van to the port of Tanga (Cok, 2014).

2.5. Sisal statistics

In the 1960's and 1970's, annual world production of sisal fiber reached 800,000 metric tons, with east African countries producing roughly 400,000 tons, and Brazil producing about 200,000 tons of sisal fiber annually (CFC, 2000). The introduction of synthetic fibers in the 1960's ushered in a decline of global sisal demand and production levels (Brenters, 2000). Nowadays, Brazil is the world's largest producer and exporter of sisal fiber. Figure 5 shows the sisal fiber production over the past decades for the most important producing countries.

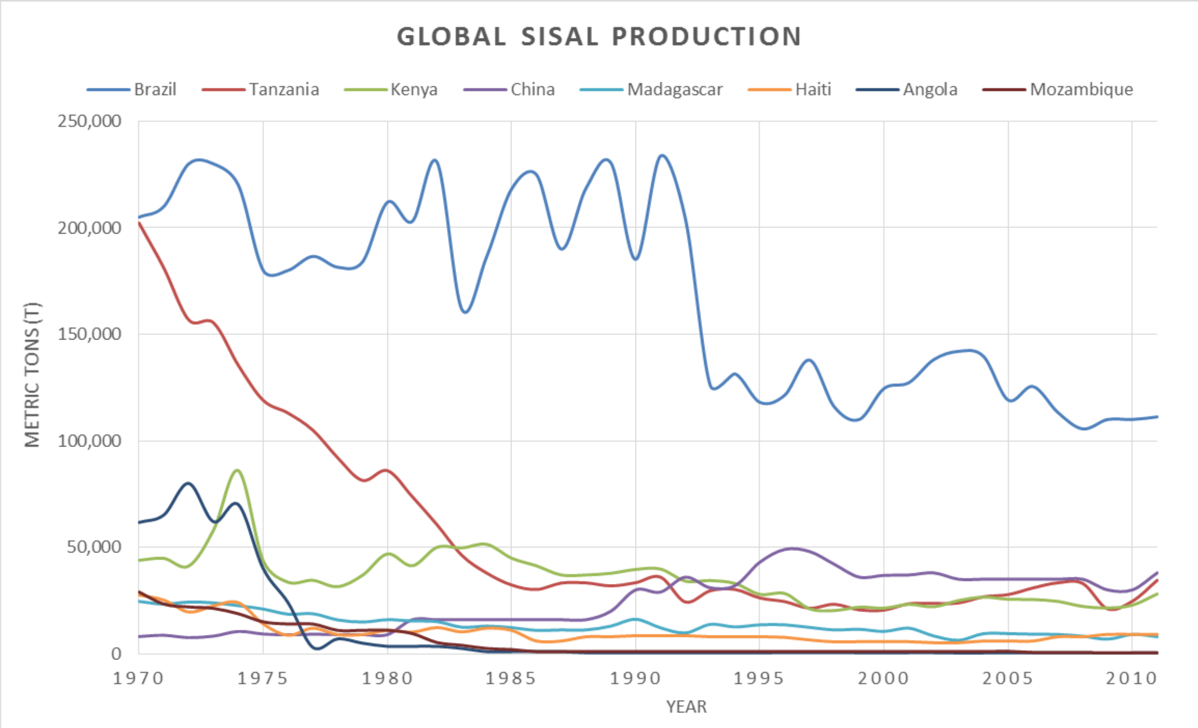

FIGURE 5: HISTORICAL SISAL FIBER PRODUCTION BY COUNTRY, 1970-2011 (SOURCE: FAO, 2014)

Figure 6 shows the total export of sisal products in recent years by the main exporting countries.

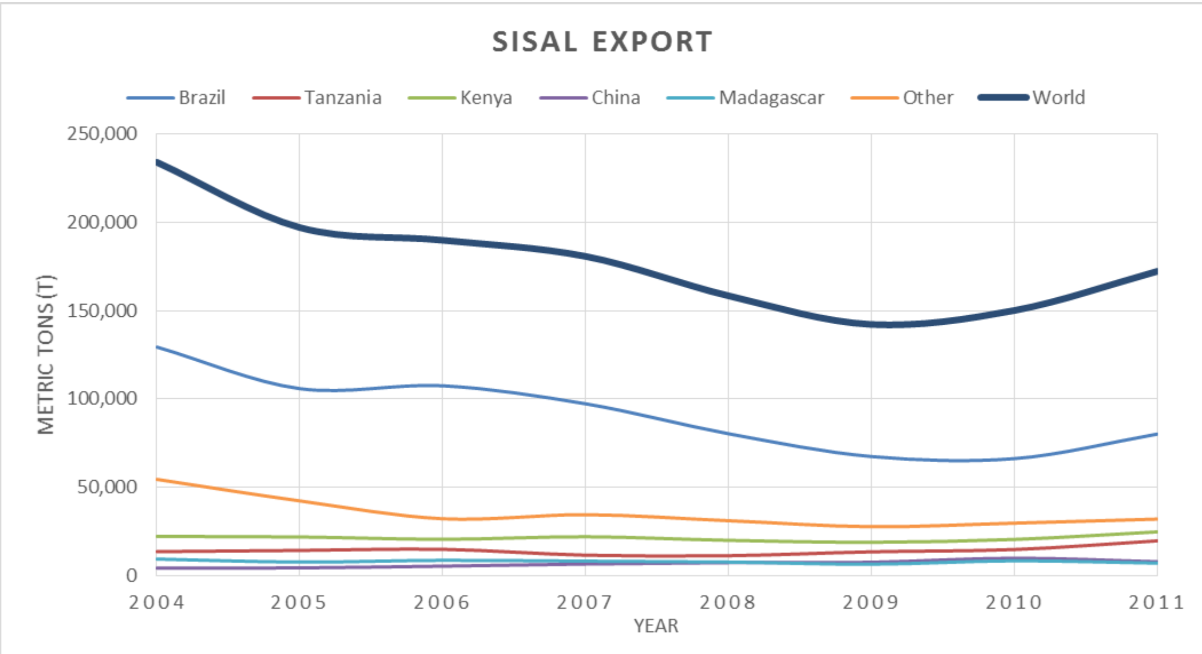

FIGURE 6: HISTORICAL SISAL EXPORT BY COUNTRY, 2004-2011 (SOURCE: FAO, 2010, 2012A)

Sisal is exported as fiber but also as products such as twines, ropes and carpets. Figure 7 shows how the sisal export from Brazil is made up.

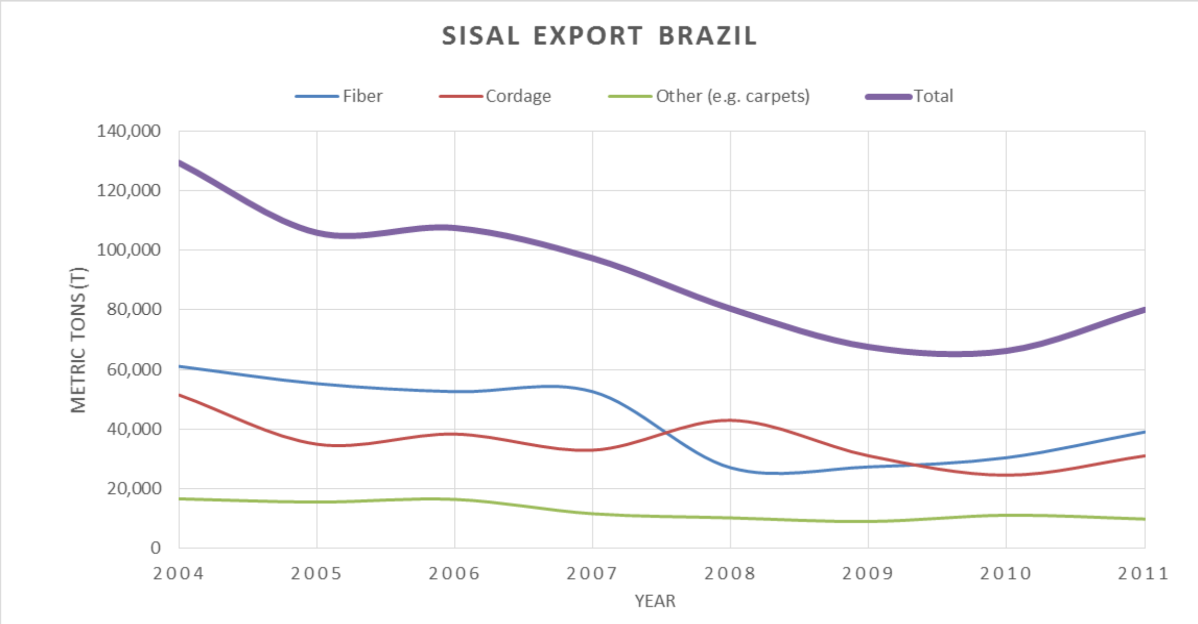

FIGURE 7: HISTORICAL SISAL EXPORT BRAZIL, 2004-2011 (SOURCE: FAO, 2010, 2012A)

About half of the sisal is exported as fiber. China is the largest importer of Brazilian sisal fiber with a share of over 40% (WGC, 2013a). Annual revenue from Brazilian sisal exports is estimated to be between R$80 and R$100 million (Embrapa, 2014).

2.6. Fiber reinforced polymers

In this section, the production and properties of glass fiber, FRP's and the technical specifications of the different fibers and composites are briefly discussed. The production of sisal fiber has been explained in section 2.3.2.

2.6.1. GLASS FIBER PRODUCTION

Glass fiber exists of very thin glass filaments (4-34 µm). To produce glass fiber, silica and any potential additives are mixed together in a process called batching. Various additives can modify the properties of the final glass fiber. The materials are melted and blended in a furnace at 1400°C. The viscous glass is subsequently extruded through bushings containing very small orifices, followed by the cooling of the glass filaments using water jets. The glass fibers are mechanically drawn into thin filaments in a process called attenuation. Finally, a chemical coating or size is applied to the glass fiber, followed by drying and packaging (Gardiner, 2009).

2.6.2. FIBER REINFORCED POLYMER PRODUCTION

A common production method of FRP's is through injection molding. The fibers are cut short (2-5 mm) and added to a melt of polymer and selected additives. The mixture is injected into a mold and cooled. If natural fibers are used, the melting temperature can not be above 230°C, to avoid fiber degradation. Given these restrictions, thermoplastics such as polyethylene and polypropylene are most suitable for NFRP production (Bledzki & Gassan, 1999). Polypropylene (PP) is often used as polymer matrix for FRP composites, because of its low price, low density, high surface hardness, low processing temperatures and good recyclability (Arzondo et al., 2004).

Bonding between the materials is determined by the interface between the fibers and the polymer matrix, which can affect the mechanical properties of the FRP. Natural fibers, which tend to have a polar and hydrophylic surface, generally bond poorly to the non-polar and hydrophobic polymer matrix (Arzondo et al., 2004). However, several physical and chemical treatment methods are available to improve the bonding between the fibers and the matrix and thereby improve the mechanical properties (Bledzki & Gassan, 1999; Fung et al., 2002). The weight ratio of natural fiber to polymer matrix depends on the specific purpose of the fiber in the composite material (e.g. filling, strengthening). When replacing glass fiber, the natural fiber to matrix ratio can be optimized for high strength, or to offer similar weight or volume to the conventional GFRP component (Zah et al., 2007).

2.6.3. TECHNICAL SPECIFICATIONS

The composition of sisal, flax and jute fibers is shown in Table 1.

TABLE 1: CHEMICAL COMPOSITION OF SEVERAL PLANT FIBERS (SOURCE: BLEDZKI & GASSAN, 1999)

	Cellulose	Hemi-cellulose	Pectin	Lignin	Water	Wax
Sisal	65.8 %	12.0 %	0.8 %	9.9 %	11.2 %	0.3 %
Flax	64.1 %	16.7 %	1.8 %	2.0 %	13.9 %	1.5 %
Jute	64.4 %	12.0 %	0.2 %	11.8 %	11.1 %	0.5 %

Similar to other plant fibers, sisal fiber is composed of mostly cellulose. Table 2 shows the technical specifications of glass fiber, sisal fiber and other natural fibers (coir, flax and jute). The tensile strength is defined as the force per unit of cross-sectional area at which the material fails when stretched under tension. Young's modulus is a measure of material stiffness, reflecting the amount of pressure needed to achieve a certain deformation.

TABLE 2: TECHNICAL SPECIFICATIONS OF GLASS FIBER, PP AND NATURAL FIBERS (SOURCE: BLEDZKI & GASSAN, 1999; JOSEPH ET AL., 2002)

Fiber	Density (g/cm^3)	Elongation at break (%)	Tensile strength (MPa)	Young's modulus (GPa)
Sisal	1.5	2.0 - 2.5	511 - 635	9.4 - 22.0
Coir	1.2	30.0	175	4.0 - 6.0
Flax	1.5	2.7 - 3.2	345 - 1035	27.6
Jute	1.3	1.5 - 1.8	393 - 773	26.5
Glass	2.5	2.5	2000 - 3500	70.0

Although glass fiber is substantially stronger and stiffer, it is also heavier than the natural fibers. Table 3 shows the technical specifications of PP and sisal, flax and glass fiber mat-reinforced PP composites at a fiber content of 40% by weight. For the NFRP's, the specifications of both the chemically treated and untreated materials are shown.

TABLE 3: TECHNICAL SPECIFICATIONS OF PP AND FIBER MAT-REINFORCED PP COMPOSITES AT 40 WT% FIBER CONTENT (SOURCE: BLEDZKI & GASSAN, 1999)

Materials	**Tensile strength (MPa)**	**Young's modulus (GPa)**
PP	35	0.5
PP – sisal	38	3.6
PP – sisal, treated	55	4.8
PP – flax	47	5.1
PP – flax, treated	67	6.7
PP – glass	100	6.0

Polypropylene is not a very strong or stiff material in itself. However, by reinforcing the material with fibers, strength and stiffness are significantly increased. PP composites containing chemically treated natural fibers perform better than the untreated versions. However, the PP/glass fiber composite remains the strongest material. Concerning impact behavior, it was found that increased fiber toughness was accompanied by an increase in fracture energy. The toughness of a sisal fiber reinforced polyethylene composite was found to be only ca. 25% lower compared with a GFRP, based on same fiber volume content (Bledzki & Gassan, 1999).

2.6.4. RECYCLING OF FIBER REINFORCED POLYMERS

Material recycling of FRP's is possible, but generally reduces some of the mechanical qualities of the material. Most of the deterioration is due to fiber breakage during reprocessing. The effect of reprocessing on the tensile strength and Young's modulus of FRP's was investigated in Bourmaud & Baley (2007). For the PP/sisal composite, the reduction in strength between the first and seventh recycling process was 17%, compared to a reduction of 53% for the PP/glass fiber composite. Furthermore, the reduction in Young's modulus was 10% for the PP/sisal composite, compared to a reduction of 40% for the PP/glass fiber composite (Bourmaud & Baley, 2007). In addition to offering improved material recycling capabilities, NFRP's are also more suitable for energy recovery through combustion (Zah et al., 2007).

3. METHODOLOGY

In this chapter, the sustainability assessment method used in this study is explained, followed by a description of the methodological choices for this assessment.

3.1. Integrated sustainability assessment methods

Many research methods have been developed over the years to assess sustainability issues or performance of products. However, these methods have usually been limited to one dimension of sustainability. Common methods include Life Cycle Assessment (LCA), which can be used to study environmental impacts, and Life Cycle Costing (LCC), which can be used to assess costs related to the life cycle of a product. While respected for their individual purposes, these methods do not address the full scope of sustainability. However, in recent years, substantial work has been published on designing complete sustainability assessments, aimed at addressing all commonly recognized aspects of sustainability over the entire life cycle of products. Four methods are briefly discussed here; the PROSUITE project, the CALCAS project, the Roundtable on Sustainable Biomaterials (RSB) and Life Cycle Sustainability Assessment (LCSA).

The assessment method developed in the PROSUITE project recognizes five major impact categories: human health, social wellbeing, prosperity, natural environment and exhaustible resources. The method also proposes indicators for these categories and methods to integrate the results for the integrated assessment of new and existing technologies (Blok et al., 2013). The CALCAS project proposes a 'New-LCA' method; a modification of the original LCA method to also encompass economic and social aspects and include more mechanisms such as rebound, behavior and price effects (CALCAS, 2009). Finally, the RSB defines a list of principles and criteria covering the full scope of sustainability applying to biomaterials production. Biomaterials production following these principles and criteria can be regarded as sustainable and eligible for RSB certification (RSB, 2010).

This study uses the LCSA method, designed by the United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC). The main benefit of LCSA is that it combines three existing methods to address all three pillars of sustainability. In LCSA, LCA is used for the environmental assessment, LCC for the economic assessment and Social Life Cycle Assessment (S-LCA) is used to conduct the social sustainability assessment (UNEP/SETAC, 2011).

LCA is the preferred environmental assessment method for this study since it has been used in earlier assessments within this project and is standardized in ISO guidelines 14040 and 14044 (ISO, 2006a, 2006b). Furthermore, LCA has been often applied in literature and used for the generation of environmental data on a wide range of products and processes, available in LCA databases. This allows for the comparison of environmental impacts between materials such as glass fiber and Brazilian sisal fiber.

LCC has been adapted by UNEP and SETAC to be more compatible with LCA. This has led to the proposal of Environmental LCC (E-LCC), although in the context of LCSA it is still mostly referred to as LCC (Swarr et al., 2011). E-LCC is defined as "an assessment of all costs associated with the life cycle of a product that are directly covered by any one or more of the actors in the product life cycle (e.g., supplier, manufacturer, user or consumer, or End of Life actor) with complementary inclusion of externalities that are anticipated to be internalized in the decision-relevant future" (SETAC, 2011).

S-LCA has been proposed as a social sustainability variation of the LCA method, retaining its basic framework (UNEP/SETAC, 2009). Both S-LCA and LCSA are still surrounded by methodological uncertainties and case studies applying these methods are still relatively scarce. For S-LCA, problems exist in selecting and quantifying social impacts, a lack of readily available data sources, the need for appropriate impact assessment methods and the current disregard of causal pathways for social impacts (e.g. what causes the social impact and how is the cause related to the production system) (Benoît et al., 2010; UNEP/SETAC, 2009). For LCSA, methodological issues remain in combining and presenting the results of the three individual assessments (Finkbeiner et al., 2010).

3.2. Life Cycle Sustainability Assessment

In LCSA, the three methods, LCA, S-LCA and LCC, are all structured roughly according to the framework originally known from LCA. This framework recognizes four iterative phases as seen in Figure 8. The general purpose of these phases is described and standardized in ISO 14040 and 14044 (ISO, 2006a, 2006b). Specific aspects relating to LCSA are explained below.

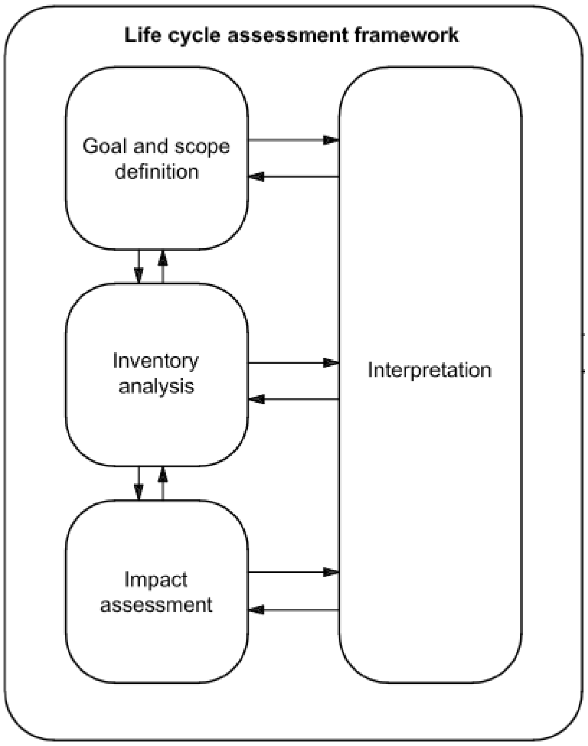

FIGURE 8: LIFE CYCLE ASSESSMENT FRAMEWORK (SOURCE: ISO, 2006A)

In the goal and scope definition phase of an LCSA, a functional unit for all three assessments is defined. Furthermore, the system boundaries chosen for the three assessments should be equivalent, not necessarily identical, whilst satisfying the objectives of the individual analyses. An essential part of this phase is to choose and motivate the social and environmental impacts that will be analyzed. Whereas LCA usually features only negative impacts on the environment, S-LCA will commonly feature also positive impacts on social conditions. In their S-LCA guideline, UNEP and SETAC propose a number of social impact subcategories and stakeholder categories, shown in Figure 22 in Appendix A. For the S-LCA, it is necessary to identify stakeholder groups related to the life cycle stages. Other assumptions or allocation methods are also listed in this phase.

In the inventory analysis, a social hotspot assessment is conducted to identify process steps or locations where significant social impacts are expected. This is followed by the actual data collection on the chosen indicators for the three assessments. In the impact assessment, the inventory data is related to the impact categories and the results of impact categories are calculated (characterization). In S-LCA, care should be taken that no location specific information is lost if aggregation is applied.

The interpretation phase consists of a critical evaluation of the study, followed by the identification and interpretation of the most significant environmental, social and economic issues. Possible trade-offs between these issues or benefits can be recognized through an integration of the results. For the S-LCA, it is important to report the involvement of stakeholders during the process (ISO, 2006a, 2006b; Rebitzer & Hunkeler, 2003; Swarr et al., 2011; UNEP/SETAC, 2011).

3.3. Goal

The goal of this LCSA is to provide quantitative results on the environmental, social and economic sustainability of the production of sisal fiber in Brazil. These results are used to: (1) identify the sustainability problems and strengths of the sisal fiber production system in Brazil, and (2) to formulate recommendations regarding the sourcing of sisal fiber from Brazil by car manufacturers.

The intended audiences are decision makers at Ford Research and Advanced Engineering, policy makers in Brazil and researchers interested in case studies using LCSA, S-LCA or regarding the specific sisal fiber production system. This thesis is publicly available in the Utrecht University thesis archive. Furthermore, the quantitative LCA results are made available to Ford in a format that allows implementation in their LCA database, enabling comparison between sisal fibers from Brazil and alternative materials. The thesis is not used as part of a public comparative assertion. Therefore, there are no official requirements for setting up a critical review of the study. However, chapter 6 on social impacts is reviewed by Ingeborg Peerboom, who is an expert on the social situation in the sisal producing region in Bahia.

In this thesis, the environmental LCA results are compared with two other production systems on non-renewable energy use and contribution to climate change. The first comparison is with the sisal fiber production system in Tanzania. The purpose of this comparison is to analyze how the different cultivation and production methods influence the environmental impacts. The second comparison is with the production of glass fiber for use in FRP's. The purpose of this comparison is to identify potential environmental gains related to the replacement of glass fiber with sisal fiber in FRP car parts.

3.4. Scope

This section addresses the methodological choices in the LCSA.

3.4.1. Functional unit and system boundaries

The function of the studied production system is to produce sisal fiber that is suited for processing into FRP car parts such as door panels, glove boxes, etc. In initial tests, type 1 graded sisal has been used to produce FRP car parts. For this reason, the functional unit for this study is one metric ton of baled, type 1 graded sisal fiber. However, according to experts, type 2 and 3 graded sisal fiber can also be used for FRP's (Andrade, 2014a). To investigate the impacts of the choice of functional unit, the difference in LCA and LCC results between type 1 and type 2 and 3 are calculated and provided in Results sections 4.2.1 and 5.2 respectively.

Figure 9 shows a flow diagram of the production system. The typical Brazilian production system is considered as it was explained in paragraph 2.3.2. Included are: the preparation of the sisal field, cultivation of the sisal plants, decortication of sisal leaves, local transportation of raw sisal fiber, processing of raw sisal fiber to make baled sisal fiber and transportation of the baled sisal fiber to the port. This scope is called cradle-to-port. For this assessment, it is assumed that the life cycle of the sisal plants is 10 years, of which 8 years are productive. Each of these 8 years, 1 metric ton of dry sisal fiber is harvested per hectare (Embrapa, 2014). Note that, on average, for every ton of high quality sisal fiber, 2.3 tons of lower quality fiber are produced. This study does not consider the production of the NFRP or other later life cycle stages. The reason for this is that the car manufacturer has ample insight into the part of the product cycle from the port onwards, but limited insight into the sisal cultivation and fiber production processes taking place in the northeast of Brazil. The results of this study can be combined with similar studies into later life cycle stages of sisal FRP car parts to get a complete picture of the sustainability impacts related to this product.

The scope of this study is similar to the scope of the Tanzania sisal study. The Tanzania sisal study also used a cradle-to-port system boundary. Furthermore, although fiber grades for Tanzania use a different classification, in both cases high quality sisal fiber is considered to keep the functional unit consistent between the two studies. Since the LCA data for glass fiber from the Ecoinvent database does not include transportation to port and is based on the average results for several European production facilities, the transportation to the port is not considered in the comparison between Brazilian sisal fiber and glass fiber. The system boundaries include all processes up to the exit gate of the fiber production facility. Furthermore, in this study, the impacts related to the production of one ton sisal fiber are compared to the impacts of the production of one ton glass fiber. However, depending on the specific purpose (see paragraph 2.6.2), one metric ton of sisal fiber may not be functionally equivalent with one metric ton of glass fiber. If necessary, the LCA database allows for comparisons on alternative weight ratios to be made.

3.4.2. Temporal and geographical scope

For this study, the aim is to collect data that is representative for the most common cultivation and production processes in the sisal sector in Brazil. Since sisal production and prices fluctuate over time, possibly leading to different results for the LCA, LCC or S-LCA, a base year is chosen for the data collection. Wherever possible, time dependent data is gathered from 2011. The situation in 2011 is considered more representative for the average situation than the most recent years (2012-2013), when an extraordinary drought plagued the sisal production in Brazil, affecting yields, labor and prices (see paragraph 2.3.5).

The geographical coverage of this study is the state of Bahia, or, when data availability permits it, the sisal producing municipalities in the state of Bahia. Approximately 95% of sisal production in Brazil takes place in the province of Bahia and the production system is assumed to be representative for the whole of Brazil.

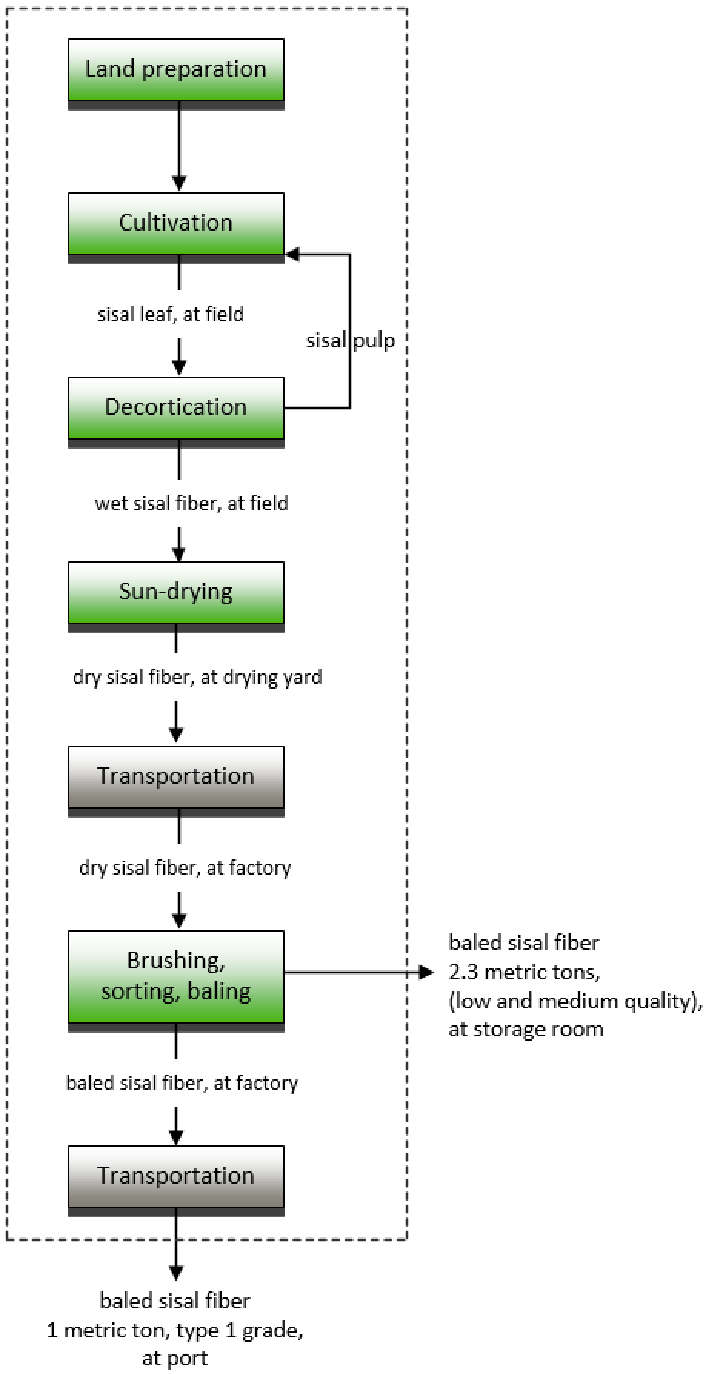

FIGURE 9: SISAL FIBER PRODUCTION SYSTEM

3.4.3. Stakeholder overview

For the S-LCA, the most important stakeholders for the Brazilian sisal fiber production system are identified. These stakeholders are considered in the choice of social impact categories since they can cause and experience social impacts throughout the sisal fiber production system. Additionally, these stakeholders are relevant for data collection purposes. Here, two types of stakeholders are distinguished following the classification of Mayers (2005); (1) primary stakeholders who can directly affect or are directly affected by the production system, and (2) secondary stakeholders who can indirectly affect or are indirectly affected by the production system.

3.4.3.1. Primary stakeholders

During the land preparation and cultivation stage, the farmer and his family, who own or rent the land on which the sisal is cultivated, are the main stakeholders. The farmer's family members often help in the sisal fields to contribute to the family income (Peerboom, 2012). Farmers who own a large amount of land may also employ other laborers to work on the land (Vale et al., 1998).

In the decortication stage, the machine owner and his crew are the most important stakeholders. Apart from hired workers, the decortication crew may also include family members of the machine owner. In the processing stage, the stakeholder involvement can be more complicated. The middleman buys the raw fiber from the machine owner, who pays a share of this money to the farmer. The middleman then sells the fiber to the *batedeira*. The owner of the *batedeira* employs a team of laborers to perform the brushing, sorting and baling of sisal fiber (Peerboom, 2012).

3.4.3.2. Secondary stakeholders

Some stakeholder groups do not directly affect or are directly affected by the production system. First of all, local communities are intrinsically connected to the social situation of the famers and workers in their area and many types of interactions are possible between the two. At a larger scale, Brazilian society as a whole is impacted by the sisal sector. Then there are the actors further downstream in the value chain. These may be exporters or producers of cordage, carpets, paper, fiber reinforced composites etc. These stakeholders can influence the system through their choice of supplier.

Furthermore, there is the Brazilian government, who is responsible for making and enforcing legislation concerning labor conditions, minimum wage, trade etc. The Brazilian government has several programs addressing issues of social sustainability relevant to the sisal sector and region. Also, the raw materials agency CONAB buys raw sisal fiber for an annually set minimum price that is often higher than the price offered by local middlemen (CONAB, 2014).

Finally, there are scientific institutes, unions and local and non-governmental organizations (NGO's) that are influencing the sisal sector through their activities. Scientific institutes such as universities and Embrapa are active in research into improved agricultural practices, equipment and new applications of sisal by-products. The rural labor unions (STRAFs) look out for the rights of the rural workers. Local organizations are for example FATRES and APEAB. FATRES is an umbrella organization for the rural labor unions, aiming to strengthen the position of these unions and contribute to solving the problems that farmers and agricultural laborers face in the northeast of Brazil (Magalhães, 2008; Peerboom, 2012). The APAEB is a local collective in which sisal farmers and laborers in the sisal region are organized to improve their bargaining position, provide training and buy equipment collectively (Mendonça & Alves, 2012). Furthermore, some of the most important NGO's for the sisal sector are MOC, UNICEF and DISOP, who are involved in investigating and solving social, socio-economic and environmental issues in the area. MOC has been active in community mobilization, education, housing, food and water safety and the eradication of child labor (Magalhães, 2008). DISOP has been involved in providing training and credit for farmers in the northeast of Brazil, aimed at increasing production, profitability and independence (DISOP, 2014). Finally, UNICEF has been involved in funding and assisting the national program to eradicate child labor (Magalhães, 2008; Mendonça & Alves, 2012).

3.4.4. Social hotspot assessment

In this section, significant and relevant types of social impacts related to the Brazilian sisal sector are identified. For the social assessment, addressing both negative and positive aspects is important in order to identify further improvement possibilities and advise on the use of sisal fiber from Brazil. Based on the findings in this hotspot assessment, specific impacts from the list by UNEP/SETAC (2013) are selected in paragraph 3.4.5.3.

To identify social impacts concerning the workers in the sisal sector (primary stakeholders), a selection of reports and data from organizations such as the International Trade Union Confederation (ITUC), the International Labour Organization (ILO) and Understanding Children Work (UCW) are consulted (ILO, 2008; ITUC, 2009, 2014; UCW, 2004, 2010). These organizations are concerned with labor issues around the world. Furthermore, Peerboom (2012) writes extensively on the social situation in the sisal producing region in Bahia. These sources mention several social impacts that could apply to workers in the Brazilian sisal sector.

The first impact identified is concerning the freedom to unionize and bargain collectively. According to ITUC, there are large barriers for workers to form or join trade unions and exercise the right to collective bargaining in Brazil (ITUC, 2009). Furthermore, there have been large struggles in the past of workers in the sisal fields and brushing facilities who could not get access to social security benefits such as a retirement, minimum wage, disability or unemployment benefits. This is related to the fact that many workers in the sisal sector did not have an official contract or signed labor card (Peerboom, 2012).

Child labor remains a problem in Brazil and is especially widespread in rural areas, where children are mostly active in the agricultural sector (Magalhães, 2008; UCW, 2010). Sisal in Brazil is also directly associated with child labor (US Department of Labor, 2012; Yap et al., 2002). At the same time, primary school attendance is very high in Brazil and most working children attend school regularly. This could mitigate some of the negative effects of child labor and should therefore be reflected in the S-LCA (ITUC, 2009; UCW, 2004, 2010). Forced labor in the form of debt bondage is also a persisting problem in Brazil, especially in agriculture (ILO, 2008; ITUC, 2009). However, the US Department of Labor (2012) identified the Brazilian sisal sector as not being specifically prone to forced labor.

Many sources mention the unsafe working conditions for workers in the Brazilian sisal fiber production system. Accidents with the decorticator, sharp leaf tips, snake bites and sunstroke represent considerable hazards (Magalhães, 2008; Peerboom, 2012). Furthermore, excessive working hours are not uncommon in the sisal sector and can exacerbate the risk of accidents. Long working hours are usually made voluntarily to compensate for the low wages per unit of production (Peerboom, 2012). The wages for workers in the sisal fiber production system are considered very low and the earnings made throughout the production system are not equally distributed (Peerboom, 2012). Although the price for sisal fiber has increased in recent years, little of this increase has benefitted the sisal farmers or field workers (WGC, 2012). Additionally, discrimination of women and minorities is widespread in Brazil (ITUC, 2009). Women in the sisal sector generally get paid significantly lower wages than men (Peerboom, 2012).

In addition to impacts on the primary stakeholders, the Brazilian sisal sector also affects and is affected by secondary stakeholders. Sisal cultivation and fiber production take place in a low-income region, where many workers lack higher education and work at several jobs to earn a living. The sisal sector provides many jobs, both full time and temporary and is therefore considered a significant social and economic development factor in the region (Peerboom, 2012). Furthermore, in section 3.4.3.2 some of many active secondary stakeholders were discussed. These organizations concentrate specifically on improving the social and socio-economic conditions in the sisal sector and the sisal producing region through organizing and performing programs and projects.

3.4.5. Impact categories

The three analyses within the LCSA each consider several sustainability aspects related to the production of sisal fiber in Brazil. The impacts considered in this study are shown in Figure 10 and explained in the following paragraphs.

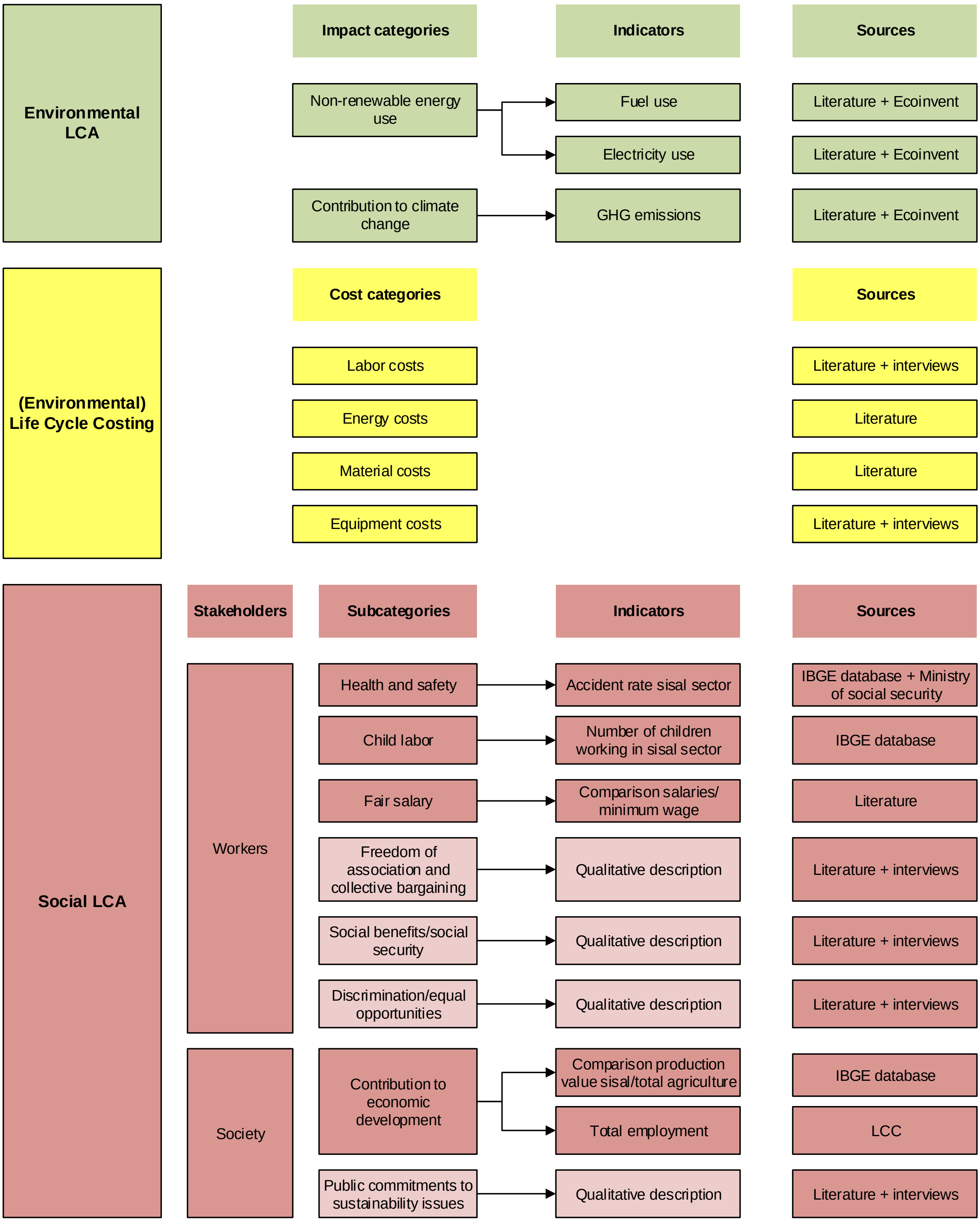

FIGURE 10: SELECTED LCSA IMPACT CATEGORIES

3.4.5.1. LCA

Two mid-point impact categories are considered for the environmental LCA: (1) non-renewable energy use (NREU), measured in mega joule (MJ) per ton fiber, and (2) contribution to climate change, measured in kilogram carbon dioxide (CO_2) equivalent emissions per ton fiber. Although NREU is not technically an environmental impact, the term impact is used in this thesis.

The reason for choosing these impact categories is that both non-renewable energy use and contribution to climate change are relatively easy to calculate and are straightforward to interpret. Furthermore, climate change is regarded as one of the main environmental issues of this time (UNEP, 2010). Finally, non-renewable energy use is considered a good proxy indicator for a range of environmental impacts such as resource depletion, acidification, eutrophication, ozone depletion and human toxicity (Huijbregts et al., 2006).

Similar to other biological materials, sisal fibers contain carbon that originates from atmospheric CO_2. This CO_2 can no longer act as GHG during the further life cycle of the fiber, yielding a negative contribution to climate change. Although this carbon is released in the form of CO_2 when the material is incinerated at the end of its lifetime, this part of the life cycle falls outside the considered system boundaries. There are several accounting methods that consider this CO_2 in different ways and each method has its strengths and weaknesses (Pawelzik et al., 2013). To keep the LCA results in this paper straightforward, GHG emissions are given both with and without this biogenic carbon sequestration.

Although indirect land use change is often included in the calculation of GHG emissions of non-food crops, it is not considered in this assessment. The reason for this is that the acreage for sisal cultivation in Brazil has decreased in recent decades, meaning that no agricultural land is being transformed into sisal fields. Furthermore, sisal is mainly cultivated on poor soils where there are few alternative crops that can be grown (Cunha et al., 2011). Some of the processes in the production system use manual labor. The environmental impacts of manual labor are considered negligible for this assessment.

The life cycle impact assessment is done using two standard characterization methods:

- Cumulative Energy Demand (1.08): This method includes the characterization factors for renewable and non-renewable energy resources.
- IPCC 2007 (GWP 100a): This method includes the IPCC characterization factors for the direct (except CH_4) global warming potential of air emissions over 100 years (PRé Consultants, 2008).

3.4.5.2. LCC

The LCC analysis is performed from the perspective of the car company. Only the costs directly or indirectly paid by the car company for processes within the system boundaries are considered. Since the external costs of environmental impacts or accidents are not expected to be internalized in the sisal price and are currently not paid by actors within the sisal sector, these were not included. The cost categories considered in the LCC are: labor costs, energy costs, material costs and equipment costs and maintenance. No discount rate is used. Furthermore, taxes are not specifically considered.

Although the costs considered are not directly paid by the car company, a cost breakdown of the product can provide valuable insight on what factors have the largest effect on the final price. To relate the costs to the functional unit, economic allocation is applied to produce the final LCC results.

3.4.5.3. S-LCA

The impact categories for the S-LCA are selected from the publication on S-LCA impact categories by UNEP and SETAC (2013), based on the findings of the social hotspot assessment (section 3.4.4). An overview of these impact categories is given in Figure 22 in Appendix A. All of the impacts identified in the hotspot assessment apply to the 'worker' or 'society' stakeholder categories, where society includes the government and non-governmental organizations. Eight social impact subcategories for workers and society are selected for the present study (see Figure 10). These subcategories and their operationalization are discussed below. The calculation methods for the indicators are explained in the respective sections in chapter 6.

The remaining stakeholder categories are not considered in this study. The stakeholder category 'consumer' is not involved within the system boundaries of this study. Concerning value chain actors and local communities, no distinct and significant impacts were identified in the hotspot assessment. Furthermore, two S-LCA subcategories for the 'worker' stakeholder category are not considered here: 'working hours' and 'forced labor'. Since the long working hours are generally made voluntarily to compensate for the low wages, including the 'working hours' subcategory would result in overlap with the 'fair salary' subcategory.

Given the novelty of the S-LCA methodology, there is much theoretical and practical work to be done on identifying reliable indicators and clear impact pathways. Only the selected subcategories for which appropriate quantitative data is available are assessed quantitatively. However, to avoid leaving the picture incomplete, the remaining subcategories are addressed in a descriptive and qualitative manner.

Health and safety

This subcategory addresses occupational health and safe working conditions. This study focuses on occupational accidents in the sisal fiber production system. Two quantitative indicators are used for this subcategory:

- The annual number of severe occupational accidents in the sisal fiber production system.
- A side by side comparison of the accident rate in the sisal sector and two overarching economic sectors for Bahia and Brazil.

Child labor

This subcategory addresses the incidence and severity of child labor. In this study, two quantitative indicators are used to assess the incidence and severity of child labor in the sisal fiber production system:

- The number of children under 18 working in the sisal cultivation and decortication in Bahia.
- The percentage of these children that do not attend school.

Fair salary

This subcategory addresses whether workers receive a salary that is reasonable in relation to the wage necessary to provide for basic needs. In this study, the actual wages of workers in the sisal fiber production system are assessed through a quantitative comparison with a set of "fair" wage levels in Brazil. The indicator for this subcategory is the number of full time equivalent (fte) jobs in the sisal fiber production system with earnings at a certain wage level, compared to the "fair" wage levels.

Contribution to economic development

This subcategory addresses the contributions of a company or sector to economic development such as: revenue creation, job creation, providing education or training and conducting research of societal value (UNEP/SETAC, 2013). In this study, the socio-economic significance of the sisal fiber production system in Brazil is quantified through two (sets of) indicators:

- The number of full time equivalent jobs (fte) offered by sisal fiber production (excluding further processing).
- The economic significance (i.e. production value) of raw sisal fiber production in relation to the agricultural and total production value in Bahia and the sisal producing municipalities.

Freedom of association and collective bargaining

This subcategory addresses the workers' freedom to form and join associations of their choosing, their rights to organize in unions, to engage in collective bargaining and to strike (UNEP/SETAC, 2013). In this study, the legal framework in Brazil concerning freedom of association and collective bargaining is qualitatively discussed, followed by the practice in Brazil and in the sisal sector.

Social benefits/social security

This subcategory addresses the right of workers to retirement, disability, dependents, and survivors' social security benefits (UNEP/SETAC, 2013). In this study, the Brazilian social security scheme and the practice in rural Bahia are qualitatively discussed.

Equal opportunities/discrimination

This subcategory addresses the presence of discrimination in the opportunities in education, employment, advancement, benefits and compensation for the workers (UNEP/SETAC, 2013). For this study, wage discrimination between men and women in Brazil in general and the sisal sector in particular, is qualitatively discussed.

Public commitments to sustainability issues

This subcategory addresses the public commitments made by organizations to the sustainable development of society (UNEP/SETAC, 2013). In this study, several nationwide and regional programs aimed at the relief of social, environmental or economic problems related to the sisal sector are qualitatively discussed.

3.4.6. Allocation method

The sisal fiber production process yields fibers of a range of quality levels. For this study, the focus lies on the highest quality for FRP car parts. Since higher quality sisal fibers represent a higher economic value, economic allocation is used to allocate the sustainability impacts between the main product of interest and the other commercially relevant by-products.

Typically, about 30% of the produced fibers are of high quality, 50% of medium quality and 20% of low quality. The price levels in 2011 for brushed fiber were R$ 1640 per ton of high quality fibers, R$ 1370 per ton of medium quality fibers and 1265 per ton of low quality fibers (Silva, 2014). Table 4 shows the economic allocation percentage per type of fiber quality.

TABLE 4: ALLOCATION OF IMPACTS

	Production (mass)	Price (R$/ton)	Economic allocation
High quality fiber (type 1 & superior)	30%	1640	34.4%
Medium quality fiber (type 2 and 3)	50%	1370	47.9%
Low quality fiber (*refugo*)	20%	1265	17.7%

In the interpretation sections of the LCA and LCC (sections 4.2.1 and 5.2), the impact of using economic allocation is investigated by comparing the results with those calculated using mass allocation. Furthermore, since using medium quality fiber may also be possible for FRP's, these results are also given.

3.4.7. Data collection

The main data collection is done through a search in literature, reports from relevant organizations and statistical databases. The LCA background data is from the Ecoinvent v.2 database. To complement these data collection methods and fill specific data gaps, a questionnaire is sent via Embrapa, a Brazilian scientific institute aimed at agricultural research, to experts and relevant organizations related to the Brazilian sisal sector. The questionnaire can be found in Appendix B.

3.4.8. Data processing

Data processing and analysis is done using several software packages. Microsoft Excel is used to maintain data sheets, for doing basic calculations and creating visualizations. SimaPro 7 is used to model the sisal fiber production system and calculate the environmental impacts. SimaPro is also used for the characterization of environmental impacts into midpoint indicators.

4. LCA

This chapter addresses the inventory analysis, impact assessment and interpretation of the (environmental) LCA.

4.1. Inventory analysis

In paragraph 2.3.2, the sisal fiber production system was introduced and described in general terms. Specific environmental aspects of the production system are now elaborated upon to generate the LCA inventory. An overview of the processes and inventory data for SimaPro can be found in Appendix C. The flow diagram in Figure 11 shows the inventory of material and energy flows that apply to the Brazilian sisal fiber production system. Note that renewable energy and material flows are not shown. Furthermore, in addition to 1 ton of high quality fiber, 2.3 tons of medium and lower quality fibers are produced.

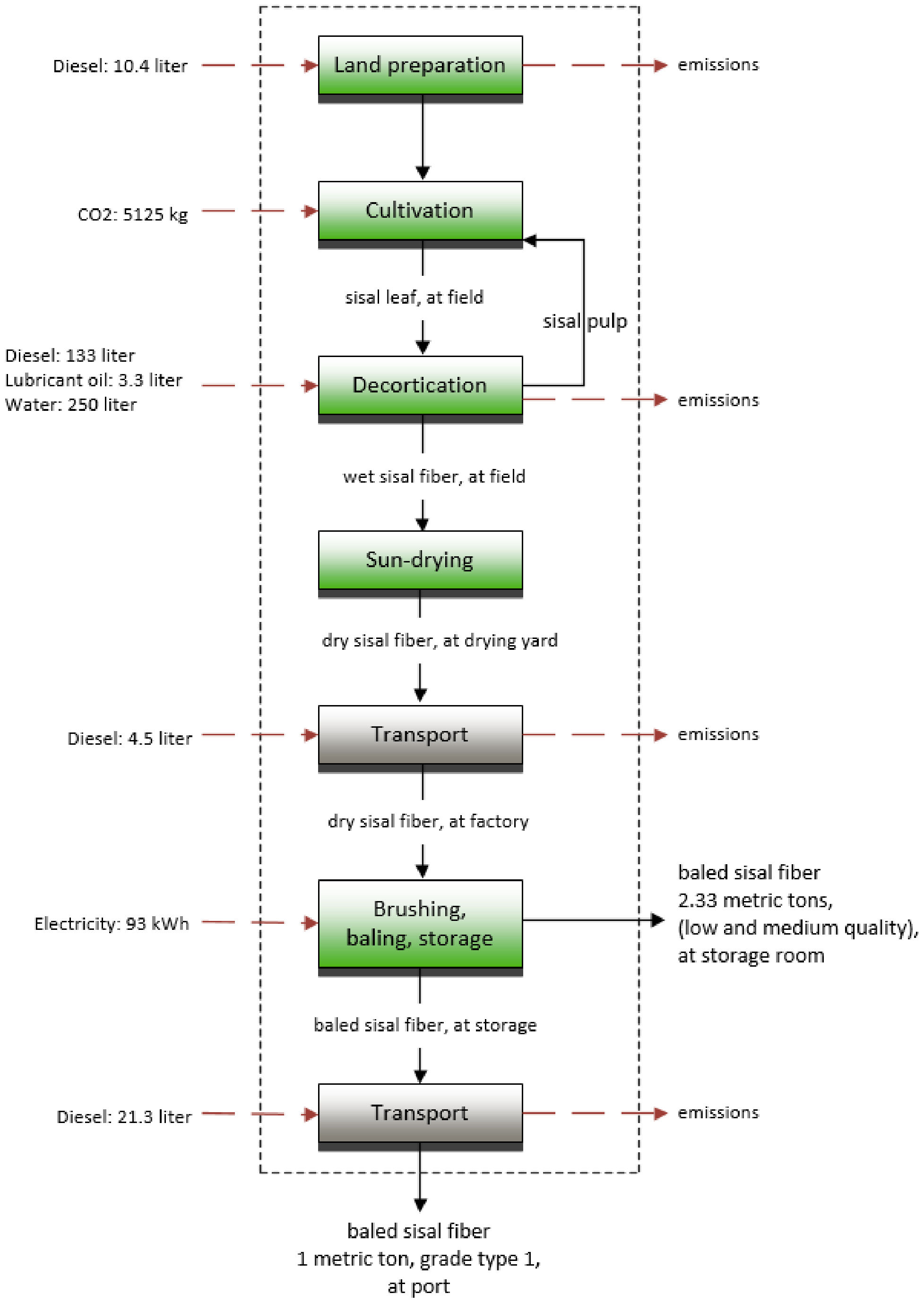

FIGURE 11: LCA FLOW DIAGRAM SISAL FIBER PRODUCTION SYSTEM

4.1.1. LAND PREPARATION

Land preparation, consisting of land clearing, plowing and harrowing, can be performed using manual labor, animal traction or mechanized equipment. Only mechanized equipment causes environmental impacts considered in this assessment. The share of farms using mechanized equipment in 2011 is estimated at 50% by Silva (2014). The diesel use per ton fiber is estimated using land preparation processes in the Ecoinvent database. The land is prepared only once in the plants 10 year life cycle. A full life cycle yields ca. 8 t of sisal fiber per ha. If these machines are used for 50% of the sisal fields, an average of 3.1 liters of diesel per ton of fiber is used.

4.1.2. CULTIVATION

Sisal cultivation uses mainly manual labor. Sisal residues are distributed on the field by hand for the restoration of nutrients to the soil and to limit evapotranspiration (Sindifibras, 2012). No commercial fertilizers, pesticides or irrigation are used (FAO, 2012b; Peerboom, 2012; Silva et al., 2008). During their life, the sisal plants fix carbon taken up from atmospheric CO_2. The carbon content of sisal fiber is ca. 42%, resulting in 1539 kilograms of CO_2 per ton of fiber that are taken from the air during plant growth (Salazar & Leão, 2006).

4.1.3. DECORTICATION

Cutting the sisal leaves is done by hand. The leaves are transported by donkey to the decorticator. Generally, a decortication machine called *paraibana* is used. It runs on a 7-12 horsepower diesel engine and uses 40 liters of diesel and 1 liter of lubricating oil per ton of dry fiber produced (Embrapa, 2014). After decortication, fiber washing is applied at ca. 15% of the farms. Approximately 500 liters of water are used per ton fiber (Silva, 2014).

4.1.4. TRANSPORT TO *BATEDEIRA*

Transporting the raw fiber from the farm to the brushing and baling facility (*batedeira*) is done by a small truck or trailer (Peerboom, 2012). To estimate the average distance from the farms to the closest *batedeira*, the following calculation is done. The total area of the sisal producing municipalities is 68,047 km² (IBGE, 2014a). There are 60 *batedeira's* in Bahia, which means that each, on average, needs to service an area of 1,134 km² (Andrade et al., 2009). If these areas are imagined to be a circle and farms and *batedeira's* are evenly distributed over this area, every *batedeira* needs to service a circle with a 19 km radius (R). The average distance of every point within the circle to the center of the circle is given by 2R/3, resulting in 13 km on average from the farm to the *batedeira*. Since the truck will need to drive to the farm first, a round trip of 26 km is assumed. The diesel use is estimated using a transport process in the Ecoinvent database, resulting in 1.33 liters per ton of fiber.

4.1.5. BRUSHING AND BALING

In the *batedeira*, the sisal fiber is brushed, sorted and baled. The brushing machine uses approximately 20 kilowatt-hours (kWh) of electricity per ton of dry fiber while the baling press requires ca. 8 kWh per ton (Silva, 2014). It is assumed that grid electricity is used.

4.1.6. TRANSPORT TO PORT

For this assessment, it is assumed the baled sisal fiber is transported by truck from the *batedeira* to the sea port of Salvador de Bahia. To estimate the average distance, the center of gravity of the sisal producing areas is determined using a map of the sisal fiber production per municipality in Bahia (Figure 23 in Appendix D). From the map, it is estimated that the center of gravity lies around the municipality of Ponto Novo (black dot). The average distance by road is calculated using Google Maps. From Ponto Novo to Salvador de Bahia (red dot) is 340 km by road, a 5 hour drive (Google, 2014).

To consider the specific case of sisal FRP production, LCA results are also calculated for two alternative scenarios where the baled sisal fiber is transported from the *batedeira* to a molding factory near São Paulo. In the first scenario, the fibers are transported by truck. In the second scenario, the fibers are first transported by truck to the port of Salvador, then transported by ship to the port of Santos and finally to the molding factory by truck. From Ponto Novo to the molding factory is ca. 2,000 km by road. From Salvador to Santos is ca. 2,000 km on sea and from Santos to the molding factory is ca. 60 km by road (Google, 2014; Ports.com, 2014). It is assumed that the trucks and ships will carry a load of economic value if they return, so only a single trip is considered.

4.2. Impact assessment and interpretation

The sisal fiber production system is modeled in SimaPro 7 to calculate the environmental impacts and use the built-in characterization methods to generate midpoint results. An overview of the process inventories in SimaPro can be found in Appendix C. All results in this section are for 1 ton of type 1 sisal fiber.

4.2.1. CHARACTERIZATION

Table 5 lists the midpoint LCA results generated by SimaPro, subdivided by process. As explained in section 3.4.5.1, carbon sequestration is also reported. Within the chosen system boundaries, CO_2 is removed from the atmosphere during plant growth (see paragraph 4.1.2). 1765 kg of CO_2 sequestration can be allocated to the production of one ton of type 1 sisal fiber. Figure 12 shows the contribution to climate change of the production of sisal fiber in Brazil and the CO_2 removed from the atmosphere during sisal cultivation.

TABLE 5: CHARACTERIZED LCA RESULTS FOR TYPE 1 SISAL FIBER FROM BRAZIL

Process	**Non-renewable energy use (MJ/ton)**		**GHG emissions (kg CO_2-eq./ton)**	
Land preparation	229.7	5.5%	14.8	5.5%
Cultivation	0.0	0.0%	0.0	0.0%
Decortication	2282.7	54.4%	151.3	56.0%
Transportation to *batedeira*	146.1	3.5%	9.2	3.4%
Brushing & baling	49.0	1.2%	7.4	2.7%
Transportation to port	1490.1	35.5%	87.3	32.3%
Total	4197.6		270.1	

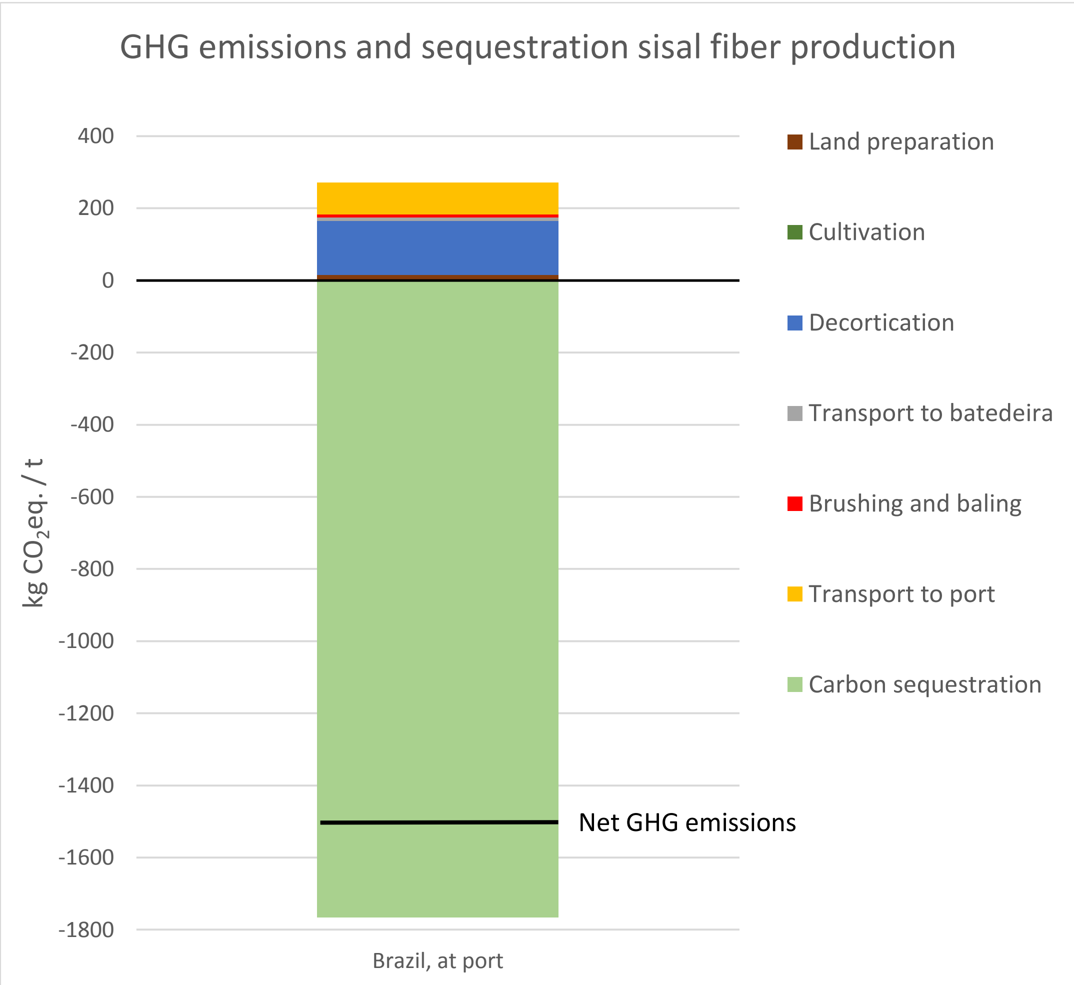

FIGURE 12: GHG EMISSIONS AND SEQUESTRATION OF TYPE 1 SISAL FIBER PRODUCTION IN BRAZIL

Figure 13 and Figure 14 give the NREU and GHG emissions of sisal fiber production in Brazil including the scenario in which the fiber is transported to the molding factory by truck, and the scenario in which the fiber is transported to the molding factory by truck and ship.

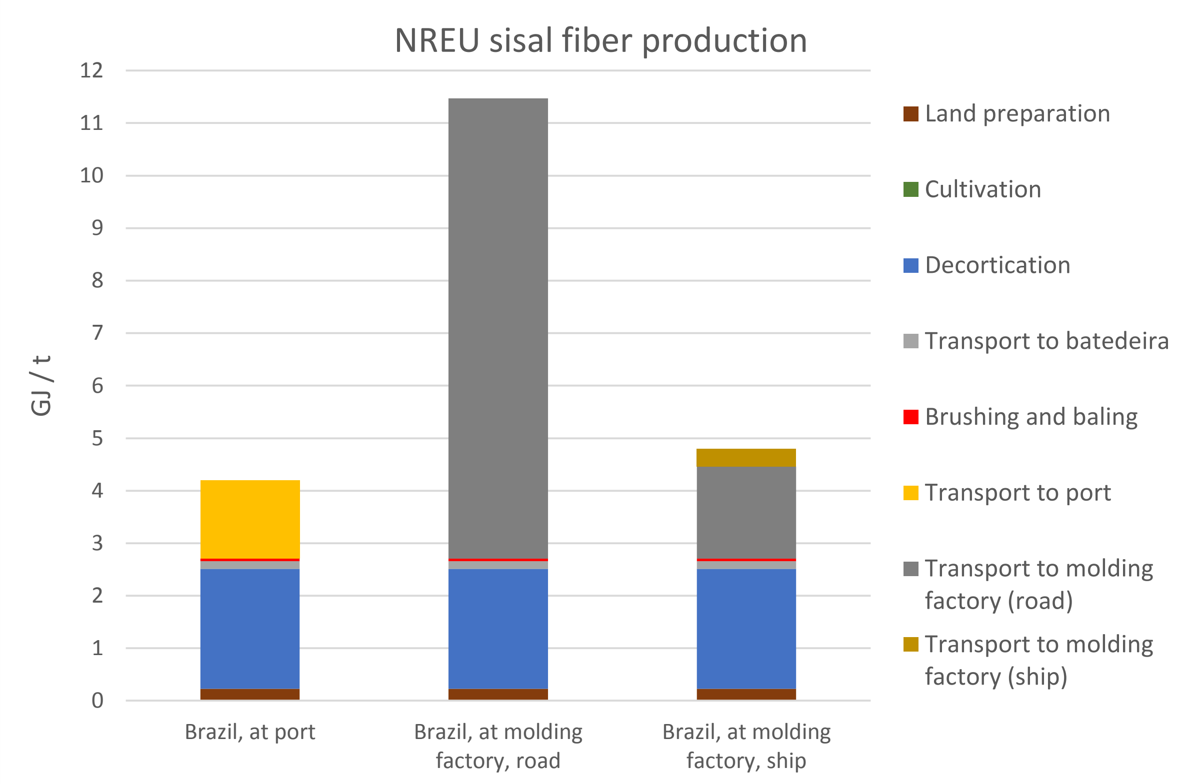

FIGURE 13: NREU TYPE 1 SISAL FIBER PRODUCTION IN BRAZIL FOR DIFFERENT TRANSPORT MODES AND DESTINATIONS

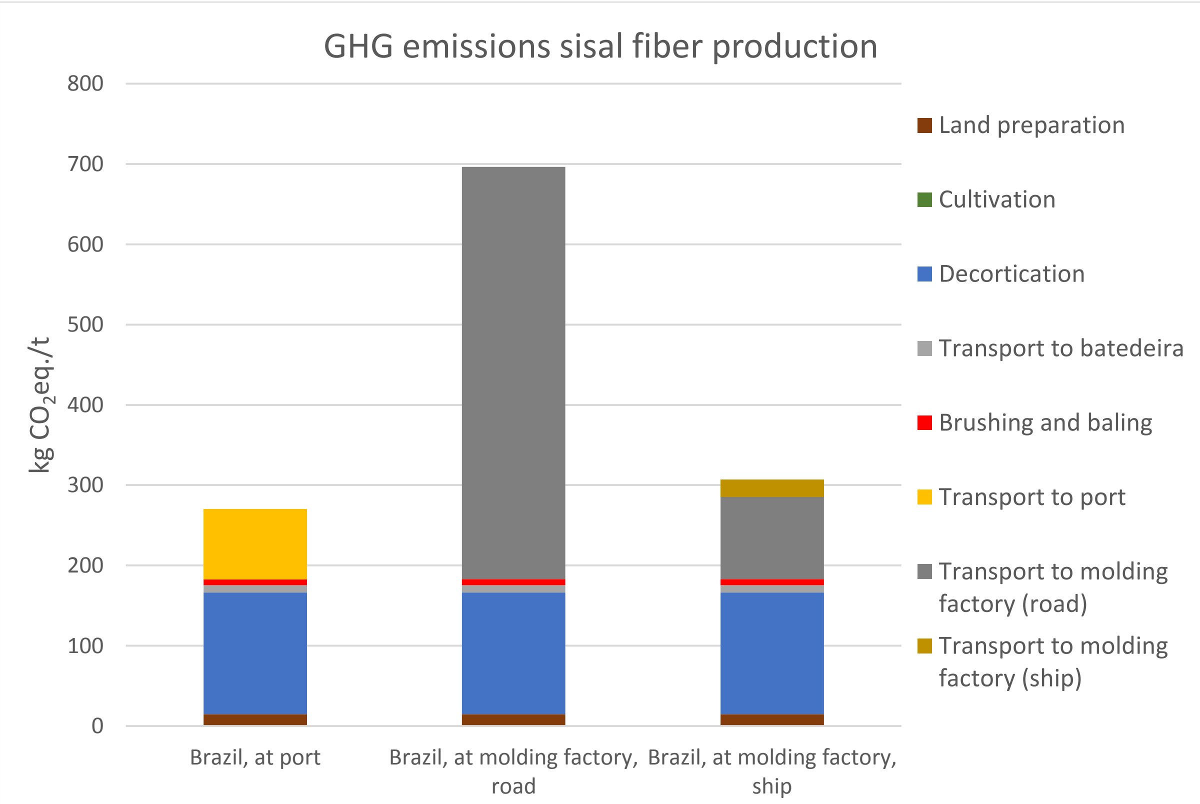

FIGURE 14: GHG EMISSIONS TYPE 1 SISAL FIBER PRODUCTION IN BRAZIL FOR DIFFERENT TRANSPORT MODES AND DESTINATIONS

The production of a ton of type 1 sisal fiber in Brazil requires ca. 4.2 Gigajoule (GJ) non-renewable energy. Furthermore, 270 kg of CO_2 equivalent GHG emissions are released. When considering carbon sequestration, the net emissions per ton of type 1 sisal fiber are -1495 kg CO_2 eq. In terms of the contribution per process, the results for non-renewable energy use closely resemble the results for contribution to climate change.

Land preparation has a small influence (5.5%) since it happens only once in 10 years and is mechanized only on ca. 50% of the farms. There are no GHG emissions or NREU identified during the sisal cultivation phase. The decortication phase causes the majority of the environmental impacts (ca. 55%), caused by the diesel use of the decorticator. Local transport (3.5%) and brushing and baling (1.2 - 2.7%) are found to have small contributions to GHG emissions and NREU. Finally, transportation to the molding factory, has the second largest environmental impact (ca. 34%). This can be explained by the large average transport distance of 340 km by truck.

There is discrepancy in the contribution of brushing and baling to GHG emissions (2.7%) and NREU (1.2%) not seen for other processes. The brushing and baling machines are both powered by grid electricity. In Brazil, over 80% of electricity was produced using hydro power plants in 2011 (IEA, 2014). Although hydro power is considered renewable, the construction of dams often leads to deforestation. Also, anaerobic digestion of plant material submerged by the constructed water reservoir of the dam causes methane emissions (Bauer et al., 2007). Since methane has a very high global warming potential, significant GHG emissions are attributed to hydro power production (IPCC, 2007). This results in limited use of non-renewable energy per kWh electricity, but relatively high GHG emissions.

Further transportation of the sisal fiber to the molding factory can significantly influence the LCA results. If transportation occurs fully by truck, the NREU and GHG emissions increase almost threefold and this transport becomes the most important contributor. The impact increases only ca. 14% if the transportation to the molding factory occurs partly by ship. This can be explained by the fact that transportation by container ship is much more energy efficient than transportation by truck.

If it is assumed that medium quality fibers are preferably used, the environmental impacts allocated to one ton of sisal fiber are ca. 11% lower. Furthermore, if mass allocation is applied rather than economic allocation, the environmental impacts allocated to one ton of sisal fiber are ca. 8% lower.

4.2.2. Comparison sisal from Brazil and Tanzania

The sisal fiber production systems in Brazil and Tanzania have several important differences as described in sections 2.3 and 2.4. The LCA results for sisal fiber from Tanzania are taken from an earlier study within the URP project. Both systems include transportation of the baled sisal fiber to the most important sea port in the area. Figure 15 and Figure 16 show the results for non-renewable energy use and contribution to climate change for the production of high quality sisal fiber by both production systems.

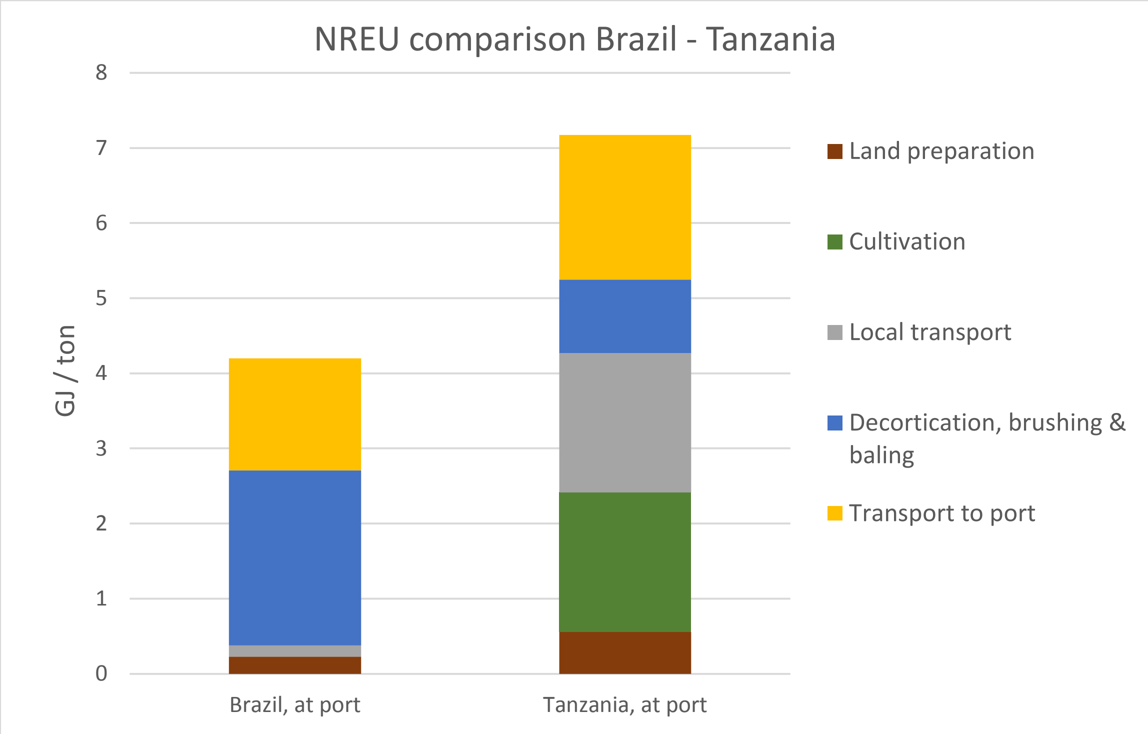

FIGURE 15: NON-RENEWABLE ENERGY USE OF HIGH QUALITY SISAL FIBER PRODUCTION IN BRAZIL AND TANZANIA

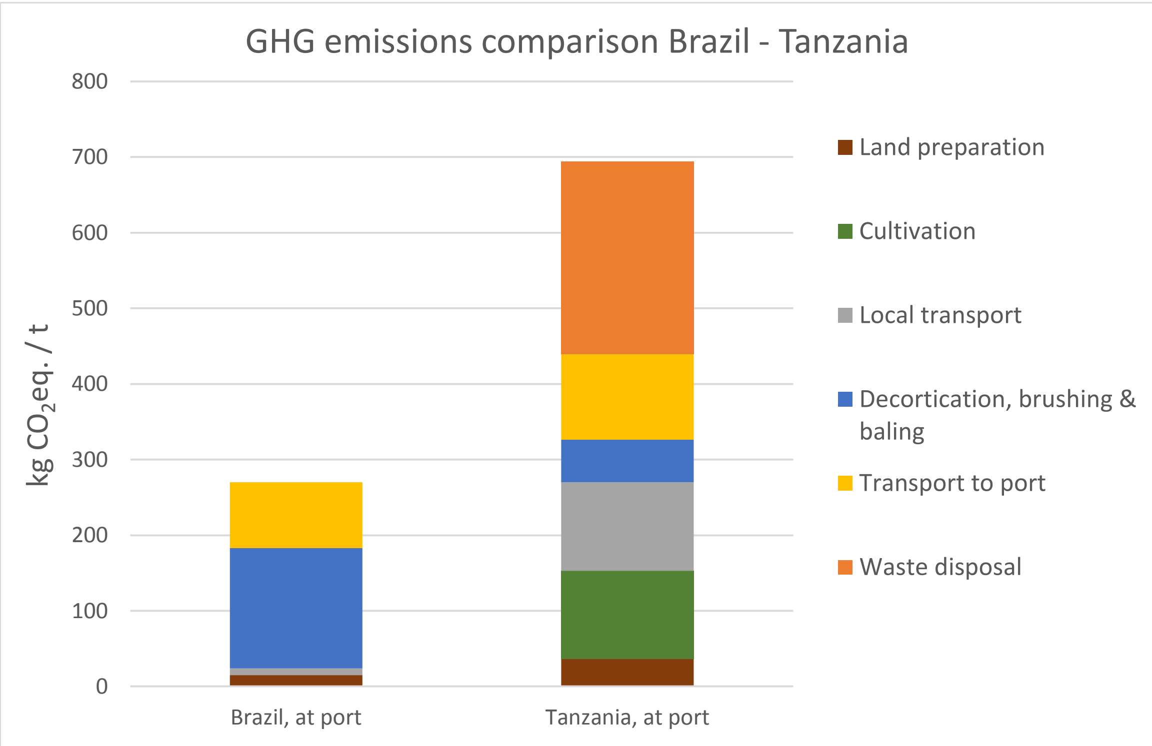

FIGURE 16: CONTRIBUTION TO CLIMATE CHANGE OF HIGH QUALITY SISAL FIBER PRODUCTION IN BRAZIL AND TANZANIA

The Brazilian and Tanzanian sisal fiber production systems yield considerably different results for NREU and contribution to climate change. The NREU of sisal fiber production in Tanzania is 71% higher and GHG emissions are 157% higher. Due to the use of a nursery field and more common use of mechanized land preparation practices in Tanzania, land preparation in Tanzania has a higher impact than in Brazil. Furthermore, during the cultivation of sisal plants, the use and transportation of fertilizers cause significant environmental impacts in Tanzania, while in Brazil, where no commercial fertilizers are used, no impacts are associated with the cultivation stage. Although decortication, brushing and baling are not separated for Tanzania, decortication in Brazil uses more non-renewable energy and causes more GHG emissions than these processing steps in Tanzania combined. The use of small, mobile decorticators is clearly much less efficient for decorticating sisal leaves than the use of a large stationary decorticator. This is partially counterbalanced by the need to transport the sisal leaves by truck from the field to the stationary decorticator at Tanzanian sisal estates. For every ton of fiber, 25 tons of leaves must be transported, making the local transport a large contributor to the NREU and GHG emissions of Tanzanian sisal fiber. In Brazil, only the dry fibers are transported by truck. The impacts of the transportation to the port are similar for the two production systems. One process that does not use any non-renewable energy but does contribute substantially to climate change, is the disposal of sisal waste and wastewater in Tanzania. During the anaerobic digestion of plant material, methane is produced and released to the atmosphere.

4.2.3. COMPARISON SISAL FROM BRAZIL AND GLASS FIBER

The production of sisal fiber in Brazil is now compared to the production of glass fiber on NREU and GHG emissions. The LCA data on glass fiber production is taken from the Ecoinvent v.2 process "glass fibre, at plant/RER". Here, the systems are considered without any transportation after fiber production. Figure 17 and Figure 18 show the final results for NREU and contribution to climate change for the two products.

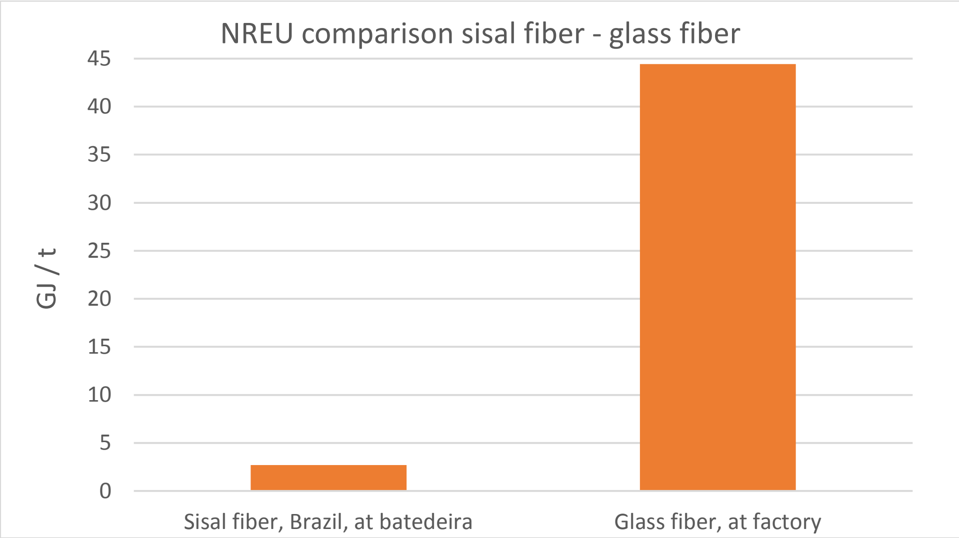

FIGURE 17: COMPARISON NREU GLASS FIBER AND TYPE 1 SISAL FIBER FROM BRAZIL

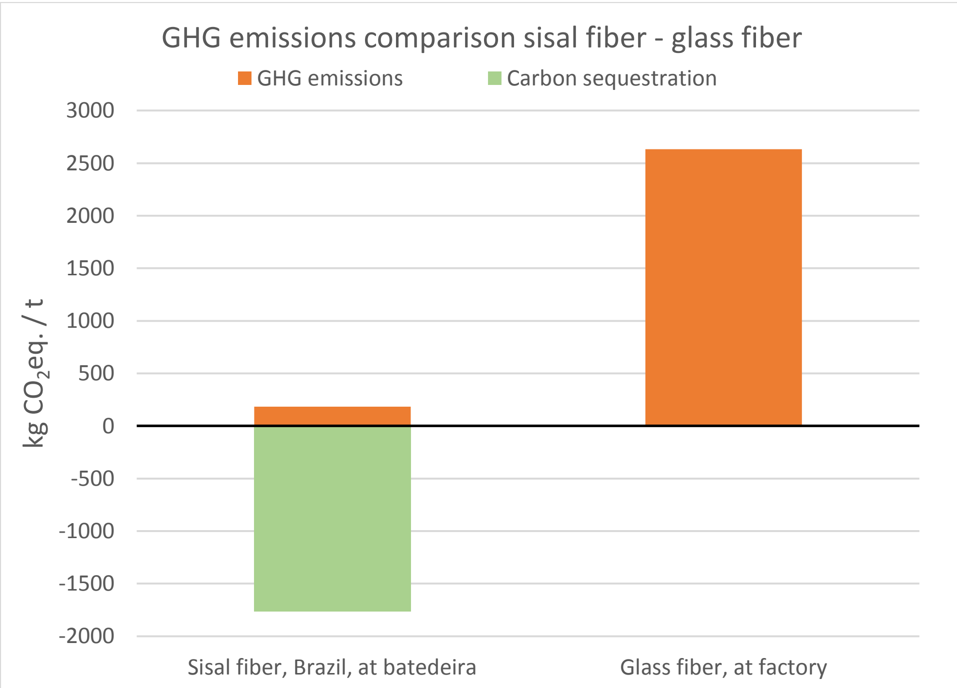

FIGURE 18: COMPARISON CONTRIBUTION TO CLIMATE CHANGE GLASS FIBER AND TYPE 1 SISAL FIBER FROM BRAZIL

The non-renewable energy use for producing 1 ton of Brazilian sisal fiber is ca. 94% lower than for the production of 1 ton glass fiber. If carbon sequestration is not taken into account, the emission of GHG's, and thereby the contribution to climate change is ca. 93% lower for sisal fiber. The contribution to climate change including carbon sequestration is -1582 kg CO_2 eq. emissions per ton sisal fiber. It is clear both NREU and contribution to climate change of Brazilian sisal fibers are much lower than glass fiber for this part of the life cycle. Note that even if the sisal fiber is transported to the molding factory by truck (section 4.2.1), the environmental impacts are still a factor 4 lower than for glass fiber production.

5. LCC

This chapter addresses the inventory analysis, results and interpretation of the LCC.

5.1. Inventory analysis

To generate the LCC inventory (cost overview) of Brazilian sisal fiber production, equipment costs (Section 5.1.1), energy and material costs (Section 5.1.2), and labor costs (Section 5.1.3) are subsequently reviewed in detail. The costs in the LCC inventory are for the average quality of sisal fiber. To generate the results in section 5.2, these average costs are related to the functional unit using economic allocation.

5.1.1. EQUIPMENT

The equipment requirements for sisal fiber production in Brazil consist of agricultural machines for land preparation, a decorticator, a small truck for local transportation, a facility including a brushing machine and baling press (*batedeira*), and a medium sized truck for transporting the fiber to the port. The cost of this equipment per ton fiber produced is estimated in Table 6.

As mentioned in paragraph 4.1.1, many farmers use animal traction or manual labor to prepare the field. This requires some basic agricultural equipment which is not considered for this analysis. In case agricultural machines are used for land preparation, these are typically hired, since most farmers do not own their own tractor. Hiring a tractor and driver to plow one *tarefa* (0.4 ha) cost about R$ 15 in 1998, which was equivalent to three daily land laborer wages at the time (Peerboom, 2012). In 2011, the typical daily wage for a land laborer is three times as high (Moreira, 2011). Using this increase to estimate the price of renting a tractor gives R$ 112.50 per ha. Given the share of farmers using a tractor and the fact that land preparation happens only once per cycle, an average cost of R$ 7.03 per ton fiber can be calculated for hiring agricultural machines. There are no other equipment costs during land preparation or cultivation. In the decortication process, the main equipment costs are from the depreciation and maintenance of the decorticator. The price of a decorticator is ca. R$ 4000 (Moreira, 2011). The cost of building a new *batedeira* is estimated at R$ 280,000 in SECTI (2013). An internet search on second hand trucks in Brazil yields a range of prices. For a small truck, a purchasing cost of R$ 30,000 is assumed, while for a larger truck a purchasing cost of R$ 50,000 is assumed (MarketBook, 2014).

The decorticator and trucks are depreciated over 10 years, while the *batedeira* is depreciated over 20 years. For all equipment, a yearly maintenance cost of 10% of the initial value is assumed (Brenters, 2000). To translate these investment and maintenance costs into a cost per ton of fiber, the annual capacity is estimated. There are approximately 3000 decorticators servicing sisal farms. With a total sisal fiber production of ca. 110,000 tons, a decorticator has an average capacity of 37 tons per year. For the small truck, the annual fiber capacity is estimated at one ton of fiber per day during 46 weeks a year. The larger truck is estimated to handle five tons of fiber per day, during 46 weeks. Since there are around 60 *batedeiras* in Bahia, which process about 110,000 tons of sisal fiber per year, the capacity of a *batedeira* is estimated at 1833 tons per year (Andrade et al., 2009).

TABLE 6: LCC INVENTORY EQUIPMENT

Equipment	Capacity (t/yr)	Cost (R$)	Lifetime (yr)	Cost (R$/t)
Hiring agricultural machines				7.03
Decorticator	37	4,000	10	10.91
Decorticator maintenance	37	400		10.91
Truck to factory	230	30,000	10	13.04
Annual truck maintenance	230	3,000		13.04
Batedeira	1,833	280,000	20	7.64
Annual *batedeira* maintenance	1,833	28,000		15.27
Truck to port	1,150	50,000	10	4.35
Annual truck maintenance	1,150	5,000		4.35
Total equipment cost				86.54

5.1.2. ENERGY AND MATERIALS

Sisal fiber production in Brazil requires plantlets, electricity, diesel and lubricant oil as energy and material inputs. The estimated costs of these inputs are summarized in Table 7.

The diesel and electricity use of the production processes have been determined in the LCA (see section 4.1). During land preparation, diesel used by a tractor is the only energy input. However, the diesel costs for the agricultural machines are assumed to be borne by the owner of the tractor and included in the rent. Furthermore, the plantlets used for cultivation come from suckers growing out of mature sisal plants grown by the farmer and do not represent a cost factor. The decorticator needs ca. 40 liters of diesel and 1 liter of lubricant oil per ton of fiber produced (Embrapa, 2014). The diesel price in Brazil was R$ 1.99 per liter in 2011 (GIZ, 2011). Lubricant oil to decorticate one ton of sisal fiber cost ca. R$ 40 (Campbell, 2007). The brusher and baling press use grid electricity. There are large fluctuations in the commercial electricity price in Brazil; it is estimated that the price was around R$ 300/MWh in 2011 (ANEEL, 2011).

TABLE 7: LCC INVENTORY ENERGY AND MATERIALS

	Input (per ton fiber)	**Unit**	**Cost (R$/ton)**
Diesel for decorticator	40.00	liter	79.56
Diesel for transport to factory	1.33	liter	2.65
Diesel for transport to port	21.33	liter	42.43
Electricity for brushing machine	20.00	kWh	6.00
Electricity for pressing	8.00	kWh	2.65
Lubricating oil	1.00	liter	40.00
Total energy and materials cost			173.04

5.1.3. COST OF LABOR

Sisal fiber production in Brazil requires the labor of several workers. Table 8 shows the estimated labor requirement and labor costs per production activity. The hired laborers earn a daily wage. However, the farmer, decorticator owner, middleman and owner of the *batedeira* do not earn a wage. Their income depends on the revenue and expenses they make.

Table 19 in Appendix E gives an overview of the typical labor requirement for all land preparation, cultivation and decortication processes. Since land preparation requirements are given in machine hours, these are translated into man days using the assumption that 1.5 hours plowing by tractor takes about one day using animal traction (Peerboom, 2012). For the labor requirement of the middleman, who transports the fiber from the farm to the *batedeira*, the assumption of 1 man day per ton fiber is made based on the carrying capacity of a small truck or trailer (up to 1 ton) and the distances traveled. In the *batedeira*, there are assumed to be two brushing machines operated by four people (Campbell, 2007). With an annual capacity of 1833 ton per *batedeira*, this means one person can process 2 t of dry fiber per day, which translates into 0.5 man days per ton fiber. Furthermore, the labor requirement for sorting and pressing and baling of sisal fiber are both estimated at 0.5 man days per ton (CFC, 2001). Finally, transporting the baled fiber to the port is estimated to take 0.2 man-days per ton of fiber, based on transport capacity (ca. 5 tons) and distance. In total, the production system requires 67 man days to produce one ton of baled sisal fiber.

Land preparation and cultivation are performed by the farmer, possibly with help of hired laborers or unpaid family members. The farmer and the owner of the decorticator negotiate on a distribution of the revenue of selling the raw sisal fiber. The farmer typically receives between 20% and 40% of the raw sisal price, which was R$ 1100 per ton in 2011 (Campbell, 2007; CONAB, 2013; Sindifibras, 2012). A share of 35% is assumed here, resulting in a revenue of R$ 385 per ton sisal fiber. The owner of the decorticator receives the remaining revenue of the sold sisal fiber (65%), ca. R$ 715 in 2011. For this assessment, the labor cost of land preparation and cultivation are assumed to be equal to the revenue for the farmer minus the expenses made (i.e. renting a tractor), resulting in R$ 384.30 per ton sisal fiber.

The labor costs for hiring a complete decortication crew are estimated at R$ 522 per ton fiber (Campbell, 2007). The income of the machine owner is the revenue of R$ 715 minus the equipment, energy, material and labor costs, resulting in only ca. R$ 51.50 per ton. In practice, the profit for the machine owner may be so low that he works at the decorticator himself to save one laborers wage (Campbell, 2007; Peerboom, 2012). The labor cost of the middleman is also estimated by the revenue minus expenses made. The middleman earned ca. 15 centavos per kg raw sisal fiber in 2011 (Silva, 2014). This yields an income of R$ 150 per ton for 2011. After paying expenses, this leaves R$ 121.26 per ton sisal fiber for the middleman as the cost of labor.

The workers hired by the *batedeira* owner earn a wage of ca. R$ 30, which corresponds with the minimum wage of R$ 30.80 per day (Receita Federal, 2011; Silva, 2014). This is consistent with the notion that industrial laborers generally earn more than land laborers (Peerboom, 2012). The income of the owner of the *batedeira* is estimated to be the revenue from selling the sisal fiber (R$ 1400 in 2011) and the costs of equipment, energy and hired labor (CONAB, 2013). This results in ca. R$ 15.20 per ton sisal fiber.

TABLE 8: LCC INVENTORY LABOR

Activity	**Labor (man days/ton)**	**Person**	**Daily wage (R$)**	**Labor cost (R$/ton)**
Land preparation	1.00	Farmer	12.92	12.92
Cultivation (incl. field restoration)	28.25	Farmer	12.92	365.05
Decortication	35.00	Decortication crew	14.92	522.14
Decorticator management	5.00	Decorticator owner	10.30	51.48
Transportation to *batedeira*	1.00	Middleman	121.26	121.26
Brushing	0.50	Industrial laborer	30.80	15.40
Sorting	0.50	Industrial laborer	30.80	15.40
Pressing and baling	0.50	Industrial laborer	30.80	15.40
Managing/bookkeeping	0.13	*Batedeira* owner	121.61	15.20
Transportation to port	0.20	Trucker	30.80	6.16
Total labor requirement	67.08			1140.42

5.2. Results and interpretation

The tables in section 5.1 represent the costs per average ton of fiber. Here, economic allocation is applied to calculate the results for the functional unit. The total cost for producing 1 ton of type 1 sisal fiber is estimated at R$ 1597. Figure 19 shows the breakdown of production costs for one ton of type 1 sisal fiber.

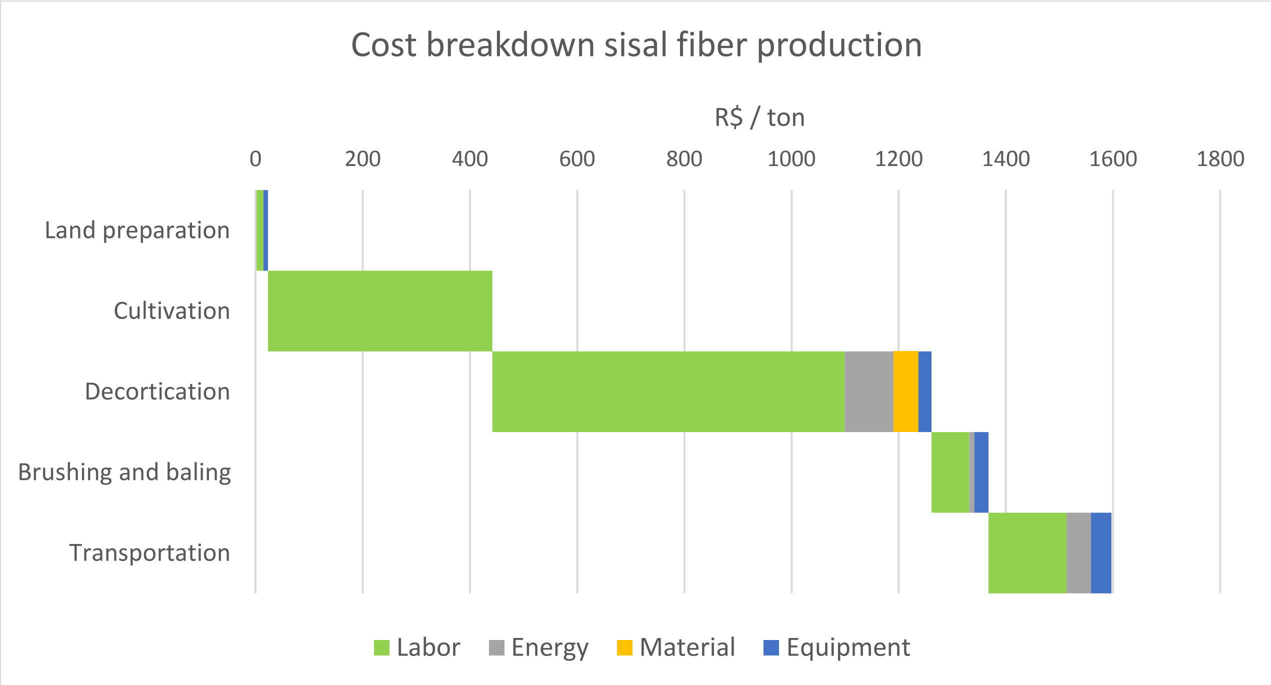

FIGURE 19: LCC BREAKDOWN PRODUCTION COSTS TYPE 1 SISAL FIBER

The LCC results show that labor is the major cost factor (82%) for the production of sisal fiber in Brazil. Since a significant share of the labor on the field is manual, increased mechanization could potentially decrease the labor demand. For example, increased use of mechanized plowing and the use of herbicides could reduce the labor demand for land preparation and weeding. The costs for decortication represent more than half (51%) of the total costs. The LCA showed that decorticators in Tanzania are much more energy efficient (see section 4.2.2). Although these machines are different in some respects, it is likely that the replacement or improvement of old decorticators in Brazil offers potential for cost reduction in this step of fiber production.

The total cost for producing one ton of medium quality (type 2 and 3) sisal fiber is estimated at R$ 1344. Furthermore, if mass allocation is applied rather than economic allocation, the production costs allocated to one ton of baled sisal fiber are ca. R$ 1400.

Note that the average exchange rate was ca. 1 US$ = R$ 1.75 in 2011. This yields a price of ca. US$ 915 per ton type 1 sisal fiber. The average international price of glass fiber was ca. US$ 2400 per ton in 2011 (Guti & Bono, 2013). Although a comprehensive cost comparison between sisal fiber and glass fiber is not part of this study, these results show that, assuming a 1:1 weight replacement ratio of glass fiber by Brazilian sisal fiber, sisal fiber had a clear price advantage over glass fiber in 2011.

6. SOCIAL LCA

This chapter addresses the inventory analysis, results and interpretation of the selected impact categories for the S-LCA. Data uncertainties are discussed in the interpretation of each section.

6.1. Health and safety

To assess the danger of accidents in the sisal sector, two quantitative indicators are used: (1) the number of severe accidents in the sisal sector in Bahia in 2011; and (2) a comparison of the accident rate per 1000 workers in the sisal sector in Bahia with the accident rate in the total agricultural and textile sectors in Bahia and Brazil in 2011.

6.1.1. INVENTORY

The Brazilian Ministries of Social Security and Labor and Employment publish annual statistics on occupational accidents (Previdência Social, 2012). For the first indicator, data on occupational accidents in Bahia in 2011 is used. The 2011 data is checked against earlier years (2009, 2010) and found to be representative. Accidents are grouped by economic activity according to the CNAE system (*Classificação Nacional de Atividades Econômicas*) (Previdência Social, 2012). Sisal cultivation and processing are not themselves distinct activities within this CNAE system, but are categorized under two broader activity categories: (1) #0139, the cultivation of permanent crops excluding coffee, cacao and fruits; and (2) #1312, the preparation and spinning of natural fibers excluding cotton. Sisal cultivation and decortication activities are part of the first category, while sisal fiber brushing, sorting and baling activities are part of the second category. Data per CNAE category is available at the province level. Table 9 lists the number and type of accidents in these economic activities in 2011.

TABLE 9: NUMBER AND SEVERITY OF ACCIDENTS IN ECONOMIC SUBSECTORS IN 2011 (SOURCE: PREVIDÊNCIA SOCIAL, 2012)

	0139: Cultivating permanent crops	1312: Processing and spinning of natural fibers
Short medical assistance	18	4
Less than 15 days disability	9	12
More than 15 days disability	9	23
Permanently incapacitated	0	1
Death	0	0
Total accidents	36	40

In this study, severe accidents are defined as those accidents that cannot be fully attended to by short medical assistance, i.e. where, after medical attention, the person promptly recovers and can resume working (Previdência Social, 2012). Since the activities in these two CNAE categories are not limited to sisal fiber production, the share of accidents specifically for sisal fiber production is estimated. The shares of sisal within the cultivated “permanent crops” under category 0139 and produced “natural fibers” under category 1312, are determined based on production value. Sisal accounted for ca. 64.8% of the production value of cultivated permanent crops and ca. 68.0% of the production value of natural fibers produced in the state of Bahia in 2011 (IBGE, 2014b).

The second indicator compares the total accident rate per 1000 workers in these two economic subsectors in Bahia to the accident rate in these subsectors in Brazil and in their overarching economic sectors in Bahia and Brazil. The accident rate in cultivating permanent crops in Bahia is used as a proxy for the accident rate in sisal cultivation and decortication. This accident rate is compared with the accident rate in cultivating permanent crops in Brazil and the accident rate in the agricultural sector in Bahia and Brazil. The accident rate in processing and spinning natural fibers in Bahia is used as a proxy for the accident rate in sisal brushing, sorting and baling. This accident rate is compared with the accident rate in the processing and spinning of natural fibers in Brazil and the accident rate in the textile and apparel industry in Bahia and Brazil. For this indicator it is not possible to exclude other activities within the CNAE subsectors. Table 10 and Table 11 show the data on this indicator.

TABLE 10: ACCIDENT RATES PER 1000 WORKERS IN CULTIVATION OF PERMANENT CROPS AND AGRICULTURE IN 2011 (Source: Previdência Social, 2012)

	#0139: Cultivating permanent crops	**#01xx/#02xx/#03xx: Agriculture**
Bahia	13.85	20.15
Brazil	30.09	20.09

TABLE 11: ACCIDENT RATES PER 1000 WORKERS IN PROCESSING AND SPINNING OF NATURAL FIBERS AND TEXTILE AND APPAREL INDUSTRY IN 2011 (SOURCE: PREVIDÊNCIA SOCIAL, 2012)

	#1312: Processing and spinning of natural fibers	**#13xx/#14xx/#15xx: Textile and apparel industry**
Bahia	32.62	16.41
Brazil	24.42	20.48

6.1.2. Results and interpretation

Combining the data on accidents and the share of sisal within the economic activity categories yields the result on the first indicator, listed in Table 12.

TABLE 12: NUMBER OF SEVERE ACCIDENTS IN SISAL FIBER PRODUCTION IN 2011

	Bahia 2011
Number of severe accidents in cultivation and decortication of sisal	12
Number of severe accidents in brushing and baling of sisal	24
Total severe accidents in sisal fiber production	36

The results on the second indicator are visualized in Figure 20. The outlined columns are used as proxy for sisal related activities.

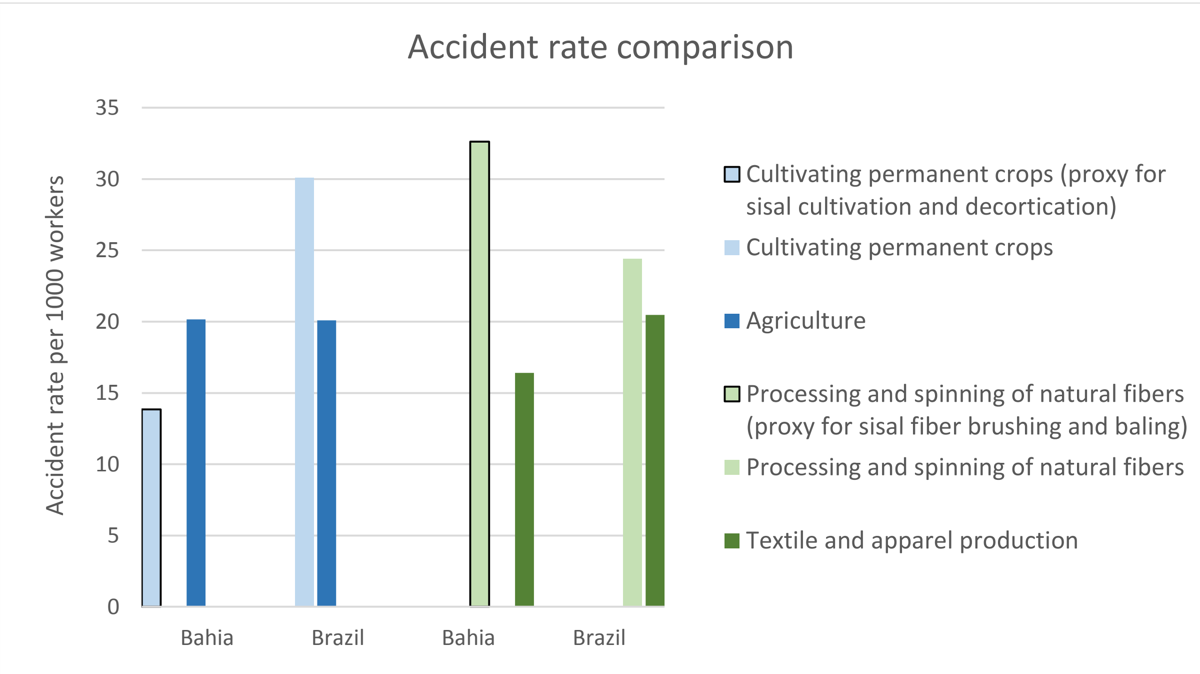

FIGURE 20: COMPARISON ACCIDENT RATES 2011

The results indicate that there are a few dozen severe accidents happening every year in the sisal sector in Bahia. Although many literature sources mention the dangers of the work at the decorticator and in the field, the results suggest that the work in the *batedeira* is actually more dangerous. The comparison of accident rates indicates that working in the cultivation of permanent crops in Bahia has a lower risk of accidents than the risk in the entire agricultural sector in Bahia and Brazil. This too is surprising considering the attention given to the dangers of sisal cultivation and decortication. Workers in the processing and spinning of natural fibers in Bahia run a higher risk on accidents than the risk in the entire textile and apparel production sector in Bahia and Brazil. Based on these results, efforts to minimize the occurrence of accidents should be equally focused on the labor in the *batedeira* and on the labor in the fields and at the decorticator.

Although the data available on occupational accidents is extensive, it remains limited to accidents that are registered. It is possible that accidents in the *batedeira* are more systematically registered than accidents on the sisal farms. Furthermore, accidents are registered by economic activity, which do not fully coincide with sisal fiber producing activities. Attributing a share of the accidents to the sisal fiber production system based on production value follows the assumption that the accident rates within the CNAE category are equally distributed over the different activities. This may ignore specific dangers in the sisal fiber production system. The same issue applies to the second indicator, where the accident rate in a larger CNAE category is used as proxy for the accident rate in sisal related activities. The source data for the statistics on occupational accidents may be able to provide more specific data on accidents in the sisal sector.

6.2. Child labor

To assess the incidence and severity of child labor, two quantitative indicators are used: (1) the number of children working in the sisal fields; and (2) the percentage of working children that do not attend school.

6.2.1. Inventory

Child labor is defined as work that is: "Mentally, physically, socially or morally dangerous and harmful to children" and interferes with their opportunity to attend school (UNEP/SETAC, 2013). It refers to such work carried out by children under the age of 15, or to work considered to be hazardous or morally dubious carried out by children under the age of 18 (UNEP/SETAC, 2013). Child labor can be both paid and unpaid work. Under Brazilian law, labor in the sisal fields and factories is considered hazardous and may not be performed by children under the age of 18 (UCW, 2010).

For the first indicator, the number of children working in the sisal fields is estimated. Brazilian data on the number of child workers in agriculture is available at the municipality level from IBGE (IBGE, 2014a). Table 20 in Appendix F shows the number of children aged 10-13, 14-15 and 16-17 who were working in agriculture in sisal producing municipalities in Bahia in 2011. The number of children working in agriculture is multiplied with the share of sisal in total agricultural production value to estimate the number of children working in the cultivation and decortication of sisal. Table 21 in Appendix F shows the total production value of agriculture and of sisal per municipality in 2011. Only municipalities where sisal was produced in 2011 are considered. Furthermore, the database does not contain labor data on children younger than 10 years old. For the 16-17 age group, only children working in agriculture without a formal contract are considered.

For the second indicator, the share of working children that do not attend school is estimated. Table 22 in Appendix F shows the data available from IBGE (2014a) on the number of working children that do not attend school and the total number of children working per age group in sisal producing municipalities in Bahia in 2011. Dividing the former by the latter yields an estimate of the share of working children that do not attend school.

6.2.2. Results and interpretation

Table 13 shows the estimated number of children working in sisal and the percentage of working children that did not attend school in Bahia in 2011. Note that the age group 10-13 is wider than the other two age groups.

TABLE 13: CHILDREN WORKING IN SISAL AND SHARE OF WORKING CHILDREN NOT ATTENDING SCHOOL IN SISAL PRODUCING MUNICIPALITIES IN BAHIA IN 2011

	Children working in sisal	Working children not attending school
Aged 10-13	3812	4.4%
Aged 14-15	3342	10.0%
Aged 16-17	3444	24.2%
Total	10598	14.0%

The results suggest that, despite efforts to eradicate child labor in Brazil (see section 6.8.1.2), many children still work in the sisal fields or at the decorticator under circumstances that, under Brazilian law, are considered dangerous and bad for the development of the child. Older children (age 14-17) are more likely to work in the sisal sector than younger children (age 10-13). At the same time, school attendance is high, especially at younger ages, indicating that most children do not work full time in the sisal sector. As they grow older, more children stop attending school. Since wages increase with age, the perceived benefits of working full time may then be estimated higher by the children or their parents than finishing their secondary education. However, education requirements are increasing throughout Brazil and even many low paid jobs currently require a secondary school diploma (Peerboom, 2012). Furthermore, poverty is not only an important driver for child labor, it can also be a result of child labor when education or health are neglected (UCW, 2007; UNEP/SETAC, 2013). The impact of child labor can thus extend much further than the direct adverse impacts of the work itself.

The uncertainty of the results is affected by several factors. Firstly, no compatible data on child labor is available for children under the age of 10. Furthermore, the data is not specifically for child labor in the sisal sector and the method of attributing child labor to the sisal sector is based on the assumption that child labor is equally distributed over agricultural activities in sisal producing municipalities.

To validate the results, literature and experts were consulted. In Alves & Santiago (2004), the number of children working in the sisal sector is estimated at approximately 9,000. However, there have been large efforts to eradicate child labor since 2004. Two local experts indicated that there are currently (almost) no children working in the sisal sector. Furthermore, the IBGE data was said to be often inaccurate (Andrade, 2014; Silva, 2014). Further research is necessary to explain these differences. It is important to note that there are sisal suppliers (e.g. APAEB) who guarantee that no child labor is used during production (Magalhães, 2008).

6.3. Fair salary

Fair wages in the sisal sector can contribute to the alleviation of poverty for workers and their families. For this impact category, the wages in the sisal sector are compared to several ‘fair’ wage levels.

6.3.1. Inventory

For the indicator, the labor in man days per ton fiber for every relevant actor is multiplied with the total sisal fiber production in Brazil in 2011 to estimate the total number of FTE salaries at a certain wage level. The wages of workers in the sisal sector in Bahia are estimated in the LCC (section 5.1.3).

The legal minimum wage is a typical measure for a fair salary. However, it must be noted that in many countries, the minimum wage is not adequate for workers to avoid poverty (UNEP/SETAC, 2013). In Brazil, the minimum wage in 2011 was R$ 545 per month, to be paid 13 times a year (Receita Federal, 2011). This amounts to R$ 30.80 per day, based on an assumption of 230 work days a year.

The Department of Statistics and Socio-economic Development (DIEESE), an organization created by the Brazilian labor movement, tracks the adequacy of the legal minimum wage by monthly calculating and publishing figures on the “required wage”. The required wage is an estimate of the actual amount needed to provide for the basic needs mentioned in the Brazilian constitution: housing, electricity, education, health, leisure, clothing, hygiene, transportation and social security for a family consisting of 2 adults and 2 children, anywhere in Brazil (DIEESE, 1993). Compared to the required wage, the legal minimum wage in Brazil is found to be inadequate to provide for the needs mentioned (DIEESE, 2014). Table 14 shows the legal minimum wage and required wage in 2011, expressed in Brazilian real per day. The actual wage levels are compared to the legal minimum wage and the required wage determined by DIEESE.

TABLE 14: “FAIR” WAGE LEVELS LABOR BRAZIL 2011

	Daily wage (R$ / working day)
Legal minimum wage 2011	30.80
Required wage DIEESE 2011	128.47

6.3.2. Results and interpretation

Figure 21 shows the number of FTE labor at a certain wage level compared to the legal minimum wage and the required wage.

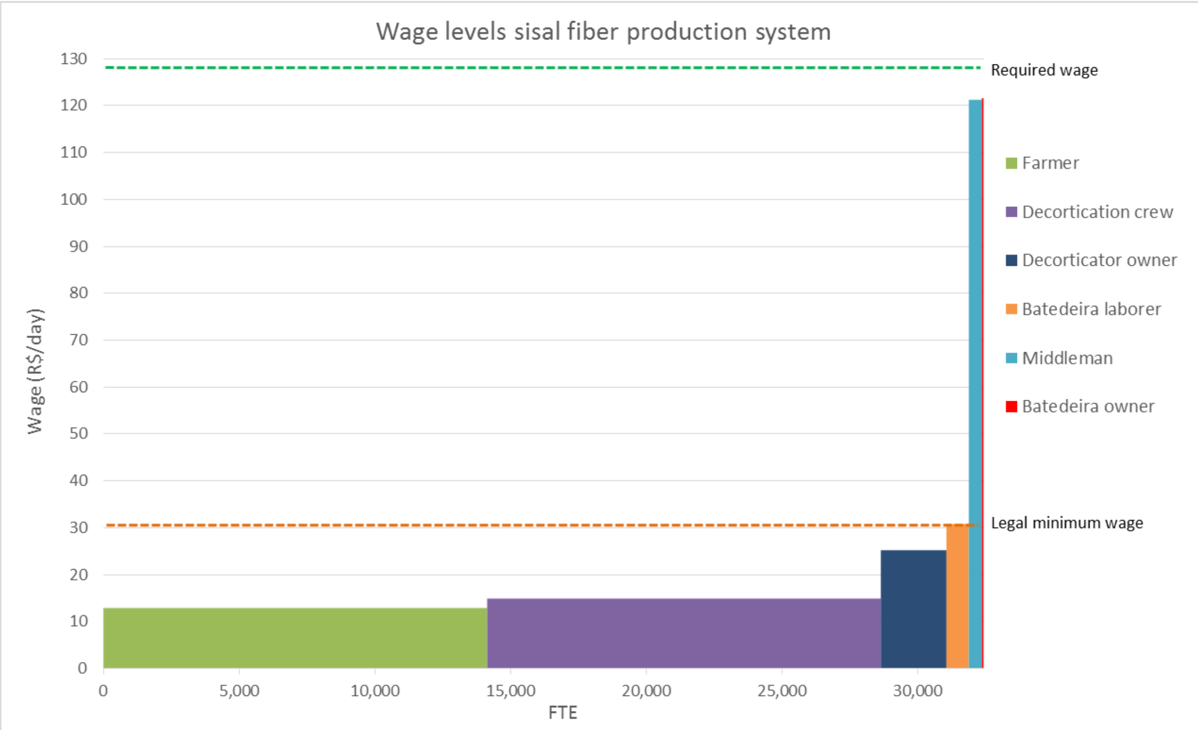

FIGURE 21: ESTIMATED WAGE LEVEL IN SISAL SECTOR BRAZIL COMPARED TO MINIMUM AND REQUIRED WAGES

The results show that most workers in the sisal sector earn a wage that is below the legal minimum wage and significantly below the required wage. These wages are likely insufficient to provide for all the basic needs of the workers and their families and can perpetuate poverty levels in the area. There are a few jobs within the sisal sector that provide a decent wage which can be substantially higher than other wages in the sector. The middlemen and *batedeira* owner in particular are relatively well off compared to the farmers, machine owners and other laborers. This corresponds with the notion in literature that the profits from sisal are unequally distributed and businessmen are much better off compared to the farmers, machine owners and other laborers (Peerboom, 2012).

To further analyze the fair salary issue, two values are now calculated: (1) the daily wage for all actors if the earnings were spread evenly throughout the supply chain, and (2) the increase in total production costs of baled sisal fiber if the unfair wages are increased to the legal minimum wage. For the first option, the total labor cost is divided by the total labor demand, which yields R$ 17 per man-day. For the second option, all wages below the minimum wage are set to be equal to the minimum wage. This yields total production costs that are ca. 77% higher than in the standard situation. These results show that even an equal distribution of the earnings does not lead to fair wages for all actors. Furthermore, the introduction of minimum wages for all actors earning below the minimum wage leads to much higher production costs and, therefore, much higher sisal fiber prices.

The difference between the legal minimum wage and the required wage is substantial. Since neither is region specific, it is not clear what wage level would be sufficient to provide for all basic needs in Bahia. It is likely that the cost of living is lower in poor rural areas where many families grow their own food. Furthermore, the results of this indicator have a similar uncertainty to the results of the LCC. Actual wages may vary per individual and per area and are largely dependent on the sisal price. This corresponds with the notion in Peerboom (2012), that in some years, the cultivation of sisal can provide for a decent living. Despite these uncertainties and variability, the wages in sisal sector can in general be considered as very low.

6.4. Contribution to economic development

Two quantitative indicators are used as a proxy for the sisal sectors' contribution to economic development: (1) the share of raw sisal fiber production in the total gross production value and the agricultural production value of the sisal producing municipalities and Bahia, and (2) the amount of FTE jobs offered by the sisal fiber production system in Brazil.

6.4.1. INVENTORY

For the first indicator, dividing the production value of raw sisal fiber by the other gross production values gives the contribution of sisal fiber production. The production value of raw sisal fiber and the agricultural and total gross product of the sisal producing municipalities and Bahia are taken from the IBGE database and are shown in Table 15. Only the agricultural component of sisal fiber production (land preparation, cultivation and decortication) is considered for reasons of data availability.

TABLE 15: INVENTORY GROSS PRODUCTION VALUES (SOURCE: IBGE, 2014A)

	Gross production value (thousand R$)
Sisal fiber in Bahia	255,824
Agriculture in sisal producing municipalities	844,982
Total gross product sisal producing municipalities	7,867,245
Agriculture in Bahia	10,398,644
Total gross product Bahia	159,868,617

For the second indicator, the number of man-days of work needed to produce one ton of baled sisal fiber is multiplied by the total production volume of sisal in 2011 and divided by the number of working days per year (230). This yields the number of FTE jobs in the sisal fiber production system in Brazil. The number of man-days work needed per ton is calculated in the LCC (section 5.1.3). A distinction is made between agricultural jobs (land preparation, cultivation and decortication) and industrial jobs (transportation, brushing and baling).

6.4.2. RESULTS AND INTERPRETATION

Table 16 shows the share of raw sisal fiber production in the total and agricultural gross production values of the sisal producing municipalities and of Bahia.

TABLE 16: SHARE RAW SISAL FIBER PRODUCTION IN TOTAL AND AGRICULTURAL GROSS PRODUCTION VALUES

	Sisal producing municipalities	**Bahia**
The share of sisal in gross product from agriculture	30.28%	2.46%
The share of sisal in total gross product	3.25%	0.16%

For the second indicator, the number of FTE jobs provided by the sisal fiber production system in Brazil is given in Table 17.

TABLE 17: NUMBER OF FTE PROVIDED BY THE SISAL FIBER PRODUCTION SYSTEM IN BRAZIL

Sector	**FTE labor**
Agriculture	31063
Industry	1366
Total	32429

The results on gross production values show that raw sisal fiber production is a significant factor (ca. 30%) in the agricultural production of sisal producing municipalities. Considering that agricultural production is commonly of limited economic significance compared to sectors such as industry and services, sisal still has a notable factor (ca. 3%) in the total gross product of sisal producing municipalities. On a larger scale, however, the strictly economic significance of sisal production is limited. Note that value created by further processing of raw sisal is disregarded here but, if done locally, can also contribute to the economic development of the area.

The sisal fiber production sector (including brushing and baling) in Brazil is estimated to offer ca. 32,500 FTE of labor. According to SECTI (2007), there are approximately 30,000 sisal farmers and 3000 decorticator owners in Bahia. This is a much lower number than the number of people in Bahia who rely to a certain degree on sisal for their living, estimated at 700,000 (Sindifibras, 2012). However, it is likely that this estimate includes the families of persons working in the sisal sector. Furthermore, the result in this study does not include jobs in the further processing of sisal fiber into yarns, twine, bags or rugs and the export or sales of sisal products. Additionally, several farmers or laborers can fulfil one FTE demand. Many sisal farmers, for example, also keep animals on their farm and spend only part of their time on sisal cultivation (Peerboom, 2012). Furthermore, the labor requirement in the sisal sector may not be constant during the year and many laborers are hired only when the sisal leaves need to be cut and decorticated. These laborers work in other jobs during the rest of the year. Similarly, children working in the sisal sector often work part-time (see section 6.2.2), so that several of them fulfil one FTE job.

6.5. Freedom of association and collective bargaining

The freedom of association and collective bargaining is one of the pillars of fair labor standards. This impact category is described qualitatively.

6.5.1. Inventory

The freedom of association and the right to collective bargaining are both embedded in Brazilian law (ILO, 2014b). There are, however, several legal restrictions. First of all, trade unions are restricted in forming branches and in affiliating with national and international organizations. Secondly, under the *Unicidade* system, the number of trade unions per economic or occupational category is limited to one per territorial area. Furthermore, the armed forces, police and various other civil servants have no rights to collective bargaining or organization. Finally, free and voluntary bargaining is restricted by the exclusion of certain matters, such as wage and working hours, from the scope of bargaining (ITUC, 2014). The ITUC criticizes the legal framework in Brazil and notes that "the law prohibits anti-union discrimination, but does not provide adequate means of protection against it." (ITUC, 2014). Especially in rural areas, employers are hostile towards trade unions and violence against trade union members is a serious problem (ITUC, 2009). Violations of workers' rights to organize, strike and collective bargaining in Brazil in the past 3 years (2011-2013) include:

- The dismissal and harassment of trade union leaders and other anti-union practices.
- Violence against trade union leaders, including targeted assassinations.
- Denials of the right to collective bargaining.
- Restriction and criminalization of demonstrations and strikes (ITUC, 2014).

In the whole of Brazil, 17.8% of the working population was a union member in 2011 (ILO, 2014b). Furthermore, 60% of the working population was covered by some form of collective agreement in 2006 (ILO, 2014a). Approximately 50% of the workers in the sisal sector are member of a rural labor union (Andrade, 2014; Silva, 2014). The rural labor unions (STRAFs) advocate the rights of rural laborers. The foundation for the support of family farming in semi-arid Bahia (FATRES) is an umbrella organization coordinating the efforts of the rural labor unions in Bahia. The unions and FATRES are active in the sustainable resolution of social problems in the area (FATRES, 2014). In addition to self-initiated projects, the unions coordinate and provide assistance to projects initiated by NGO's or the local government. Among their activities are:

- Supporting maimed and disabled workers in their claims for disability benefits.
- Educating and training workers.
- Organizing and mobilizing workers.
- Supporting programs aimed at eradicating child labor.
- Helping workers getting their retirement.
- Supporting a fairer distribution of agricultural land.
- Training rural representatives for political functions.
- Improving the participation and treatment of women (FATRES, 2014).

The efforts and effectiveness of the work done by the unions are recognized in literature (Quan, 2011; Silva, 2012). Despite some of the legal issues mentioned before, there seem to be no restrictions to union membership for the sisal workers. For farmers and rural laborers without a formal contract, union membership is the easiest way to formally register their profession and prove that they are entitled to social benefits and security. Getting access to retirement, disability benefits, maternity leave and other social benefits is an important incentive to join a rural labor union for many workers (Peerboom, 2012).

Still, many rural workers and farmers choose not to be a union member. This can be explained by the fact that many farmers and laborers regard the labor unions as too progressive for their support for land reform and other delicate socio-political issues. Furthermore, the rural population is used to doing business within their local community based on the principles of reciprocity; social relations are one-on-one and based on trust. Many workers may fear that, within the larger framework of a union, such traditional relationships are no longer possible. Finally, in many cases it is possible to join a union and manage the registration of profession when the need for certain benefits arises (Peerboom, 2012). Despite the important role that labor unions play in this regard, it is argued that this relation between unions and access to social benefits is unfortunate since most labor unions have an outspoken political ideology which is not shared by all rural laborers (Peerboom, 2012).

6.5.2. Results and interpretation

The issue of freedom of association and collective bargaining remains ambiguous for the sisal sector in Brazil. On the national level there are some problems with the legal framework and the actual safeguarding of workers' right to unionize, strike or bargain collectively. In the province of Bahia, labor unions coordinate with other organizations and local governments to try and solve some of the social and economic problems in the region. However, not all workers are interested in joining a labor union and some laborers join primarily to formalize their status and get access to certain social benefits. It is possible that the *Unicidade* system prevents the formation of labor unions of different ideological backgrounds, thereby limiting the broader participation of rural workers.

6.6. Social benefits/social security

Access to social benefits and social security can reduce the financial vulnerability of workers. This impact category is described qualitatively.

6.6.1. Inventory

The Brazilian social security system exists of multiple pillars. Individuals who contribute to the Social Welfare Fund (*Previdência social*) may be eligible to payments for the following:

- Maternity leave
- Long-term sickness
- Temporary incapacity
- Disability
- Retirement
- Imprisonment
- Death
- Low-income families (Previdência Social, 2008).

To contribute and receive benefits, the individual must have a labor and social security card (*Carteira de Trabalho e Previdência Social*). Furthermore, to be eligible for payments for long-term sickness or disability, the individual must have contributed to the *Previdência social* for at least one year, except in case of an accident. Retirement is only available for individuals who have contributed to the *Previdência social* for at least 15 years (Previdência Social, 2008).

However, many people in poor rural areas do not contribute to the *Previdência social* and only ca. 2% of workers in sisal cultivation and decortication have a labor card (Alves & Santiago, 2004; Peerboom, 2012). To provide for these people, there is an additional welfare fund available, the Rural Worker's Assistance Fund (FUNRARAL). FUNRURAL is funded by a tax on the sale of rural products. Under FUNRURAL, individuals who can prove their rural worker status can retire at the age of 60 (men) or 55 (women), and receive a monthly retirement of one minimum wage (Lloyd-Sherlock & Barrientos, 2008). Other benefits are: survivor's benefits, funeral assistance, disability benefits and health services (Previdência Social, 2008). As was discussed in section 6.5, official registration as farmer or rural worker can be performed through membership of a labor union. Through FUNRURAL, social security benefits are in principle available to all the workers in the sisal fiber production system. Since many rural workers in the sisal fiber production system earn much less than the minimum wage, retirement benefits have a strong positive influence on the income of a family with retired individuals (Peerboom, 2012). However, Peerboom (2012) notes that a lack of knowledge keeps some rural workers from benefitting from all available benefits under FUNRURAL. In addition to FUNRURAL, there is also a countrywide scheme to assist the poorest families, the *Bolsa Família*. This program is discussed in section 6.8.1.1.

6.6.2. Results and interpretation

The standard social welfare fund is used by fewer than 2% of workers in the sisal sector. However, the Brazilian government has created an alternative fund for rural workers. The availability of basic social security benefits for rural workers has a strong positive influence on the financial vulnerability of workers in the sisal fiber production system. Adequate communication about the benefits under FUNRURAL could help all sisal workers to be covered under social welfare.

6.7. Equal opportunities/discrimination

For this impact category, the issue of equal treatment of women working in the sisal fiber production system is described qualitatively.

6.7.1. Inventory

Discrimination based on race, skin color, sex, religion, political opinion or social background is forbidden in Brazil (ILO, 2014b). In practice, however, women in Brazil are often disadvantaged. According to Monsueto & Simão (2008), gender inequality in Brazil manifests itself in the following ways: "(1) unequal participation in the labor market; (2) the lower economic and social value ascribed to work performed by women …; (3) unequal access to production resources such as credit, land and other types of production capital, and (4) unequal access to jobs with decision-making power …". Since there is limited influence from decision-making positions in sisal cultivation and processing, the focus here is on the first three issues.

In the whole of Brazil, the gender wage gap was ca. 23% in 2011 (ILO, 2014b). Female farm workers earned on average 34% less than male farm workers in 2001 (ILO, 2014c). Furthermore, the number of women working in Brazil was 39.4 million in 2011, versus 54.1 million men working (ILO, 2014a).

In Bahia, women account for less than a third of agricultural employment (IBGE, 2014b). With respect to land ownership, in 2006, women owned ca. 136,000 agricultural establishments in Bahia, versus ca. 625,000 agricultural establishments owned by men (IBGE, 2014b). When inheriting land or property, many women register these under their husband's name (Peerboom, 2012). In the sisal fiber production system, participation of women is around 30% (Silva, 2014). Women are involved mainly in certain specific positions: cutting sisal leaves, transporting leaves to the decorticator, drying wet sisal fibers after decortication and sorting fibers in the *batedeira*. In many cases, women work within the family atmosphere, contributing to the family income without earning a wage. Paid female land laborers typically earn only half the wage of male land workers in the sisal region (Peerboom, 2012). Many women are generally occupied by household obligations. In combination with the fact that wages for women are significantly lower, especially in the informal sector, this makes performing paid labor difficult and unattractive for many women (Monsueto & Simão, 2008; Peerboom, 2012).

Since labor is the main source of income for the rural workers, (gender) discrimination also exacerbates poverty in the rural areas in Bahia (Monsueto & Simão, 2008). Peerboom (2012) notes that when the financial situation of a family improves, women tend to work less in paid jobs and spend more time doing household tasks.

6.7.2. Results and interpretation

Discrimination against women is prevalent throughout Brazil, but is generally worse in poor and rural areas such as rural Bahia. Women tend not to be paid in family farming situations and are receive a substantially lower wage as paid rural workers than men. The low wages and culturally held belief that women are responsible for the household causes female participation to be much lower. As long as this inequality remains, decreasing poverty levels may even decrease female participation on the (paid) labor market.

6.8. Public commitments to sustainability issues

The Brazilian government, unions, scientific institutes, NGO's and local organizations are contributing to programs aimed at alleviating social, economic and environmental problems in Bahia and Brazil. Here, several programs that have an influence on the conditions in the sisal sector are discussed.

6.8.1. INVENTORY

Throughout literature, the significance of the *Bolsa Família* and PETI programs are widely recognized (Glewwe & Kassouf, 2012; Magalhães, 2008; Peerboom, 2012; UCW, 2009; Yap et al., 2002). More directly linked to the sisal fiber production system are development programs in the sisal producing region and research and development efforts to improve safety, economic feasibility and environmental sustainability of sisal fiber production.

6.8.1.1. BOLSA FAMÍLIA

The *Bolsa Família* is a nationwide conditional cash transfer program aimed at supporting the poorest families in Brazil to ensure that they have access to food, education and healthcare. Very poor families (monthly income < R$ 77), or poor families (monthly income < R$ 154) that include pregnant women or children between 0 and 17 years old, are eligible for the program. Very poor families can get a monthly sum of R$ 77. Furthermore, poor and very poor families can get R$ 35 for every child up to 16 years and pregnant or breastfeeding woman in the family, up to a maximum of R$ 175 per family. These families can also receive R$ 42 per teenager of 16 or 17 years old, up to a maximum of R$ 84 per family. These payments amount to between 6% and 62% of a monthly minimum wage in 2011 (CAIXA, 2014a).

There are, however, several conditions to receive the *Bolsa Família*: pregnant women must attend prenatal consultations, breastfeeding women must attend educational activities on breastfeeding and healthy eating, young children must be properly vaccinated, children aged 6-15 must attend school at least 85% of the time and children aged 16-17 must attend school at least 75% of the time. These conditions are aimed at creating a virtuous circle through health and education for the participating families (CAIXA, 2014a).

In 2009, the *Bolsa Família* covered 12 million households. The program has been successful in alleviating poverty and reducing inequality (UNDP, 2013). Especially in poor rural areas in Bahia, the effects of the program are evident and strongly positive (Peerboom, 2012).

6.8.1.2. PETI

The *Programa de Erradicacao do Trabalho Infantil* (PETI) is a nationwide program aimed at eradicating child labor in Brazil. The PETI is partly integrated with the *Bolsa Família*. Families are eligible if their monthly income is above R$ 120 and they have children younger than 16 in a work situation. Families earning less are covered by the *Bolsa Família*. In rural areas, families can receive a monthly sum of R$ 25 per child, in urban areas the amount is R$ 40. The conditions are that the child is removed from the work situation and attends school at least 85% of the time. Additionally, the child must attend extended day programs. These additional educational activities are also funded through the program (CAIXA, 2014b).

Since its creation in 1996, the PETI has had a big impact in reducing child labor in Brazil, especially in the sisal region. Although child labor has not been fully eradicated, some 1.2 million children in Brazil have been removed from child labor between 1996 and 2006. For the sisal territory, estimates vary between 35,000 and 80,000 children no longer working in hazardous conditions (Magalhães, 2008). Together with the *Bolsa Família*, the PETI has also increased nationwide school enrollment with ca. 6 percentage points between 1998 and 2005 (Glewwe & Kassouf, 2012). The program's success in Bahia has been ascribed to the concerted efforts of the Ministry of Social Development, the municipal and state governments, the MOC and the labor unions. In 2008, almost 900,000 children in Brazil were registered to the program, of which 96,000 in Bahia and 21,500 in the sisal territory (Magalhães, 2008).

6.8.1.3. CODES SISAL

The Regional Council of Sustainable Rural Development in the sisal territory, CODES sisal, brings together a number of NGO's and local organizations (e.g. FATRES, MOC and APAEB), all 20 municipalities of the sisal territory and the rural labor unions. CODES sisal was founded in 2002 with the goal of sustainable social, economic and environmental development of the sisal territory. For sisal specifically, the goal is to increase the productivity and successfully introduce new technologies through the following strategies:

- Research into combating plant diseases and creating higher yielding sisal varieties;
- Research into the use of sisal by-products, for example as animal feed;
- Ongoing technical assistance for stakeholders in the sisal production process;
- Implementation of new sisal processing units (e.g. decorticators and *batedeira's*);
- Organize and fund marketing of sisal products.

The CODES sisal coordinates the projects executed by the member parties on these topics. In their territorial development plan, CODES sisal allocated over R$ 12.9 million to projects aimed at the sustainable development of the sisal region (CODES sisal, 2008). According to Silva & Olalde (2010), the CODES sisal has been successful in setting out the priorities for the region and bringing together the most important public actors. They also find that the evaluation of projects executed through CODES sisal has been lacking, making the precise impacts that have been achieved unclear. However, the historic success of member organizations such as the APAEB and MOC in improving social conditions in the sisal sector and region have been extensively discussed in literature (Alves & Santiago, 2004; Machado, 2006; Magalhães, 2008).

6.8.1.4. SISAL BASE TECHNOLOGY PROJECT

In addition to R&D efforts through CODES sisal and other organizations, an important program for sisal R&D is the sisal base technology project (*Projeto Sisal de Base Tecnológia*). This project brings together the Bahian secretariats of Science, Technology and Innovation (SECTI) and Agriculture (SEAGRI), several universities and other scientific institutions to organize and fund R&D efforts to improve social, economic and environmental conditions in the sisal sector. The research topics within this program are:

- Improvement of planting material and the use of sisal varieties;
- Development of new decorticator models for improved safety, decortication quality and efficiency;
- Utilization of sisal juice for the production of pesticides and veterinary drugs;
- Use of sisal residue for animal feed;
- Development of fiber reinforced composite materials;
- Production of edible mushrooms grown on sisal residues.

In their latest report, the project members reserved over R$ 19.3 million for investments into sisal related R&D (SECTI, 2013). It is worth mentioning that earlier efforts to design safer and more efficient decorticators have not been very successful. Although several models have been designed that virtually eliminate the risk of accidents, none could match the mobility and productivity of the *paraibana* machine, which remains the most popular model (Alves & Santiago, 2004; Campbell, 2007).

6.8.2. RESULTS AND INTERPRETATION

A concise overview of programs and other efforts shows that the *Bolsa Família* and PETI programs have been able to reduce poverty and child labor throughout Brazil and in Bahia in particular. Furthermore, cooperation of unions, local organizations, NGO's and the government in the CODES sisal follows the broad aim of sustainable social, economic and environmental development of the sisal territory. Its success will have to be determined in the future. Although the influence of R&D has been limited so far, efforts through the CODES sisal and the sisal base technology project may increase sisal yields, safety and earnings for the people in the sisal sector. Given the large number of projects and institutions involved, it is not possible to give an exhaustive overview of all relevant sustainable development commitments. Also, most programs do not produce immediate and easily measurable benefits. However, it is clear that both the Brazilian government and a large number of organizations and institutes are concerned with social and economic problems in general and in the sisal sector in particular.

7. INTEGRATION OF RESULTS

In this chapter, the results of the LCA, S-LCA and LCC are brought together to identify several important interrelationships between the environmental, social and economic characteristics of the Brazilian sisal fiber production system. Studying these interrelationships can reveal both trade-offs and reinforcing effects between the three 'pillars' of sustainability, which could be overlooked in conventional, single-issue analyses.

The Brazilian sisal fiber production system is characterized by the low level of mechanization and the use of mainly manual and animal labor. In this study, manual labor does not cause any environmental impacts within the considered impact categories. However, manual labor does significantly affect the breakdown of the sisal fiber production costs, where labor amounts to ca. 82% of the total cost. From a cost perspective, the amount of labor would ideally be decreased through increased mechanization. However, since the high labor demand per ton sisal generates employment for tens of thousands of unskilled workers in the region, a decrease of the labor demand is not desirable from a social perspective. Furthermore, the comparison with Tanzanian sisal fiber showed that increased mechanization of the sisal sector may also have negative impacts regarding the environmental sustainability.

Wages represent a similar trade-off. Higher wages can promote economic development in the region, lower poverty and increase the participation of women in the sector. Furthermore, poverty can be an important driver for child labor, as it is often used to supplement a family's total income. However, if all sisal laborers would receive at least the minimum wage, the production costs of sisal fiber would be ca. 77% higher. Higher production costs could reduce the competitiveness and reduce demand of Brazilian sisal fiber. As a result, demand could shift to other, cheaper natural fibers or natural fibers produced in lower cost regions. The poorest workers currently depend on the *Bolsa Família* and other government programs to provide an additional income. These programs come at a cost for the Brazilian taxpayers. However, for the sisal sector this construction may offer some advantages compared to having all sisal laborers receiving at least the minimum wage; Brazilian sisal fiber can remain competitive on the world market and jobs and production are preserved, while the poorest workers receive financial aid. At the same time, the FUNRURAL social security fund reduces the financial vulnerability of rural laborers against illness, disability, old age and death.

Finally, the replacement of old and poorly maintained decorticators and brushing machines may lead to reinforcing effects between the three pillars of sustainability. Decortication, brushing and baling of sisal in Brazil have a NREU that is more than two times higher than in Tanzania. Furthermore, old machinery is connected with poor sisal fiber quality and severe occupational accidents. Developing and investing in new machinery can reduce environmental impacts, reduce the occurrence of accidents and improve sisal fiber quality. Higher quality fibers may yield higher prices on the world market, thereby contributing to local economic development. Although these investments may be too expensive for the machine owners themselves, R&D programs funded by unions, local organizations, research institutes and the government, can play an important role by developing and funding improved equipment for the sisal sector.

8. DISCUSSION

In this section, the methodological choices, data, validation and uncertainty of the present work are critically reviewed. Uncertainties in the S-LCA data are discussed in the interpretation of the respective sections. Furthermore, LCSA and S-LCA are briefly discussed in light of their recent development and current limitations.

Methodological choices

The most important methodological choices made were concerning the scope, the allocation method and the impact categories. Regarding geographical coverage, this study aimed to present the typical sisal fiber production system in Brazil. It is important to note that many aspects such as cultivation and production methods, wages and social situations, can vary per location and that there are specific locations or sisal suppliers in Brazil for which some of the issues discussed do not apply. In case a specific sisal supplier is used, an analysis specified on the related supply chain can give more accurate results for the sisal fiber that is used. Furthermore, the impact of the temporal scope is expected to be large. As was seen in paragraph 2.3.5, sisal prices and production are volatile. This can have an effect on the data used for the LCC and the use of economic allocation in the LCA and LCC. However, a comparison between mass allocation and economic allocation has shown that the difference in results is smaller than 10%.

For the LCA, two impact categories were chosen that are easy to interpret and feasible with regard to data collection. Although there are more comprehensive impact assessment methods available, NREU is regarded as a good proxy indicator for many environmental impacts.

Due to the cradle-to-port system boundaries and company perspective, the LCC in this study did not cover the full life cycle cost of sisal FRP's but was limited to providing a breakdown of the cost of baled sisal fiber. The costs associated with environmental impacts or accidents were not included since they are not expected to be internalized in the sisal fiber price and are currently not paid by actors within the sisal sector. However, including the costs of these so-called externalities, the costs related to the use phase and to the end-of-life of the material, would to give a more accurate measure of the economic sustainability of the use of Brazilian sisal in FRP car parts. Taxes were not specifically considered, but are included in the final sisal fiber price. Since the labor costs of the *batedeira* owner were calculated from the final sisal fiber price minus expenses, the labor costs for the *batedeira* owner may be slightly overestimated. Furthermore, since no discount rate was used, the cost of equipment was likely overestimated. However, since the cost of equipment is small in comparison to labor and energy cost, the effect on the final result is estimated to be limited.

The choice of S-LCA impacts categories was based on an initial social hotspot assessment and the subcategories proposed by UNEP/SETAC. Since the hotspot assessment was based on literature, it is bound to uncover only social impacts that have been documented earlier by others. Including additional social impacts may give a more complete picture of the social situation in the sisal sector. For example, including social impacts from the "local community" stakeholder category may reveal positive consequences of economic development on local communities or negative consequences caused by low wages and child labor. Furthermore, investigating social impacts from the "value chain actors" stakeholder category may give more insight into how choices between suppliers are made. However, the chapter on S-LCA was reviewed by an expert on the social situation in Bahia to ensure that the most important social impact categories were selected for this study.

To fit the specific case study, the interpretation of some social subcategories in this study differs from the definitions proposed by UNEP and SETAC. For example, the impact category "Public commitments to sustainability issues" was used to investigate activities by secondary stakeholders to solve sustainability issues instead of focusing on the sustainability policy of one specific company. For some impact categories, designing quantitative indicators was either not feasible due to data availability (e.g. freedom of association and collective bargaining) or was not considered the preferred method to convey the complexity of the social situation (e.g. social benefits/social security). However, the S-LCA guideline allows for such adaptations (UNEP/SETAC, 2009).

Data

Since it was not possible to visit Brazil for this study, data collection was limited to literature, LCA databases, statistical data and a questionnaire sent to local organizations and experts. For lack of more specific data, LCA background data from the Ecoinvent database was used for several processes, such as mechanical land preparation, local transport, and transport to port. Since the sisal sector is known for its low technological level, standard data is possibly not representative for the average equipment used in the sisal sector. This is mainly relevant for the transportation to the port, since this process has a large influence on the final results. Ideally, local data on average truck fuel efficiencies would be used. Furthermore, the functionality of 1 ton sisal fiber may not be equivalent with the functionality of 1 ton of glass fiber. However, the LCA database allows comparisons of different weight ratios to be made if required. Furthermore, the difference in environmental impacts is so large, that sisal fiber retains its environmental advantage over glass fiber at any conceivable weight replacement ratio for FRP's.

To validate the LCA results, the NREU and GHG emissions were compared to the impacts related to the production of jute and kenaf fibers in India, present in the Ecoinvent database (v.2: Jute fibres, rainfed system, at farm/IN and Kenaf fibres, at farm/IN). The NREU is ca. 13% higher for jute and kenaf fiber production, while GHG emissions are approximately 3 times higher. This latter difference can be explained by the use of a retting process to extract jute and kenaf fibers, in which large amounts of methane are released.

There are also uncertainties in the LCC data. However, since the final selling price of sisal fiber in 2011 is known, the uncertainty lies in the cost breakdown and not in the total production costs. The LCC results suggest that the life cycle cost is strongly dependent on local wages and energy costs (ca. 91%), but less influenced by material and equipment costs (ca. 9%). Therefore, fluctuations in the costs of diesel and electricity and variations in the local wages also represent the largest uncertainties for the LCC results. Although the costs of specific equipment were estimated based on literature sources and typical lifetimes and maintenance costs were assumed, the impacts of these assumptions are likely small due to the relatively low importance of equipment costs (ca. 6%).

S-LCA method

S-LCA and LCSA are both fairly new in literature and are still surrounded by many methodological uncertainties. With this case study, these methods were tested in practice. The S-LCA method as described by UNEP/SETAC was found to be a good tool to scan for possible social issues or benefits related to a product or production system. However, the method is highly dependent on the availability of data. Finding quantitative or qualitative information that fits the impact categories can be very time consuming and determine how the indicators are operationalized. Furthermore, the fact that many social impacts are not directly linked to a single process step in sisal fiber production limits the possibilities of expressing the S-LCA results per functional unit. This is related to the issue of unclear impact pathways and causal links (section 3.1), which make it hard to draw unequivocal conclusions from the S-LCA results; although it is clear that the sisal sector is troubled by several social problems such as child labor or discrimination, it cannot be stated that these problems are necessarily caused by the production of sisal fiber. This also means that attempts to solve these problems should not be limited to the sisal sector.

LCSA method

The LCSA method intends to integrate the assessment of the three pillars of sustainability. Key characteristics are the drawing of a concerted goal and scope for the three assessments and the integrated interpretation of the results. While the former does not yield difficulties, the lack of a guideline on the integration of results leaves this final and crucial aspect open to the preferences of the researcher. Further research must show whether a general structure for this integration, for example grouping the results of the three analyses by life cycle process, is desirable and feasible. Again, the unclear social impact pathways make it hard to relate social issues or benefits to environmental or economic aspects.

9. CONCLUSION

The sisal fiber production system in Brazil is characterized by small family farms, traditional agricultural techniques and a high share of manual labor. This allows the production of sisal fiber in Brazil to have environmental impacts that are between 41% and 61% lower compared to the production of sisal fiber in Tanzania and ca. 93% lower compared to the production of glass fiber. The use of inefficient machinery for the decortication process causes the highest environmental impacts (55%), while a comparison with Tanzania shows that this process has ample room for improvement. The economic assessment also indicates that manual labor plays a crucial role. Although labor costs are relatively variable due to varying regional labor costs, an estimated 82% of the production costs are labor costs. Reducing these costs can only be achieved by reducing the labor demand for production or by lowering wages. The analysis of important social issues in the sisal sector and the region showed that there are significant social problems such as gender discrimination and the possible use of child labor. Furthermore, most wages in the sisal sector are significantly below the minimum wage and the occupational accident rate is high. These issues, however, are not limited to the sisal sector and may also be present in other local production systems. There are also positive social aspects; workers are free to organize in the rural labor unions and the social security scheme can provide benefits for illness, disability, retirement etc. Furthermore, the sisal sector contributes to local socio-economic development through providing jobs and income to many unskilled workers. Finally, the Brazilian government, local organizations, scientific institutions and labor unions are working together to actively address general issues such as poverty and child labor, and sisal specific issues such as inefficient machinery and limited utilization of the sisal plant.

By integrating the results of the three assessments, several interrelationships between the three pillars of sustainability were identified: (1) Using manual labor has high costs but limits environmental impacts and has positive social impacts by offering many jobs for unskilled laborers; (2) Low wages in the sisal sector can cause poverty and other social problems, but keep the Brazilian sisal competitive. Relieving some of these social problems through government programs rather than through higher wages may offer some advantages for the sisal sector since competitiveness is not adversely impacted; and (3) Improved decorticators and brushing machines can limit the occurrence of accidents, reduce energy use, and improve fiber quality and prices. The development of improved machinery can be financed by scientific institutes, unions, governments and various organizations through R&D programs.

For car manufacturers such as Ford Motor Company, it is important to carefully choose the sisal fiber suppliers to make sure that international labor standards are safeguarded. Furthermore, to help solve some of the sustainability issues in the sisal sector and region, it must be recognized that the preferred solutions are those that relieve problems from all dimensions of sustainability. For example, contributing to existing R&D and other sustainability programs may help improve the social situation in the sisal sector and the entire region, but also improve environmental performance and improve the sisal fiber quality and yield.

Future research should focus on the following points: (1) LCSA studies into later life cycle stages such as the use phase and end-of-life of sisal FRP's to get more accurate results on the total sustainability of sisal FRP car parts; (2) LCSA studies on specific sisal fiber supply chains in Brazil to uncover local differences; (3) Further studies into social issues such as the adequacy of the minimum wage and more reliable data on the use of child labor in the sisal sector; and (4) Further application and theoretical work on the S-LCA and LCSA methods to solve some of the methodological uncertainties that still remain.

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11. APPENDIX

A. Social impact subcategories

Stakeholder categories	Subcategories
Stakeholder "worker"	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities/Discrimination Health and Safety Social Benefits/Social Security
Stakeholder "consumer"	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Stakeholder "local community"	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder "society"	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors* not including consumers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

FIGURE 22: SOCIAL IMPACT SUBCATEGORIES PROPOSED BY UNEP AND SETAC (SOURCE: UNEP/SETAC, 2009)

B. Sisal questionnaires

Questionnaire for Embrapa & Sindifibras

Data questions

For questions 1-4, please fill in the table below.

1. In what mass ratio are lower quality (tow & refugo), medium/high quality (type 2 & 3) and highest quality (type 1 and superior) sisal fibers typically produced on farms in Bahia?
2. At which price levels were these different qualities of sisal sold by farmers/machine-owners in Bahia in 2011? (CONAB lists a price of R$ 1.04/kg for type 2 sisal in 2011).
3. If sisal is bought by a middleman (atravessador) at the farm and sold on to a brushing facility (batedeira), what were the typical earnings for the middleman per ton dry fiber in 2011? (According to a source, the middleman received 4-6 centavos per kg in 1996).
4. At which price levels were brushed and baled sisal fiber of different qualities sold in Bahia in 2011? (CONAB lists an export FOB price of US$ 800/ton = R$ 1360/ton for type 2 sisal in 2011).

Bahia 2011	Lower quality sisal	Medium/high quality sisal	Highest quality sisal
1. Mass ratio			
2. Price level at farm (R$/ton)			
3. Earnings middleman (R$/ton)			
4. Price level brushed & baled sisal fiber (R$/ton)			

5. Sisal is used in fiber reinforced polypropylene composites for automotive applications. Where in Brazil/Bahia are these composites for automotive applications produced?

Open questions

- Which aspects make sisal cultivation and processing so important for the northeast of Brazil?
- What are the most significant social, socio-economic and environmental issues related to sisal cultivation and processing in the northeast of Brazil?
- How, in your view, is your organization involved in improving the socio-economic situation of people involved in the sisal production system?

Questionnaire for APAEB, MOC & FATRES

Data questions

1. What percentage of workers at sisal farms has official contracts with their employer?
2. What percentage of workers in the batedeiras has official contracts with their employer?
3. What percentage of sisal workers are members of labor unions?
4. What is the participation rate of women in the sisal sector?
5. At what percentage of farms in Bahia is motorized equipment (e.g. tractors) used for preparing and maintaining the sisal fields?
6. At what percentage of farms are fibers washed after decortication?
7. If so, how much water is used per ton of sisal fiber?
8. What is the electricity requirement for a fiber brusher in kWh per ton sisal fiber?
9. What is the electricity requirement for a baling press in kWh per ton sisal fiber?
10. What were typical daily wages in 2011 for:
    - 10.1. Sisal workers at the farm and decorticator
    - 10.2. Workers in the batedeiras
    - 10.3. Other workers in the sisal supply chain (e.g. truck drivers)
11. In what mass ratio are these types of sisal fibers typically produced on farms in Bahia?
    - 11.1. Lower quality (tow & refugo)
    - 11.2. Medium/high quality (type 2 & 3)
    - 11.3. Highest quality (type 1 and superior)

Open questions

12. What is typically done with the boles of old sisal plants?
13. According to a presentation by SEAGRI, building a new stationary community decorticator facility would cost ca. R$ 400,000. Would the cost for a new brushing and baling facility be similar?
14. What is the role of sisal labor unions?
15. Do sisal workers have right on a pension and other social security benefits?
16. Is the official minimum wage adequate for families to provide for their basic needs?
17. According to our calculations based on IBGE data, an estimated 10,000 children aged 10-17 were working in the sisal fields in Bahia in 2011. Do you think this estimate is accurate?

General questions

- Which aspects make sisal cultivation and processing so important for the northeast of Brazil?
- What are the most significant social, socio-economic and environmental issues related to sisal cultivation and processing in the northeast of Brazil?
- How, in your words, is your organization involved in improving the socio-economic situation of people involved in the sisal production system?

C. SimaPro process inventories

The sisal fiber production process is modeled in SimaPro 7 to calculate the non-renewable energy use and contribution to climate change using the built-in characterization methods. The foreground data is described in section 4.1. All background data and processes used are from the Ecoinvent v.2 database.

Five main processes and two alternative scenarios (6a and 6b) are constructed:

1. Manually harvesting sisal plantlets from suckers in a mature sisal field.
2. The cultivation of sisal without machinery.
3. The cultivation of sisal with machinery.
4. The production of 3 quality levels of sisal fibers from sisal leaves.
5. The transportation of high quality baled sisal fiber from the *batedeira* to the port of Salvador.
6. a. The transportation of high quality baled sisal fiber from the *batedeira* to the molding factory near São Paulo by truck.
   b. The transportation of high quality baled sisal fiber from the *batedeira* to the molding factory near São Paulo by truck and ship.

Process 1 yields the plantlets for process 2 and 3. Process 4 uses sisal leaves from process 2 and 3 in a 1:1 ratio. Process 5 uses only the high quality sisal fiber produced in process 4. Processes 6a and 6b also use only the high quality sisal fiber produced in process 4. The LCA inventory used for SimaPro modeling is shown in Table 18 below. Bold text represents an output to the technosphere, italic text stands for an input from nature and the remaining inputs are from the technosphere.

No specific data on mechanical land preparation processes in the Brazilian sisal sector were found. Therefore, three representative processes are used: (1) tillage, ploughing/CH; (2) tillage, harrowing by rotary harrow/CH; and (3) tillage, harrowing by spring tine harrow/CH.

Since no decortication process existed in the database, a new process, “Diesel, burned in mobile decorticator/BR” is created based on the process “diesel, burned in building machine/GLO”. The new process features a diesel – lubricating oil use ratio of 40:1, as found in literature (Embrapa, 2014).

For the local transport, the process “Transport, tractor and trailer/CH” is used. For the transportation to the port or to the molding factory, the process “Transport, lorry 3,5-16t, fleet average/RER” is used. Finally, for the transportation by ship, the process “Transport, transoceanic freight ship/OCE” is used.

TABLE 18: LCA INVENTORY

Processes	Value	Unit	Comment
1. Sisal plantlets, at field/BR	1	p	Transplanted from mature field
2. Sisal leaves, at field, w/o machinery/BR	25	ton	Yields 1 ton fiber
Occupation, arable, non-irrigated	1	ha a	
Transformation, from arable, non-irrigated	1	ha	
Transformation, to arable, non-irrigated	1	ha	
Carbon dioxide, in air	1539	kg	See calculation in section 4.1.2
Sisal plantlets, at field/BR	500	P	4000p/ha / 8 tons of fiber
3. Sisal leaves, at field, with machinery/BR	25	ton	Yield 1 ton fiber
Occupation, arable, non-irrigated	1	ha a	
Transformation, from arable, non-irrigated	1	ha	
Transformation, to arable, non-irrigated	1	ha	
Carbon dioxide, in air	1539	kg	See calculation in section 4.1.2
Sisal plantlets, at field/BR	500	P	4000p/ha / 8 tons of fiber
Tillage, ploughing/CH	0.125	ha	1 ha divided by 8 tons of fiber
Tillage, harrowing, by rotary harrow/CH	0.125	ha	1 ha divided by 8 tons of fiber
Tillage, harrowing, by spring tine harrow/CH	0.125	ha	1 ha divided by 8 tons of fiber
4. Sisal fibers, high quality (type 1), baled, at factory/BR	1	ton	Allocation: 0.344
4. Sisal fibers, medium quality (type 2, type 3), baled, at factory/BR	1.67	ton	Allocation: 0.479
4. Sisal fibers, low quality (refugo), baled, at factory/BR	0.67	ton	Allocation: 0.177
Water, unspecified natural origin/kg	250	kg	250 liter
Sisal leaves, at field, with machinery/BR	42	ton	50% x 3.33 x 25 ton
Sisal leaves, at field, w/o machinery/BR	42	ton	50% x 3.33 x 25 ton
Diesel, burned in mobile decorticator/BR	4800	MJ	40 l/ton x 3.33 ton x 36 MJ/l
Transport, tractor and trailer/CH	87	tkm	26 km x 3.33 ton
Electricity, medium voltage, production BR, at grid/BR	67	kWh	20 kWh/ton for brushing
Electricity, medium voltage, production BR, at grid/BR	27	kWh	8 kWh/ton for pressing and baling
5. Sisal fibers, high quality (type 1), baled, at port/BR	1	ton	Functional unit is type 1 sisal fiber
Sisal fibers, high quality (type 1), baled, at factory/BR	1	ton	
Transport, lorry 3,5-16t, fleet average/RER	340	tkm	See section 4.1.6
6a. Sisal fibers, high quality (type 1), baled, at molding factory/truck/BR	1	ton	
Sisal fibers, high quality (type 1), baled, at factory/BR	1	ton	
Transport, lorry 3,5-16t, fleet average/RER	2000	tkm	See section 4.1.6
6b. Sisal fibers, high quality (type 1), baled, at molding factory/ship/BR	1	ton	
Sisal fibers, high quality (type 1), baled, at factory/BR	1	ton	
Transport, lorry 3,5-16t, fleet average/RER	400	tkm	See section 4.1.6
Transport, transoceanic freight ship/OCE	2000	tkm	See section 4.1.6

D. Sisal producing municipalities

Using Figure 23, the municipality of Ponto Novo (black dot) is estimated to be the geographical center of gravity of the sisal fiber production in Bahia in 2011. The distance to Salvador de Bahia (red dot) is 340 km over the road.

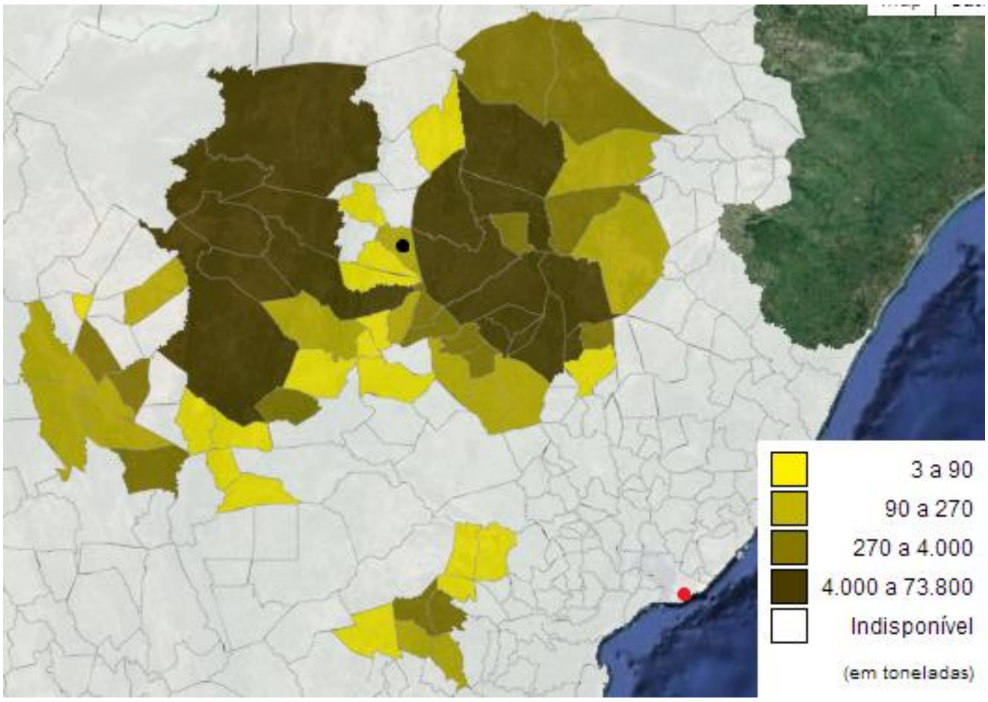

FIGURE 23: SISAL FIBER PRODUCTION IN BAHIA IN TONS PER MUNICIPALITY IN 2011 (IBGE, 2014A)

E. Overview labor requirement

TABLE 19: LABOR REQUIREMENT LAND PREPARATION, SISAL CULTIVATION AND DECORTICATION (EMBRAPA, 2014)

Specification	**Amount**	**Unit**
Land preparation		
Plowing and disking	6	Machine hours
Land cleaning	4	Machine hours
Collecting remaining material	2	Machine hours
Cultivation		
Marking, preparation of pits and planting seedlings	8	Man days
Weeding – hoeing (1st year)	16	Man days
Weeding (2nd year)	12	Man days
Stump removal (from 3rd year)	8	Man days
Eradication of suckers (from 3rd year)	6	Man days
Distribution of sisal waste (from 3rd year)	5	Man days
Field restoration		
Removal of suckers and stumps	16	Man days
Removal of old plants	5	Man days
Recovery of the plant stand	5	Man days
Weeding – hoeing (1st year)	8	Man days
Weeding (2nd year)	4	Man days
Decortication		
Removal of suckers and stumps	5	Man days
Cutting leaves	5	Man days
Transportation of leaves	5	Man days
Decortication	10	Man days
Waste removal	5	Man days

F. Inventory child labor

TABLE 20: CHILDREN WORKING IN AGRICULTURE, FISHERIES, FORESTRY AND AQUACULTURE IN SISAL PRODUCING MUNICIPALITIES BAHIA 2011 (SOURCE: IBGE, 2014A)

Municipality	Age 10-13	Age 14-15	Age 16-17 (w/o contract)
Andorinha	101	50	112
Araci	643	679	461
Barra do Mendes	36	30	59
Barro Alto	216	161	177
Barrocas	217	138	160
Bonito	271	141	192
Brejões	17	26	30
Caém	76	74	65
Caldeirão Grande	183	131	115
Campo Formoso	496	573	551
Canarana	220	279	309
Cansanção	530	287	328
Canudos	127	66	105
Capela do Alto Alegre	58	61	80
Capim Grosso	97	129	137
Conceição do Coité	393	317	328
Cravolândia	40	29	40
Euclides da Cunha	219	245	301
Gavião	6	19	35
Ibipeba	42	78	91
Ibititá	49	53	155
Irajuba	28	13	27
Iraquara	169	118	163
Itatim	11	41	37
Itiúba	347	232	361
Jacobina	279	227	244
João Dourado	87	97	267
Lajedinho	24	21	23
Mairi	126	89	118
Miguel Calmon	170	159	271
Milagres	25	5	14
Mirangaba	109	141	189
Monte Santo	597	443	465
Morro do Chapéu	242	211	203
Nordestina	216	109	107
Nova Fátima	23	9	23
Nova Itarana	43	10	27
Ourolândia	119	93	108
Pé de Serra	132	103	113
Pindobaçu	82	28	49
Piritiba	193	154	75
Planaltino	42	65	62
Ponto Novo	107	118	62
Presidente Dutra	39	67	102
Queimadas	253	207	161
Quijingue	276	267	157
Quixabeira	58	53	42
Retirolândia	34	76	90
Riachão do Jacuípe	203	56	103
Santa Inês	0	6	3
Santaluz	153	64	163
Santa Teresinha	56	26	69
São Domingos	19	22	52
São José do Jacuípe	64	75	80
Serrinha	634	436	408

Serrolândia	47	49	65
Souto Soares	363	178	214
Tapiramutá	0	38	47
Teofilândia	144	273	162
Tucano	311	298	215
Uauá	121	62	131
Umburanas	20	41	65
Utinga	59	84	82
Valente	109	86	118
Várzea do Poço	28	24	72
Várzea Nova	68	80	90
Wagner	46	34	69

TABLE 21: PRODUCTION VALUE SISAL IN 2011 AND GROSS PRODUCT FROM AGRICULTURE IN 2011 (SOURCE: IBGE, 2014A)

Municipality	**Production value sisal (thousand R$)**	**Gross product agriculture (thousand R$)**
Andorinha	19	5,183
Araci	11,880	14,695
Barra do Mendes	98	7,937
Barro Alto	159	7,339
Barrocas	4,910	3,107
Bonito	7	79,130
Brejões	371	44,904
Caém	32	4,434
Caldeirão Grande	45	5,540
Campo Formoso	73,800	47,125
Canarana	425	15,167
Cansanção	5,400	11,502
Canudos	417	8,976
Capela do Alto Alegre	225	5,300
Capim Grosso	367	5,639
Conceição do Coité	21,120	23,477
Cravolândia	85	5,145
Euclides da Cunha	183	11,567
Gavião	324	2,818
Ibipeba	204	7,187
Ibititá	245	16,893
Irajuba	148	5,727
Iraquara	630	15,351
Itatim	18	3,074
Itiúba	5,393	12,235
Jacobina	12,285	27,584
João Dourado	87	30,073
Lajedinho	14	4,055
Mairi	18	5,784
Miguel Calmon	131	13,259
Milagres	99	2,364
Mirangaba	4,725	14,609
Monte Santo	6,480	14,184
Morro do Chapéu	14,976	39,209
Nordestina	1,584	2,707
Nova Fátima	378	2,990
Nova Itarana	630	4,374
Ourolândia	9,360	17,534
Pé de Serra	135	7,339
Pindobaçu	35	4,117
Piritiba	42	10,219
Planaltino	78	7,069
Ponto Novo	217	15,429
Presidente Dutra	18	7,833
Queimadas	3,960	10,585
Quijingue	2,376	10,454
Quixabeira	122	2,388
Retirolândia	4,680	8,291
Riachão do Jacuípe	189	9,568
Santa Inês	143	2,897

Santaluz	27,720	19,139
Santa Teresinha	3	6,384
São Domingos	6,144	10,682
São José do Jacuípe	960	3,840
Serrinha	9	9,883
Serrolândia	35	4,426
Souto Soares	200	6,113
Tapiramutá	275	27,259
Teofilândia	1,237	3,926
Tucano	162	16,977
Uauá	432	19,821
Umburanas	4,040	8,032
Utinga	19	14,187
Valente	11,520	18,359
Várzea do Poço	72	4,212
Várzea Nova	13,728	14,103
Wagner	1	13,272
Total	255,824	844,982

TABLE 22: CHILDREN WORKING AND CHILDREN WORKING AND ALSO NOT ATTENDING SCHOOL IN SISAL PRODUCING MUNICIPALITIES BAHIA 2011 (SOURCE: IBGE, 2014A)

Municipality	Age 10-13 working	Age 10-13 working and not attending school	Age 14-15 working	Age 14-15 working and not attending school	Age 16-17 working	Age 16-17 working and not attending school
Andorinha	121	5	80	4	181	58
Araci	828	35	852	113	804	149
Barra do Mendes	69	4	72	0	137	30
Barro Alto	234	0	180	11	268	78
Barrocas	253	4	217	12	211	79
Bonito	331	7	199	31	287	64
Brejões	45	0	45	4	101	21
Caém	95	0	112	12	130	38
Caldeirão Grande	208	16	160	9	199	25
Campo Formoso	683	37	738	61	836	167
Canarana	356	12	384	51	614	141
Cansanção	586	8	377	42	454	110
Canudos	159	0	91	11	176	10
Capela do Alto Alegre	71	0	92	12	152	52
Capim Grosso	224	12	207	22	406	164
Conceição do Coité	626	27	570	37	719	203
Cravolândia	52	2	42	2	80	7
Euclides da Cunha	320	21	437	43	652	223
Gavião	9	0	26	4	56	13
Ibipeba	69	6	145	14	154	35
Ibititá	135	11	104	22	225	59
Irajuba	43	2	31	5	53	11
Iraquara	184	16	153	6	259	63
Itatim	32	0	130	20	157	54
Itiúba	514	39	385	36	533	106
Jacobina	485	23	500	129	770	204
João Dourado	143	33	169	27	377	128
Lajedinho	24	0	24	3	23	15
Mairi	162	13	131	15	241	82
Miguel Calmon	227	20	202	43	380	125
Milagres	40	0	25	0	92	32
Mirangaba	158	5	187	0	250	54
Monte Santo	711	11	502	33	722	98
Morro do Chapéu	383	30	315	80	371	105
Nordestina	216	0	128	11	148	19
Nova Fátima	27	0	24	3	66	20
Nova Itarana	57	0	39	3	36	8
Ourolândia	163	4	140	8	226	57
Pé de Serra	171	6	138	0	238	37
Pindobaçu	136	8	98	0	150	48
Piritiba	236	23	237	18	193	34
Planaltino	59	5	108	6	119	12
Ponto Novo	132	0	152	17	143	33
Presidente Dutra	58	5	73	6	143	32
Queimadas	307	11	304	10	301	71
Quijingue	328	0	330	32	249	49
Quixabeira	95	7	82	0	96	11
Retirolândia	52	0	97	4	130	21
Riachão do Jacuípe	252	10	165	10	317	65
Santa Inês	28	7	21	0	53	5
Santaluz	240	20	131	0	349	117
Santa Teresinha	79	4	37	5	88	18
São Domingos	25	0	54	5	99	31
São José do Jacuípe	86	3	127	17	144	34
Serrinha	779	17	778	63	857	172

Serrolândia	66	0	135	6	158	31
Souto Soares	404	5	196	16	258	78
Tapiramutá	4	0	63	15	130	54
Teofilândia	166	11	283	41	300	47
Tucano	509	25	515	7	638	189
Uauá	201	0	92	14	222	46
Umburanas	29	0	79	15	114	26
Utinga	72	13	153	37	290	30
Valente	182	11	169	0	273	38
Várzea do Poço	64	0	54	0	138	17
Várzea Nova	94	12	138	19	166	56
Wagner	50	11	49	5	91	49
Total	13947	617	13073	1307	17993	4358