Master Thesis
MSc Sustainable Business and Innovation

The environmental performance of footwear in an eco-friendly company and recommendations to increase sustainable value creation

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Word count: 19603

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ABSTRACT

The fashion industry ranks among the world's most polluting sectors, where the production of footwear plays a significant role in terms of sales and environmental impact. The manufacturing of conventional footwear uses synthetic rubber, genetically modified cotton, chromium tanned leather, and chemical-based adhesives. The production and disposal of these materials require large quantities of water and energy, contribute to GHG emissions and produce toxins that are harmful to both human and ecosystem health. To address these issues, some companies have started to identify ways to embrace sustainability as a business opportunity, by using non-conventional materials in their products or adopting alternative business models. Nonetheless, due to the wide range of natural and synthetic materials and several footwear designs, it is extremely difficult for companies to implement the findings from previous studies regarding sustainable value creation in the footwear industry.

To assess the environmental performance of footwear made with alternative materials, a Life Cycle Assessment is carried out for three different footwear models. The vast majority of the impact is incurred during the upstream processes, whereas the transport of materials to shoe manufacturer, production and assembly of the footwear, as well as its distribution and end of life have a minor contribution to the overall impact of the product. Using this approach, it is estimated that the impact of the model with the highest amount of alternative materials has the best environmental performance. Moreover, the foremost culprit for the performance of the other two models is the leather, since the material is responsible for not less than 70% of their total impact.

Furthermore, a range of interviews and an online survey are conducted to understand the main drivers of shareholder and stakeholder value. Thereby, based on the findings of the LCA and interviews, an array of recommendations are proposed to increase the sustainable value creation of an eco-friendly footwear company.

ACKNOWLEDGEMENTS

During my Master studies, I decided to write my thesis about sustainable fashion, so I sent my curriculum to all sizes and different types of companies working in this business. From companies in Portugal to Sweden, they all got my CV. I received many negative answers, and some companies did not reply to my emails. In the end, I had three options to choose, two in the Netherlands, where I lived for one year and a half and where some of my dearest friends were, or to move to Paris and start – again – a new journey.

Finding a new place to live, getting used to a new routine, living in France without speaking a word of French, and of course, writing this Master thesis wouldn't be possible without the support and encouragement of many people. A special thanks to my supervisor, Ernst Worrell, for the patience and support throughout this process and to Blanca, my second reader for helping me with SimaPro. I would like to express my gratitude to my Parisian flatmates and VEJA team for welcoming me and switching to English every time I was around. To the VEJA team in Brazil, Ramarim and suppliers that collaborated to this study, thanks for explaining all the processes and answering my endless questions. My dear friends in Utrecht, Giulia pinnolona, Marina, Laurita and Susi that are part of the most remarkable memories I have from the Netherlands, thank you. I miss you very much, and your support gave me the strength to continue this adventure. I am thankful to Raphael who encouraged me to follow my dreams and recalled me of how brave and strong I am during the moments I was feeling down. My gratefulness to my Brazilian friends that after two years living abroad did not give up on our friendship and for making me feel like I've never left.

A big thanks to my older sisters that taught me how to defend myself and to stand for what believe. My infinite gratitude and love to my mom, for being my role model of woman and greatest example of braveness, and to my biggest supporter and source of inspiration, my dad. Lastly, thank you Dona Jô for supporting me through your daily prayers and to my angel, Ana who has always been protecting and guiding me.

ACRONYM GUIDE

CO_2	-	Carbon dioxide
CVP	-	Coagulated Latex Blocks (Portuguese ‘Coágulo Virgem Prensado’ or CVP)
EPD	-	Environmental Product Declaration
ESCO	-	Energy service company
EVA	-	Ethylene-vinyl acetate
FDL	-	Liquid Smoking Sheet (Portuguese *‘Folha Defumada Líquida’*)
GHG	-	Global greenhouse gas
Kgkm	-	Kilogram-kilometre
LCA	-	Life Cycle Assessment
LCI	-	Life Cycle Inventory
LCIA	-	Life Cycle Impact Assessment
NGO	-	Non-Governmental Organization
NREU	-	Non-renewable energy use
PCR	-	Product Category Rules
PET	-	Polyethylene terephthalate
RSL	-	Restricted Substances List

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INTRODUCTION

1.1 Problem context

The industrial revolution marked a turning point in many aspects of human life and the way humans interact with the environment and planet earth. Industries started to replace manual labor with machinery, making the production of goods faster and more efficient. More recently, globalization and the excess of global labor supply have allowed companies to lower wages and avoid the environmental costs of their operations, leading to a decrease in the price of goods (Schor, 2005). The development of new products and technologies at accessible prices helped to improve the quality of life and promoted a steady growth in the economy (Hudson, 2015). Nonetheless, it also led to unrestrained consumption and substantial negative effects on the natural environment (Schmidheiny, 1992; World Commission on Environment and Development, 1987; World Resources Institute, 2003).

The current patterns of production and consumption accelerate the depletion of natural resources and cause irreversible damages to the ecosystem (UNEP, 2011; Vermeulen, 2015). Natural landscapes have given space to pasture, monoculture farming, and mining fields, resulting in biodiversity loss, surface-water degradation and loss of soil productivity. Furthermore, the unbridled combustion of fossil fuels used to produce and transport goods was identified as the foremost source of global greenhouse gas (GHG) emissions (IPCC, 2007, 2014). The high concentration of GHG in the atmosphere has led to an upsurge in the average temperature and altered the frequency and intensity of weather events, such as heat waves, droughts, floods, cyclones, and wildfires (IPCC, 2014). The present patterns of consumption have been polluting the environment not only during the production of goods, but also after its disposal, since it frequently contaminates the water, air, and soil. Indeed, the unsustainable patterns of consumption and production were recognized during the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, to be the major cause of the continued deterioration of the global environment (UNCED, 1992).

Nonetheless, since the Conference in 1992, significant efforts have been taken. In 2012, world leaders adopted the ‘10-Year Framework of Programmes on Sustainable Consumption and Production Patterns’ (10YFP) created by the United Nations Environment Programme (UNEP, 2013). The relevance of the topic was further strengthened with its inclusion as a standalone goal among the 17 Sustainable Development Goals, adopted by the world's heads of state and governments in September 2015 at the United Nations Sustainable Development Summit (UNEP, 2017; United Nations, 2015). Furthermore, there has been a substantial increase in public awareness and engagement regarding sustainability. Consumers have begun to demand information about materials and place of production, as well as to pressure companies to develop social and environmental strategies (Berry & Rondinelli, 1998; Fineman & Clarke, 1996; Harvey & Schaefer, 2001). As a consequence, companies have started to implement strategies concerning sustainable consumption and production and to be held accountable for their social and environmental impacts (Seuring & Müller, 2008).

1.2 Fashion Industry and Footwear

In the past decades, the fashion industry has become the focus of external stakeholders, such as non-governmental organizations, media, and customers especially due to its high rotativity and products at affordable prices (Reinecke & Donaghey, 2015). To ensure competitive prices and production volume, brand-owning companies have started to outsource the different stages of production – such as milling, dyeing, weaving, cutting and sewing – to other manufacturers (Abecassis-Moedas, 2006; Caniato et al., 2012). Usually, these manufacturers are located in low-cost economies, where national laws do not assure either a reasonable living wage and safe working conditions or environmental protection. In this manner, the accountability in the fashion industry has surpassed the boundaries of the companies and now comprises other tiers of the supply chain. In fact, brand-owning companies are presently not only responsible for the impact of their products, but also for the impacts caused along their supply chain (Koplin et al., 2007).

The fashion industry ranks among the world's most polluting sectors (Caniato et al., 2012; B. Shen et al., 2017). Within the industry, footwear plays a significant role in terms of sales and environmental impact (Luximon & Jiang, 2016). According to the World Footwear Yearbook, 23,5 billion pairs of footwear were produced worldwide in 2017, representing a growth of 15% within the last 4 years (APICCAPS, 2018). The manufacturing of conventional footwear uses synthetic rubbers, genetically modified cotton, chromium tanned leather, chemical-based adhesives, among others. The production and disposal of these materials require large quantities of water and energy, contribute to GHG emissions and produce toxins that are harmful to both human and ecosystem health (Albers et al., 2008; de Brito et al., 2008; Myers & Stolton, 1999). In fact, on average, a pair of running shoes releases approximately 15 kg of CO_2 emissions throughout its life cycle (Arcenas et al., 2010; Cheah et al., 2013). Considering the worldwide footwear production in 2017, the total CO_2 emissions resulting from footwear production was roughly 352 million tons, a number slightly higher than the annual CO_2 emissions of entire France, a country that is ranked number 18 among the world biggest CO_2 emitters (Global Carbon Atlas, 2018; World Footwear, 2017).

As a result of the significant impacts of footwear production and as means to respond to external pressure, brand-owing companies, for instance, Allbirds, Toms Shoes, and El Naturalista, have started to recognize the importance of sustainability in business and their role in contributing to a prosperous future. These companies have identified ways to embrace sustainability as a business opportunity. Thus sustainable value is created through their focus on improving environmental and social quality, while gaining competitive advantage and maximizing the interest of stakeholders, i.e. stakeholder value (Baitz et al., 2012; Bowen et al., 2001; Dean, 2014; Goldbach et al., 2003; Hart & Milstein, 2003; Kovacs, 2004; Manda et al., 2016; Meyer & Hohmann, 2000; Rao & Holt, 2005). These companies – in this study referred as eco-friendly – have started to use non-conventional materials in their products, to adopt alternative business models and to work in collaboration with their suppliers in order to improve the social and environmental performance of their products (Luximon & Jiang, 2016). Hence, eco-friendly companies are making a positive change while growing as a business.

1.3 Literature review & Research gap

In the past decades, the social issues in the fashion industry have been broadly discussed by media and the general public, especially after 2013 when the Rana Plaza building collapsed killing 1.134 people and injuring other 2.500. Nonetheless, most studies regarding sustainable value creation in the footwear industry are focused on the environmental dimension. Important analysis were conducted in order to get a deeper understanding of the environmental impacts of footwear production and suggest recommendations and strategies to enhance the environmental performance of the products (Albers et al., 2008; Cheah et al., 2013; Milà et al., 1998; Perdijk & Luijten, 1994; Perdijk et al., 1994). The vast majority of these studies applied the Life Cycle Assessment (LCA) tool to quantify and compare the environmental impacts of materials and processes and to identify critical areas of improvement.

The first life cycle assessment developed in the footwear industry was carried out by Perdijk, Luijten and Selderijk in 1994 with the focus on the eco-labeling of footwear. Their study set important measures that have been used in later attempts to develop LCA within the industry. Specifically, the authors delineated the function of footwear, which in this case is 'to cover or protect the foot' and defined the functional unit of footwear as 'one year of standard use (EPD International, 2013; Perdijk et al., 1994). The definition and adoption of a singular function is the first step to ensure that future studies are comparable and were developed under the same premises.

Subsequently, another significant study was conducted by Mila et al. in 1998. The study aimed at identifying the processes and materials with the most significant contribution to the total environmental impact of a pair of leather woman shoes. From cradle to grave, the major life cycle phases were considered, such as cattle raising, slaughterhouse, tanning, footwear manufacturing processes, use, distribution, and waste management. The study is limited by the fact that no complementary materials, for instance, plastics, synthetic rubber, chemical products, metallic complements were encompassed. Nonetheless, the authors suggested to include these materials in future applications since they might become important in specific types of shoes (e.g., rubber sole shoes). The results indicated the agricultural aspect of the footwear's life cycle as the main contributor to global warming, acidification, and eutrophication. In fact, according to the study, this stage of the life cycle of the product was responsible for roughly 40% of the total impact. Moreover, the study identified the electricity generation, its use during the footwear production and waste management to be responsible for significant environmental impacts, whereas the tanning process was described as the most problematic phase of the life cycle – mostly due to their water-related impacts. Finally, the study provides recommendations for improvements such as to reduce the consumption of tanning agents and electricity consumption, implement wastewater treatment and shift energy sources to renewable energy.

Furthermore, a comparative study was conducted by three Master's degree students from University of California, in which the environmental performances of three footwear using "green materials" were compared with the impact of a pair of conventional footwear (Albers et al., 2008). The study analyzed the environmental impact of products manufactured by the footwear brand Simple Shoes, where one model was made with traditional materials, and the three other models had green materials, such as organic cotton, bamboo, recycled materials, hemp, and jute in their composition. The results of the study showed that the model with the lowest environmental impact released 1,67 kg of CO_2 eq., while the footwear made with traditional materials emitted 7,51 kg of CO_2 eq. throughout their life cycle. In fact, the results indicate that the shoe made with traditional materials had significantly higher impacts in eight of the ten environmental categories analyzed and that in general, around 90% of the impacts occur during the material production and manufacturing phases.

Later, a study conducted by Cheah et al. (2013), examined the carbon footprint of a pair of running shoes produced in China. The study evaluated the carbon emissions from cradle to grave and encompassed data from raw material extraction and processing, waste, packaging materials, manufacturing and assembly, use and end of life disposal. The study identified the manufacturing process as being the largest contributor to carbon emissions, mostly due to its electricity use and coal combustion, representing 67.1% of the total emissions (14 kg CO_2 eq.). The remaining emissions are attributed to the extraction and processing of raw materials (28.3%) which are predominantly synthetic, and to the transport (1.8%), use (0.2%) and end of life (2.6%) of the product.

Lastly, brand-owing companies have also developed studies to quantify the environmental impact of their products. Puma reported the carbon footprint of one of their models as releasing 41 kg of CO_2 throughout its life cycle. In their study, the cattle and pig raising were identified as responsible for 94% of the total impact of the product (Puma, 2009). A similar study was conducted by Nike in which it was estimated that from cradle to grave, 18 kg of CO_2 equivalent is emitted to produce a pair of running shoes. The study identified the materials processing as being responsible for more than 50% of emissions (Nike, 2010). Moreover, the Italian brand AKU together with a consultancy company developed the only Environmental Product Declaration (EPD) of footwear available at the moment (AKU, 2017). The study was conducted in accordance with the Product Category Rules for leather shoes (UN CPC 2933) and indicates the extraction and preparation of raw and semi-finished materials as the most significant contributor to the environmental performance of the product in all five impact categories analyzed.

The wide range of natural and synthetic materials available in the market, different types of footwear as well as the several design options contribute to different environmental performances. Moreover, the results and strategies proposed are commonly influenced by the geography of the value chain and different distribution channels. Thus, it is extremely difficult for companies pursuing sustainability to implement the strategies and recommendations suggested in earlier studies (Milà et al., 1998; Muthu, 2013). Moreover, none of the previous studies assessed or included the interest of shareholders and stakeholders in the recommendations with the aim of increasing sustainable value creation. Hence, there is a clear need for further and specific research to quantify and address the environmental impacts of footwear products, while at the same time considering other aspects of sustainable value creation.

1.4 Research aim/ Research questions

Building on the gaps and limitations presented above, the primary goal of this study is the quantification of the environmental impacts of three different footwear made with alternatives materials and the identification of shareholders and stakeholders' value. Subsequently, based on the findings the secondary aim is to formulate strategies and recommendations regarding the use of materials and production processes throughout the footwear supply chain in order to increase the sustainable value of the eco-friendly company analyzed.

Having explained the problem context, the research focus, and existing gaps, the research aim is reformulated into the following research question:

RQ - What is the environmental performance of footwear made with alternative materials and which recommendations can be drawn to enhance the sustainable value of an eco-friendly company?

The research question is broken down into the following sub-questions:

SQ 1 - How is the supply chain of footwear made with alternative materials characterized?

SQ 2 - What is the environmental performance of footwear made with alternative materials and which phases of the footwear's life cycle and materials have the most relevant impacts?

SQ 3 - What are the main drivers of stakeholder and shareholder value in an eco-friendly footwear company, which sustainable value is already part of their strategy?

1.5 Relevance

In order to comprehend the materials and processes with the largest contributions to the environmental performance of each footwear, LCA studies are performed. To ensure consistency, the functional unit and system boundaries of this study are in line with earlier studies and documents regarding LCA for footwear. Furthermore, a series of interviews and an online survey are conducted to understand the main drivers of stakeholder and shareholder value.

From a scientific perspective, the relevance of the study lies in understanding the benefits of the use of alternative materials and the environmental impacts of the life cycle of footwear through the application of the LCA. The outcomes assist to a common understanding regarding the life cycle phases and materials that contribute the most to the environmental performance of footwear. Furthermore, the results of interviews and survey provide new insights into the main drivers of stakeholders and shareholder value in eco-friendly companies. The study also adds to the currently limited number of Environmental Product Declarations of footwear following the guidelines of Product Category Rules of leather footwear.

Moreover, the findings of the study provide recent and quantitative data on the environmental impacts related to the materials, assembly, and end of life of a pair of footwear. This gives eco-friendly footwear companies and other brand-owing companies the ability to understand the materials and processes with highest impacts throughout the life cycle of footwear, develop similar studies and to compare the environmental performance of their products with the results of this study. Lastly, the outcomes can be used by other companies or suppliers involved in the footwear production system to improve the environmental performance of their products and reduce the overall environmental impact of footwear.

1.6 Thesis structure

Following this introduction, the analytical framework of the study is explained in chapter 2. The chapter discusses Life Cycle Assessment and its different applications to create sustainable value. In chapter 3, the research design of the study is explained, as well as the goal and scope of the LCA. In chapter 4, the case study and alternative materials are introduced, and in chapter 5 the inventory analysis, results, and interpretation are presented. Subsequently, in chapter 6, the research question is answered, and recommendations to enhance sustainable value are proposed. Lastly, the study is concluded with a brief outlook and recommendations for further research in chapter 7.

ANALYTICAL FRAMEWORK

In the last decades, the pursuit of companies for high-quality products, low cost, short lead time and high customization in a globalized and interconnected world is leading to an upsurge in business complexity (Efthymiou et al., 2012). The wide range of products, manufacturing processes with contrasting characteristics and production spread all over the world have transformed the quest for sustainability in a challenge that frequently changes according to the context (Manda et al., 2016; Muthu, 2013).

Sustainability has been defined as the ability to “meet the needs of the present without compromising the ability of future generations to meet their needs” (World Commission on Environment and Development, 1987). Over time, three core areas of sustainability have been identified, namely social, economic and environmental. The economic aspect of sustainability is already highly embedded in companies as part of their cost control to reduce expenses and increase profitability through material and energy efficiency. The social and environmental dimensions, however, are been incorporated into business activities at a much slower pace.

To assist companies to assess the environmental and social aspects of products and projects, different tools have been developed, such as Social Life Cycle Assessment (S-LCA), environmental impact assessment (EIA), the system of economic and environmental accounting (SEEA), environmental auditing and material flow analysis (MFA) (Baumann & Cowell, 1999; Finnveden & Moberg, 2005; Muthu, 2013; Wrisberg et al., 2002). However, these tools are either not mature enough, as in the case of S-LCA, or do not simplify the understanding of business complexity and interdependence of production systems, while demonstrate the burdens associated with a product or process (Hart & Milstein, 2003; Manda et al., 2016; Milà et al., 1998).

The Life Cycle Assessment (LCA) is a standardized and universally accepted tool that allows practitioners and decision makers to understand in a comprehensive way the different environmental impacts associated to the life cycle of a product (Dal Lago, Corti, & Wellsandt, 2017;

European Commission, 2010; Sarode & Qureshi, 2017; SETAC, 1994). This is done through the selection of impact categories and compilation of inputs and outputs from all phases of production – i.e. from the extraction of raw materials, product's manufacturing, use, and end of life treatment, such as recycling, incineration or landfill (European Commission - Joint Research Centre - Institute for Environment and Sustainability, 2010; Huijbregts et al., 2006; ISO - The International Standards Organisation, 2006b). The outcomes of the LCA can be used by business as an instrument to create sustainable value since action might be taken to address global problems while adding value to shareholder and stakeholders. The various applications in which the LCA can be applied to create sustainable value are explained in the next paragraphs.

Industrial activity has grown to the point where the massive consumption and disposal of materials, together with the pollution from production processes and transportation are causing irreversible effects on the global environment. Through the application of the LCA, business can understand the potential environmental impacts of their products and identify key points of improvement and inefficiencies in the different phases of the product's life cycle (Albers et al., 2008; Manda et al., 2016). Based on these findings, companies are able to lower their contribution to the permanent environmental impacts by reducing energy, water, and materials consumption, as well as diminishing air pollution, waste production, and wastewater discharged. From a business point of view, the implementation of these practices may lower the costs of production, increase efficiency and ensure compliance with regulations, which consequently reduce risks and costs of operation while rising production (Hart & Milstein, 2003; Manda et al., 2016; Schaltegger & Figge, 2000).

Currently, we are living in an interconnected world where civil society and non-governmental organizations (NGOs) undertook the function of monitoring and enforcing social and environmental standards (Hart & Milstein, 2003). Stakeholders ability to exchange information makes almost impossible for companies to operate in secrecy, turning global sustainability into a challenge where firms must operate in a responsive and transparent manner (Hart & Milstein, 2003). In this context, LCA can be applied as means of product stewardship, where companies take responsibility for the product throughout its life cycle, since the tool contemplates the entire value chain of the product (Manda et al., 2016; Piekarski et al., 2013). Thus, the tool supports business to take responsibility for the environmental impacts of their products not only during production but also over its use phase where there might be energy consumption and waste production. Furthermore, companies are able to understand the characteristics of their product's life cycle that might draw the attention of policymakers, allowing them to be prepared for future regulations (Manda et al., 2016). Therefore, by involving critical external stakeholders – i.e., suppliers, customers, regulators, NGOs, and the media – during the decision-making processes, companies are more likely to survive and continue to profit (Clarkson, 1995; Hillman & Keim, 2001). Moreover, by acknowledging and incorporating the interest of stakeholders in a proactive and responsible approach, companies can differentiate themselves as well as enhance transparency, reputation, and legitimacy (Hart & Milstein, 2003; Manda et al., 2016).

As mentioned above, the LCA allows companies to understand the materials and processes that have the most significant environmental impact in the life cycle of a product (Manda et al., 2016; Piekarski et al., 2013). This powerful insight can be used not only to lower the environmental impacts of the product but can also lead to superior environmental performances through the development of innovative materials, disruptive technologies and business models. Innovation might also encompass the management of practices, where the use of alternative materials, selection of different suppliers and collaboration with key actors of the value chain might lower costs, increase efficiency and reduce the overall footprint of the product (Manda et al., 2016). Thus, through the application of the LCA, and hence innovation and rejuvenation of the product portfolio, companies can stay ahead of the competition and create sustainable value by differentiating themselves, building customer loyalty, and creating new products and business (Kelm et al., 1995; Manda et al., 2016; Schaltegger & Figge, 2000).

The knowledge acquired through the use of the LCA tool can be applied by companies to facilitate strategic planning, priority setting, and product design. Additionally, the LCA demonstrates the environmental burdens associated with the product's life cycle through a holistic approach and has substantial applications to create sustainable value. Thus, for the purpose of this study, LCA is the preferred environmental assessment method for this study.

METHODOLOGY

3.1 Research design

In line with the aim of the present research, the LCA of three footwear models is conducted at VEJA, an eco-friendly footwear company that has built its own supply chain for agro-ecological organic cotton, natural rubber, and fabric made from recycled PET. Moreover, interviews with the founders of VEJA, communication and customer service departments, as well as an online survey are conducted to comprehend the main drivers of the stakeholders and shareholders value. The research methods and tools will be further explained in the following sections.

3.2 Life Cycle Assessment

In this study, the LCA is carried out in accordance with the Product Category Rules (PCR) for leather footwear (EPD International, 2013). The PCR specifies the rules, guidelines and defines the minimum requirements for the development and communication of LCA for a specific product group. Presently, the PCR documents are more detailed, specific and accurate than other relevant standards or methodology guides (EPD International, 2017). Moreover, although only one pair of footwear selected for the study has its upper in leather, the Product Category Rule for leather footwear is, at the present moment, the only specific guideline available for LCA of this type of product. The PCRs are administered by the International EPD® System and adheres to the framework and iterative phases of ISO 14040 and 14044 which are outlined in Figure 1 and explained below (ISO, 2006b, 2006c). Furthermore, the International EPD® System is a programme for type III of environmental declarations that was developed in accordance with ISO 14025 – environmental labels and declarations (EPD International, 2017; ISO, 2006a).

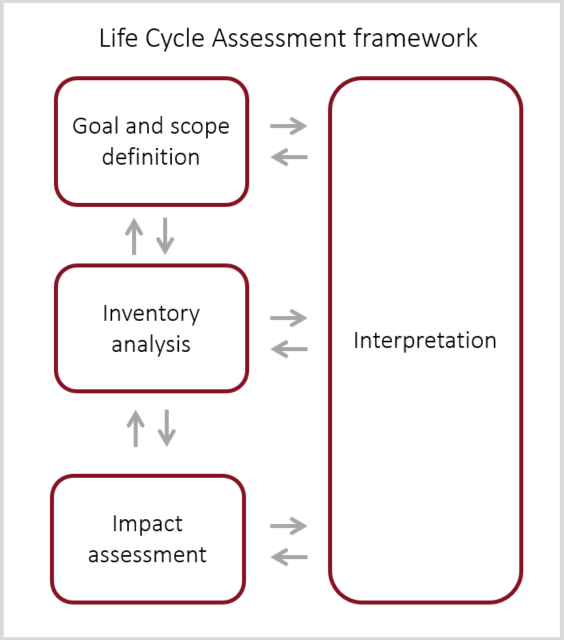

Figure 1: Phases of the LCA. Source: ISO - The International Standards Organisation, 2006b).

The first phase, namely “Goal and Scope Definition” is where the intended application, the audience of the LCA and the reasons for carrying out the analysis are defined. The scope should encompass the products and system boundaries, the characteristics of the data used, and the limitations and assumptions of the study in order to enable future consultations and comparisons. The next phase – life cycle inventory analysis (LCI) – involves the data collection necessary to meet the goal of the LCA defined in the previous phase, and it is executed by inventorying the input and output of the system studied. The inventory can be comprised of primary data, which is measured and gathered on-site, or through the compilation of secondary data, for example existing databases and bibliographic research.

Ultimately, in the Life Cycle Impact Assessment (LCIA) the LCI results are related to the impact categories previously selected and converted into potential environmental impacts. The final phase of the LCA is the life cycle interpretation, where both results from LCI and LCIA are summarized and discussed in order to reach conclusions, explain limitations and provide recommendations.

3.2.1 Goal

Given the continuous growth of the footwear market and the potential environmental impacts of footwear production and disposal, the present LCA aims to quantify the environmental performance of three different models of footwear designed by VEJA. The results are used to: (1) identify the life cycle stages, materials, and processes that contribute the most to the environmental performance of each footwear, (2) identify the footwear model with the best environmental performance and (3) to formulate strategies and recommendations to enhance the performance of VEJA's products.

The goal of the LCA includes a secondary application of the results, which is the possibility of future development of an Environmental Product Declaration (EPD). The decision to create an EPD declaring the environmental impact of the models will be taken after the analysis and conclusion of the present study. The intended audiences of the study are the founders of VEJA, the design team, actors involved in the footwear production system and researchers interested in case studies using LCA or the specific supply chain and materials used by VEJA.

3.2.2 Scope

To get a broader understanding of the environmental impact of footwear and due to the wide range of natural and synthetic materials used and several design options, the materials and production systems of three models of footwear are analyzed (V10, Esplar, and Wata). The results of the LCA are used to evaluate the individual environmental performance of each model and to compare the results obtained. Moreover, all three models chosen are evaluated based on the same functional unit and on a consistent methodology that allows the environmental impacts of the three products to be equally compared. It is important to underline that all three models selected for the study have the same target audience, market segmentation and are of the same type, i.e., public from 18 to 30 years old, that are attracted by fashion and interested in sustainability while looking for everyday sneakers.

3.2.3 Functional unit and system boundaries

In line with previous LCAs carried out for footwear, the function of the production system is one pair of footwear, size 41 EUR, used to protect or cover the foot for one year of standard use (EPD International, 2013; Perdijk et al., 1994). The reference flow or the quantified amount of material required to fulfill the functional unit varies according to the production systems and it is based on the designer's inputs. Apart from all components used to produce one pair of the footwear, it was also considered for all three production systems, the recycled cardboard box, Kraft and tissue paper used for packaging, and the silica added to the box to absorb humidity. It is important to notice that the weight of single components and final product may vary due to the artisanal characteristics of the product. The reference flow for each model under study is:

- 1 pair of V-10, size 41 EUR: 1.207,00 grams
- 1 pair of Esplar, size 41 EUR: 1.288,88 grams
- 1 pair of Wata, size 41 EUR: 1.101,64 grams

The system boundary in this study is defined as cradle to grave. This means that the study considered the processes related to material extraction, production of the footwear components, transport of materials to the shoe manufacturer, assembly processes, packaging, shipping and distribution to the warehouse in France and disposal. The life cycle was separated into three different life cycle stages, as it can be seen in Figure 2, in order to ensure compliance with the PCR for leather footwear.

The upstream processes (from cradle to the factory) produces the input to the core processes and involves the raw material extraction, acquisition and refinement, and the production of intermediate components. The core stage (from gate to gate) comprises the production of the good under study and the transport of materials and components to the factory where the product is manufactured. Moreover, the treatment processes of the waste generated during the manufacturing and the impacts caused by the electricity production used in the core processes are also considered in this stage. Finally, the downstream processes (from gate to grave) encompass the transport of the product from the factory to warehouse/consumer, use phase and end of life stages/end of life treatment of the product (EPD International, 2017).

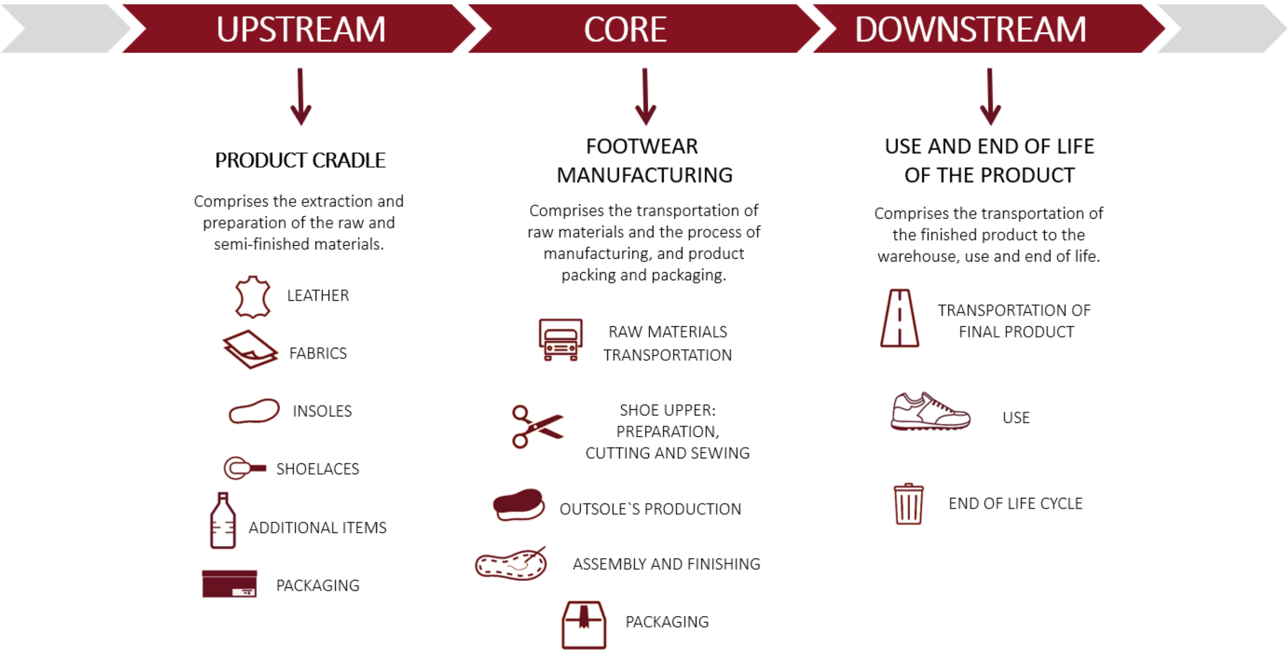

Figure 2: Three different life cycle stages within the system boundary of the LCA. Source: adapted from AKU, 2017.

3.2.4 Temporal and geographical scope

The aim is to collect data that is representative to VEJA, therefore, specific data from 2017 and 2018 are considered in the study. Furthermore, for the upstream and core stages of the life cycle the geographical coverage of this study is Brazil, since all material’s suppliers, transport of materials and shoe manufacturer are located in the country. The downstream phase, however, is in France where VEJA has its biggest market.

3.2.5 Impact Categories

The ReCiPe was chosen as the method for LCIA due to its problem-oriented approach and low level of uncertainty (PRé Consultants, 2018). In accordance with the PCR guidelines for leather footwear, five mid-point impact categories must be considered for the LCA, i.e., global warming, ozone depletion, acidification, eutrophication, and photochemical ozone formation – terrestrial ecosystems. Therefore, these impact categories are considered in this study so VEJA can use the results to apply for an EPD.

The life cycle impact assessment is calculated using the ReCiPe 2016 standard characterization method (Huijbregts et al., 2017; PRé Consultants, 2018):

- Global warming is based on IPCC 2013 (GWP 100a) and includes the IPCC characterization factors for the direct (except CH_4) global warming potential of air emissions over 100 years. It is expressed in kilos of carbon dioxide equivalents, kg CO_2 eq. to air;
- Ozone depletion is based on WMO 2011 and accounts for the destruction of the stratospheric ozone layer by anthropogenic emissions of ozone-depleting substances (ODS). The unit of ozone depletion is mass (kg) of CFC 11-eq. to air;
- Photochemical ozone formation is based on van Zelm et al. 2016 and is determined from the change in intake rate of ozone due to change in emission of precursors (NOx and NMVOC). It is expressed as the sum of ozone formation in kg NOx eq. to air;
- Acidification is the Acidification Potential (AP) and is based on Roy et al., 2014. The AP derived using the emission weighted world average fate factor of SO_2. It is expressed in sulfur dioxide equivalents, kg SO_2 eq. to air;
- Eutrophication is based on Helmes et al. 2012 and accounts for the environmental persistence (fate) of the emission of P containing nutrients. The unit of eutrophication is kg P-eq to freshwater.

3.2.6 Data collection

In order to understand the production processes, materials used in the footwear and its composition, a qualitative and quantitative in-depth analysis is performed for the three models selected. The research involved a comprehensive literature review and different interviews with VEJA team and shoe manufacturer, as well as with other experts in materials, textile supply chain and footwear industry. Additionally, to gain a better understanding of the production processes and collect foreground data, the author was in Brazil for two weeks visiting the shoe manufacturer and some of VEJA's suppliers, such as the yarn spinner, fabric mill, dyeing house, and tanneries.

Since VEJA uses materials that are not commonly used in the footwear industry, there is a lack of studies and reliable data regarding the life cycle of these materials. In order to conduct the study in accordance with the previously defined goal and scope and to deliver results that correspond to the endeavor of VEJA to reduce the environmental impact of its footwear, specific data was gathered for natural rubber, recycled PET fabric, and agro-ecological cotton. The production systems for the agro-ecological cotton fabrics – twill and canvas –, 'Liquid Smoking Sheet' (Portuguese 'Folha Defumada Líquida' or FDL) and recycled PET fabric are shown below.

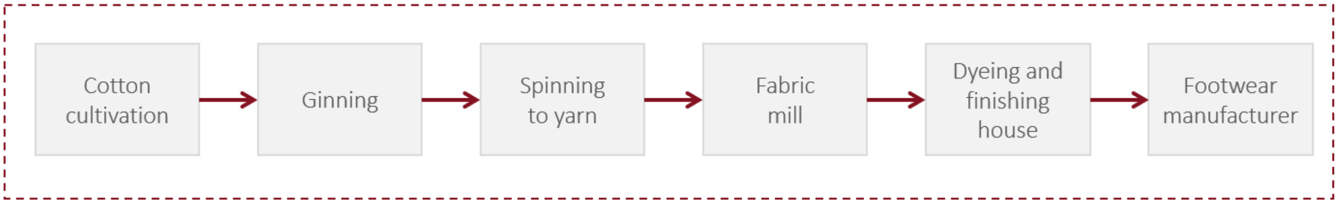

Figure 3: Agro-ecological fabric product system.

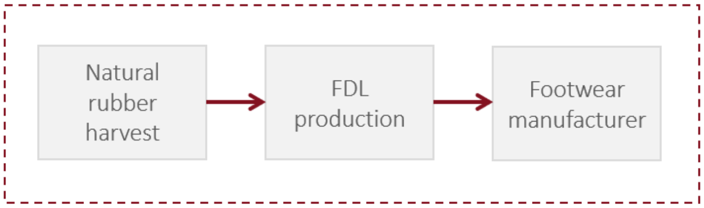

Figure 4: '*Folha Defumada Líquida'* product system.

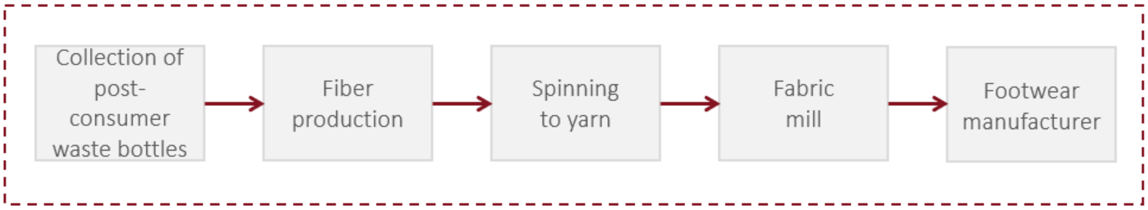

Figure 5: Recycled PET fabric product system.

The specific data on the number of resources consumed and emissions from the production processes within the dotted lines were collected from each supplier; the exception is the data regarding the collection of post-consumer waste bottles and fiber production in which the findings from L. Shen et al., (2010) were used. The machinery powered by grid electricity and water consumption were calculated according to the machinery's specifications and time of production. Heat consumption was calculated based on wood consumption and production values of 2017 and 2018, while waste production was calculated based on the supplier's internal records. Data on fuel use, air and water emissions, and packaging were not available. Therefore, inputs and outputs from similar databases available on Ecoinvent 3.4 were adopted. The life cycle inventory for each phase of agro-ecological cotton fabrics, natural rubber, and recycled PET fabric are presented in APPENDIX A – Additional product system and life cycle inventories.

Following the General Programme Instructions for the International EPD® System (2017) data used for the core process must be specific and representative, thus primary data was gathered during the author's visit to the shoe manufacturer. For the upstream and downstream processes, generic and proxy data were selected through literature review, research in reports from relevant organizations and Ecoinvent 3.4 and Agri-footprint 4.0 database. The specific data, generic and proxy data selected for the study is further discussed in section 5.1.

The data processing and analysis was done using mostly Microsoft Excel to maintain data sheets and keep records, normalize the data gathered and do basic calculations. After the inventory results achieved sufficient accuracy, completeness, and precision to meet the goal of the study, SimaPro 8.5.2 was used to model the production systems of the agro-ecological cotton fabrics, FDL production, recycled PET fabric and the manufacturing of three models of footwear selected. SimaPro was also used to calculate the potential environmental impacts through their characterization into midpoint indicators.

3.2.7 Allocation Methods

Along the cotton's supply chain, a range of different co-products are produced. In the field, the agro-ecological cotton boll – cotton lint with seeds – are sent to cotton associations where after ginning the seeds are sold to farmers to be sown in the next season. The primary purpose of farmers is to produce cotton lint, however, by following the concepts of agro-ecology that aim to minimize the environmental impacts and inputs into the system, the cotton plants are used as a substitute to animal feed and as mulching. The cotton lint represents only 8% of the total mass of the plant, the seeds represent 14% and the remaining 77% is the cotton plant. In terms of economic value, the kilo of cotton lint costs R$10,90, and a kilo of cotton seeds is sold for R$ 1,00. Moreover, the co-products from yarn spinning (on average 9% in mass) are generally given away to local farmers to be used as animal feed or mulching, whereas the fibers waste produced during weaving (4% in mass) and washing the textile (6% in mass) are donated to local artisans that use it for craftwork.

The leather used in some components of the models Esplar and V-10 is a co-product of meat production. The slaughter industry seeks to increase profit and reduce waste production through the commercialization of different parts of the animal such as bones, blood, organs, hide and tallow. Nevertheless, meat is the main product of slaughtering due to the quantity produced, but foremost due to its economic value (Arcenas et al., 2010; Kurian & Nithya, 2009). On average, 7% of an animal weight is its hide, however, based on its total market value share, the price of the hide represents 3,5% amongst the slaughterhouse products (Durlinger et al., 2017). According to PCR developed for the meat of mammals, the preferred allocation method for non-reproducing mammal destined to meat production – with rawhide as co-product, is the economic allocation since co-products of slaughtering may vary from one species to another (EPD International, 2018).

At the shoe manufacturer, the waste and co-products are separated according to its typology and can be either disposed of in landfill or sold to be used as an alternative fuel in cement kilns. Furthermore, due to a partnership between the shoe manufacturer and a supplier, the leather excesses are donated to produce footbeds that will be used by the shoe manufacturer in their own brand. The rubber excesses from pressing and trimming the outsoles are recycled in the same sector by incorporating the co-product into some other rubber products. The waste and co-products produced in the core phase of the footwear's life cycle represent 10 to 11% of the total mass entering the process depending on the model. Nonetheless, considering the price paid per pair, the weight of the footwear including its packaging, and the price per ton of the co-products sold, the footwear bears on average 99,2% of the economic value.

In the product systems analyzed, allocation could not be avoided by dividing the unit processes into different sub-processes and it was also not possible to partition the inputs and outputs of the system between its different products since physical relationships could not be established between the footwear and its co-products. Furthermore, to ensure compliance with the General Instructions for the International EPD ® System (2017) and the PCR for leather footwear, the system expansion to solve allocation problems was not used as a method since it is not applicable within the EPD's framework. The focus of this study lies on the environmental performance of footwear life cycle, but mainly on the materials of which it is comprised of. Therefore, since the preferred allocation method for leather is the economic allocation, the main purpose of cotton plantations is to harvest cotton bolls and to ensure consistency throughout the entire study, the economic allocation was used to allocate the environmental impacts between the main product and the other commercially relevant co-products.

3.3 Interviews

Although LCA can be employed to create sustainable value, the outcomes of the tool do not be used to identify the main drivers of stakeholder and shareholder value. Therefore, since the initial phases of the study, informal and unstructured interviews were conducted with VEJA's founders, Sébastien Kopp and François Ghislain Morillion and with the customer service and communication departments to understand the stakeholder and shareholder needs. Furthermore, an online survey was conducted to assess the sustainability criteria most frequently used by customers when buying from eco-friendly footwear brands. The results were used to identify the main drivers of stakeholder value and to support the development of strategies and practices to enhance VEJA's sustainable value. The questions and results from the survey can be found in APPENDIX B – Online survey and results.

CASE STUDY BACKGROUND

4.1 Introduction to VEJA

The present study was conducted at VEJA, a footwear company with its headquarter in Paris and office in Campo Bom, Southern of Brazil. At the headquarter the design department, commercial, logistics, communication team and the founders of the company are situated. Although the company's executive management is in Paris, the office in Brazil is a key element of VEJA´s structure. The team in Brazil deals with crucial aspects of production, such as the contracting of shoe manufacture and quality assurance, as well as the contract with producers of alternative materials that are used in VEJA's footwear.

The company has focused since its beginning on finding alternative solutions to conventional materials used in the fashion industry, either by contributing to minimize the environmental impact of the footwear or by having a positive impact on the communities that produce the raw materials. Ultimately, the company has embraced sustainability as a business opportunity and is now willing to take a step further and understand the environmental impacts associated with all the stages of their product's life to actively decrease its impact on the environment.

4.2 Materials

Materials have a direct influence on the lifespan and characteristics of footwear, and according to previous studies have a great impact on the environmental performance of footwear (Albers et al., 2008; Cheah et al., 2013; Staikos et al., 2006). VEJA aims at reducing the environmental and social impacts of its footwear, thus three alternative materials have been identified and since then used in VEJA's footwear after the brand has been launched. In the following section, a detailed description of these alternative materials, its supply chain and the conventional materials used are presented.

4.2.1 Cotton fabric

Since 2004 the company has been using organic cotton coming from agro-ecological plantations as raw material to produce the twill and canvas used in their footwear. The concept of agro-ecology is opposed to the conventional agricultural methods, which are centered on monoculture, highly dependent on chemical inputs and mechanization, as well as the concentration of ownership of productive lands, exploitation of rural workers and non-local consumption of goods produced (Altieri, 1995; Bellon, S., Lamine, C., Ollivier, G., de Abreu, 2011). Therefore, agro-ecological systems are usually cultivated by small farmers in rural communities following the basic guidelines (Altieri, 1995; Guthman, 2000):

- use of cover crops and mulches as effective soil protection and water saving measures;
- use of crop rotations, crop/livestock mixed systems, agroforestry for nutrient recycling;
- use of multiple and complementary crops in the same area;
- regular application of organic matter such as manure and compost to promote soil biological activity;
- use of biological pest control agents through biodiversity manipulations and introduction and/or conservation of natural enemies;
- non-use of genetically modified organisms (GMOs).

VEJA sources organic cotton from nine different associations in Northeast of Brazil (Figure 6). The associations are composed of groups of small farmers that cultivate cotton together with other crops such as beans, corn, sesame, manioc, sunflower, pumpkin in areas of around one hectare without the use of fertilizers or pesticides (Figure 7). Although the farmers prioritize the cultivation of staple

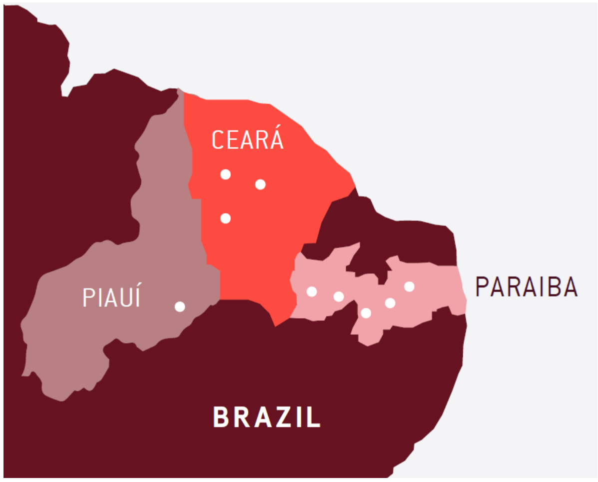

Figure 6: Cotton Associations in Northeast of Brazil that supply cotton to VEJA. Source: VEJA, 2018.

foods for their family and animals' subsistence, the cotton represents up to 60% of the cultivated area and it is of great importance due to its economic value. Since the beginning, VEJA sign one-year contracts with the associations, set market-decorrelated price per kilo of organic cotton and pre-finances the harvests up to 40%. For VEJA, the purpose of sourcing such cotton is to assist farmers to earn a decent living which increases farmers' income and encourages alternative ways of production. Moreover, VEJA aims to avoid the heavy use of irrigation practices and pollution coming from the use of fertilizers and pesticides.

Figure 7: Different crops planted by small farmers in Northeast of Brazil. Source: VEJA, 2018.

The region where the farmers are based has a semi-arid climate, which is characterized by low humidity and low volumes of rainfall. Due to its scarcity, the use of surface water and water from reservoirs are restricted to human consumption. Rainfall is the only source of irrigation used by the farmers and since cotton is a water-intensive crop, the harvest is extremely dependent on climatic factors (Murugesh & Selvadass, 2013). In fact, in the past cotton production has dropped due to a drought that affected the region and led to a shortage in VEJA's supply.

After the manual harvesting, the cotton boll is transported to the associations, where it is ginned. Usually, nearly 35% of weight is cotton lint and the rest are seeds and minor amounts of impurities such leaves, dust, stones. The material is then pressed and packed in bales to be sent to the yarn spinner.

The Brazilian transport infrastructure is characterized by road; therefore, the cotton lint is transported to the yarn spinner in Southeast Brazil by truck (2.703 km). There the cotton lint is cleaned, processed and transformed into yarn through a rotor spinning – or open-end spinning –

process, which is known by its increased productivity and energy consumption reduction (Lord, 2003). In VEJA's supply chain, two different types of cotton yarn are produced, a single yarn and a two-ply yarn. Originally, all yarns are spun as single yarns, however, due to the specific characteristics required by VEJA for the canvas such as extra strength and evenness, single yarns are combined to produce a two-ply yarn (Lawrence, 2010). Two-ply yarns, like requested by VEJA, are produced by combining two single yarns together and applying a twist on them.

Finally, the single yarns are used in the fabric mill to produce the twill, and the two-ply yarns, to produce canvas. The different fabrics differ in, weave construction, tensile strength, and aesthetics, and therefore are used for different purposes in the footwear. In this study, the twill produced has a lower tensile strength, hence it is used for lining, backing other fabrics and on the footbed, while the canvas, is used for the quarters and upper part of the models. It is important to point out that despite the production steps and machinery be the same for both textiles, the time to produce is different, leading to a different electricity consumption. Moreover, the grammage of the fabrics is different – twill: 261,66 g/m^2; canvas: 364,95 g/m^2 – and the twill has cornstarch added to its production process.

Subsequently, the twill and canvas are delivered to a dyeing house in the South of Brazil, where the twill will be washed, and the canvas dyed according to the required colors. Thereafter, the fabrics are ready to be used by the shoe manufacturer. The distinct production processes between the fabrics contribute to distinct levels of environmental impact, thus the LCI and LCIA are calculated for both textiles.

4.2.2 Natural Rubber

Natural rubber has been widely used in footwear since decades ago (Smit & Burger, 1992). Within the industry, rubber components usually contain an average of 5% natural rubber in its composition and its use is limited by its cost (Subramaniam, 1987). Currently, although there are other species that produce natural rubber, all commercialized source comes exclusively from the Pará rubber tree – Hevea brasiliensis (Figure 8), native to rainforests in the Amazon region of South America (Mooibroek & Cornish, 2000; van Beilen & Poirier, 2007).

Figure 8: The Pará rubber tree (Hevea brasiliensis). Source: VEJA, 2018

The Amazon used to be the world’s sole supplier of natural rubber, however, plantations in Asia started to appear in large quantities at low prices and drove the Amazonian product off the market (Weinstein, 1983). Nowadays, Asian countries, such as Malaysia, Indonesia and Thailand produce 90% of the world demand, whilst South American countries account for less than 3% of the world production (International Rubber Study Group, 2018; van Beilen & Poirier, 2007). Moreover, due to market changes, the traditional livelihood income of rubber tappers in the Amazon forest that formerly used to rely on the standing forest has shifted to new sources of income – usually from deforestation and cattle ranching (Salisbury & Schmink, 2007).

VEJA sources FDL from rubber tappers associations in the Amazon forest with the purpose of incentivizing the value creation within the supply chain, ensuring a better income to rubber tappers and ultimately reducing the financial incentives of deforestation. Differently from the common practice, VEJA uses up to 22% of a semi-finished product made from natural rubber in their outsoles and footbeds. The semi-finished product is called ‘Liquid Smoking Sheet’ (Portuguese

'Folha Defumada Líquida' or FDL) and was developed by Laboratory for Chemical Technology (LATEQ) at the University of Brasília (UnB) with the goal of creating a clean and simple technology that increases the aggregate value of the natural rubber through a high quality product (Ferreira et al., 2005). The traditional and most common rubber product, namely 'Field Coagulated Latex Blocks (Portuguese *'Coágulo Virgem Prensado*' or CVP) is produced by letting the latex, which is harvested from the rubber trees, to spontaneously coagulate. The CVP has a low quality and must be cleaned and purified by cooperatives before being used by the industry (Nascimento et al., 2015). Usually, the price paid for a kilo of CVP is around R$ 3,70 per kilo, whereas the FDL, due to its higher quality, is sold for R$ 10,30 the kilo (VEJA, personal communication, August 30, 2018).

To produce the FDL, rubber tappers must walk every morning through the forest to cut the bark of the rubber trees and return at the end of the day to harvest the latex in small buckets before it coagulates (Jeffries, 2014; Subramaniam, 1987). The collected latex is taken to the rubber tappers' dwelling, where with the help of their families the FDL is produced. According to the WWF's report (2015) developed to train the rubber tappers, the first step to produce the FDL is to strain the latex through a sieve or cloth to remove dirt and impurities. Subsequently, the latex must be diluted in water and a fungicide must be added to prevent the growth of mold. Afterwards, more water is added to the process and the mixture is placed on trays where pyroligneous acid – a coagulating agent – is added to the mixture. The liquid latex should rest for at least 3 hours until it is completely coagulated. The produced material resembles a sheet; however, additional water must be withdrawn with the use of a manual calender machine. The FDL sheets are then produced and hung in clothesline to dry up to six days until they are ready to be sent to the shoe's manufacturer in Southern of Brazil to be used in VEJA's outsoles and footbeds (Figure 9).

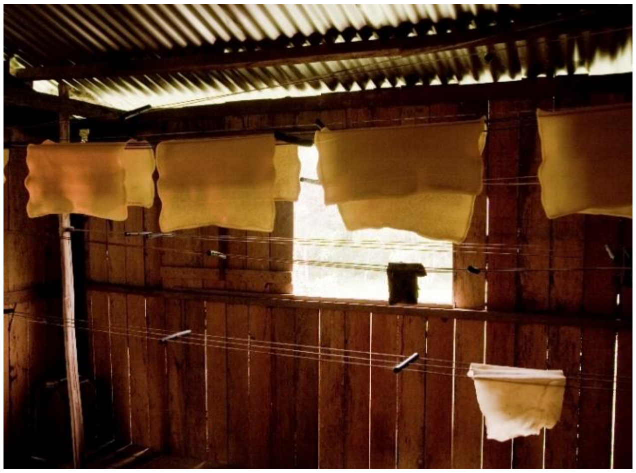

Figure 9: FDL hung in clotheslines to dry. Source: VEJA, 2018.

4.2.3 Recycled PET

Since its development by the chemical industry, polyethylene terephthalate (PET) has been widely used in different applications such as containers for liquids and foods, fibers, electronics, automotive parts, and films. Currently, fibers – referred to as 'polyester' in the textile industry – and bottles account for most of the world's PET production, corresponding to 60% and 30% respectively (Park & Kim, 2014; Telli & Ozdil, 2015). Its production and consumption have steadily increased in the past decades, and global demand is expected to have a stable growth for the next few years (Park & Kim, 2014). Nonetheless, due to its widespread application and non-biodegradability, the use of PET and its disposal has become a major concern (Edge et al., 1991; Sinha et al., 2010).

To address the issue concerning the environmental pollution of post-consumption, different recycling methods has arisen, including recycling of pre-consumer industrial scrap, mechanical recycling, semi-mechanical and chemical recycling (Choi & Kim, 2015; Park & Kim, 2014; L. Shen et al., 2010; Sinha et al., 2010). Since then, the recovery rate of PET has continually increased, being most of it converted into fibers to be used by the textile industry (Noone, 2008). In comparison with products made from virgin resin recycled PET can save 50 – 60% of energy (Eder-Hansen et al., 2017; Sinha et al., 2010). Furthermore, recycling post-consumer PET is an upcycling solution that reduces the use of fossil resources and avoids the release of pollutants into the environment that comes from incineration and landfill (Chang et al., 1999).

Due to its large quantities in the market, and relatively easy collection and segregation, the recycling of post-consumer PET bottles has become a well-established system (L. Shen et al., 2010). The recycled PET fibers and fabrics used by VEJA are produced in the Southeast of Brazil through the mechanical recycling process. First, the collected plastic bottles are sorted by color and shredded to obtain flakes (Figure 10). These flakes are then washed, cleaned and dried in order to remove external contaminants and are ready to be melted down and extruded into new forms, in this case, polyester fibers (Choi & Kim, 2015; Park & Kim, 2014; L. Shen et al., 2010; Sinha et al., 2010; Webb et al., 2013). The fibers are then sent to the yarn spinner to be spun into yarn and finally sent to the fabric mill where it will be woven into a textile. Due to the color sorting of bottles and characteristics of the recycling processes, the fibers are produced in different colors and the textile does not have to be dyed. Therefore, from the fabric mill, the textile is delivered to the shoe manufacturer to be used in VEJA's footwear.

Figure 10: Stages of Recycled PET's life cycle, i.e. sorting of plastic bottles, PET flakes, polyester fibers and fabric. Source: VEJA, 2018.

Differently from agro-ecological cotton and rubber, in this case, VEJA is aware of the processes and suppliers involved in the supply chain but is not involved in the purchase of primary materials. Anyhow, for VEJA, the use of post-consumer recycled PET is a way of reducing the use of raw petrochemical products while providing value-added to new products from waste. In fact, on average three plastic bottles are needed to produce one pair of VEJA's footwear made with recycled PET fabric.

4.2.4 Conventional Materials

There are around 40 different types of materials employed in the manufacturing of a footwear, and even though VEJA is particularly engaged in adopting alternative materials in its footwear, some materials are very challenging to replace (Weib, 1999). Thus, due to the lack of environmentally friendly alternatives or sustainable options with the quality and characteristics required to be used in VEJA's footwear, the remaining components are conventional materials such as chromium-tanned leather, polyamide, ethylene-vinyl acetate (EVA), regular polyester, polyurethane, polychloroprene among other materials. It is important to underline that although more sustainable options of tanning are available, such as vegetable tanning, the final product of these processes does not meet the quality standards set by VEJA to be used in their footwear. Most suppliers are located in the region Vale dos Sinos, where the shoe manufacturer is located, with the exception of some specific components that are sourced from the Southeast region.

4.3 Footwear Components

A footwear has approximately from 20 to 25 parts or components, which can be separated in two general sections, the 'upper' and 'sole' part (Zorn et al., 2007). The 'upper' is the superior part of the footwear whose function is to cover and protect the feet. According to the style of the footwear, the upper can be cut or molded as a single piece or comprise many pieces stitched together. The parts of a footwear's upper usually comprise the heel counter, puller, quarter, toe box, vamp, eyestay, rubber toe cover and tongue as well as other components that are used to ensure greater strength, rigidity and extend the lifespan of the footwear, such as the counter, toe puff, foam padding and lining. A brief description of each component and the footwear where it is used is presented in APPENDIX C – Definitions.

The 'upper' can be made from a variety of materials, with the most popular being leather, polyester, canvas, and suede. The materials that comprise the 'upper' are extremely important since it impacts the footwear's classification, comfort, the final price and it plays an important role in consumers' decision (European Commission, 2018; Zorn et al., 2007). The second section of the footwear, namely 'sole', is the designation of the entire lower part of the footwear. The 'sole' has the function of giving support, comfort and protect the feet from the unevenness of the ground. This part of the footwear can be further decomposed to several parts – commonly the outsole, midsole, footbed, welt and toe welt.

Although most footwear models can be split into the two general sections mentioned above, its parts and materials change according to the model. Therefore, the models chosen for this study, together with their components and materials, are described in Section 5.1.

4.4 Production and Assembly of Footwear

While VEJA is a brand, in which the company is responsible for designing the footwear, selecting the materials and approving the quality of the final product, the production and assembly are carried out by a third-party manufacturer located in the region of Vale dos Sinos – Southern of Brazil. The region is known to be one of the key clusters of footwear production in Brazil and is where the manufacturers of different footwear's components are located. Furthermore, the shoe manufacturer that VEJA has been working with, produces footwear since 1962 and it is known for being one of the largest footwear companies in Brazil.

The production and assembly of footwear in Brazil is still a highly manual process that involves a range of processes distributed into different production lines. To produce and assembly a footwear, there are around 360 process steps involved which most are performed either by hand or by workers operating individual machines (Cheah et al., 2013). The factory that manufactures VEJA's footwear employs more than 1.500 workers divided into 4 major sectors: rubber products – like outsole, midsole, welt and toe welt – cutting, stitching and assembling (Figure 13). A detailed description of the processes and machinery used throughout the production and assembly process of footwear are described in the following paragraphs.

Since VEJA designed the model and approved the materials and samples, the footwear is ready to be produced in large scale. Therefore, all the materials used in its components arrive at the warehouse where they are inspected and checked in order to ensure compliance with the quality' conditions and standards defined by the brand. The warehouse is responsible for delivering the materials to the right sectors, managing the stock replenishment, pointing non-conformities in quality and preparing specific materials for cutting. In this phase, for instance, some materials are glued together through the application of a polyurethane adhesive to increase resistance, comfort and fabric structure.

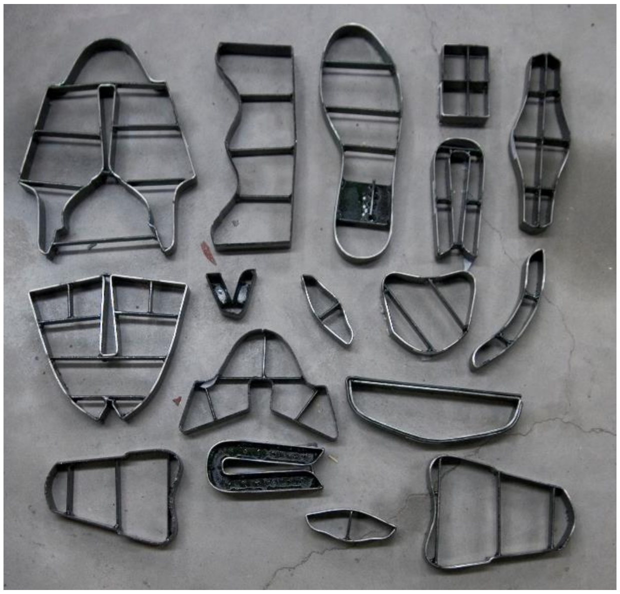

Figure 11: Sharpened-edge steel patterns. Source: VEJA, 2018.

The materials are then sent to the cutting sector, where sharpened-edge steel patterns are placed onto materials such as fabrics and leather, to be cut by a hydraulic machine. The patterns cut vary according to the model of the footwear and components that will eventually become the upper (Figure 11). The cutting sector is also responsible for chamfering the edges of the components that will be sewn or glued together in order to increase the comfortability of the footwear. The employees within this sector are highly trained in how to position the sharpened-edge steel patterns to maximize the number of components cut, therefore reducing costs and waste generated. It is in this sector of the factory where the largest amount of waste is produced. At VEJA's manufacturer, the waste is segregated according to its typology and send either to landfill, recycling or sold to cement companies that use the co-products as an alternative fuel in the cement kilns.

Figure 12: Components ready to be stitched together. Source: VEJA, 2018.

When the components are cut and chamfered, they are sent to the stitching sector of the factory. Before being stitched, the components are marked with an ultraviolet (UV) marker where the lines can only be seen under UV light. The marks serve as a guide to accurately stitch the components and position embroideries and eyelets in the right place according to the size and model of the footwear. The components that form the upper part of one footwear are then placed in a basket and pass different production steps of a conveyor belt (Figure 12). Usually, in one conveyor there are many employees executing the same function but for different sections of the upper, i.e. there are more than 6 employees sewing different components of one upper. When all components are stitched, the upper is ready to be sent to the assembling sector.

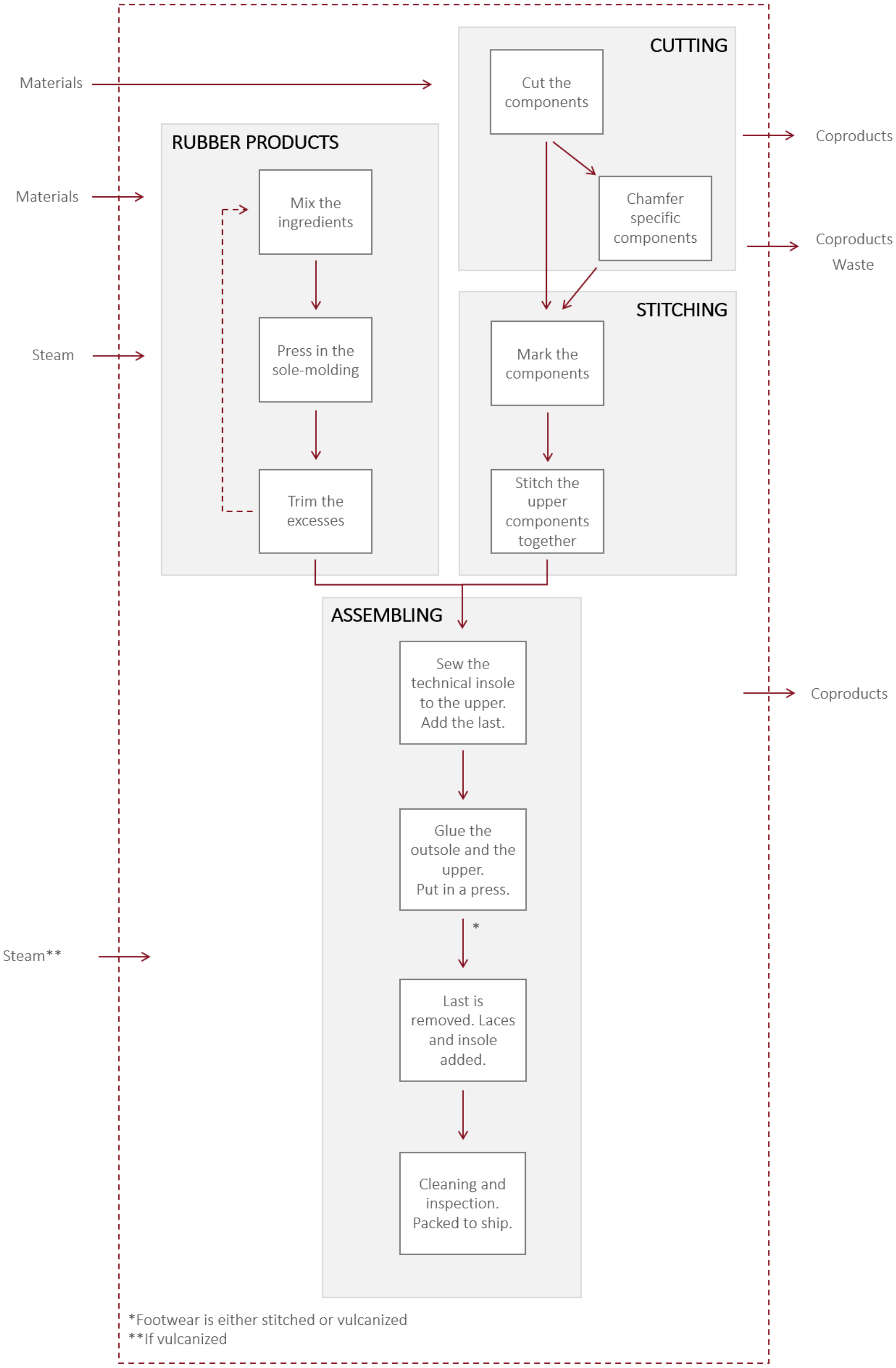

Figure 13: Footwear manufacturing flow chart.

In parallel with the cutting and stitching sectors, the sector responsible for rubber products might be part of the factory or outsourced to other companies. In the case of VEJA's manufacturer, the outsole, welt and toe welt of the footwear are produced internally, while the midsole is sourced from specialized companies in the same region. In this sector, specific ingredients that vary according to the rubber product and footwear' model are mixed. The rubber is then placed in sole-molding presses and the excesses are trimmed before being sent to the assembling sector. Usually, the excess of rubber produced in this sector is recycled internally and is often incorporated into some rubbers formulation to avoid waste.

The last sector is the assembling, where the already switched upper and the components of the "bottom" are placed in a basket and go through another conveyor belt. The first step is to sew the insole to the upper and insert the shoe last – mold in the shape of a foot – inside the upper to fill its shape in, stretch the upper and to hold it in place so the outsole can be attached (Figure 14). Next, the outsole is glued to the upper and pressed to ensure full contact between the upper and outsole. Hereafter, the upper and the outsole might be either stitched, if it's a cupsole, or vulcanized. In the latter case, the footwear is taken to the vulcanizing oven for 1 hour at 120 degrees Celsius until the welt, toe welt and outsole are fused together. The last is then removed, the laces are inserted into the uppers, the footbed is added, and the footwear is cleaned and inspected. Finally, the footwear is packed in individual boxes, and put in corrugated boxes together with other footwears that are shipped to the country of destination.

Figure 14: Upper with the shoe last. Source: VEJA, 2018.

RESULTS

5.1 Life Cycle Inventory Analysis

In the previous chapters, the alternative materials supply chain and footwear production were introduced and described in general terms in order to provide a deep understanding of how VEJA is currently operating. However, since the focus of the present study is to analyze the environmental performance of VEJA's footwear, the LCI of agro-ecological fabrics, FDL and recycled PET will not be further discussed. In this section, the general assumptions, data collection and calculations used to create the LCI of footwear will be explained.

5.1.1 General data and assumptions

To control consumption and costs, the shoe manufacturer has a list for each size and footwear model with the materials and its necessary quantity to produce a pair of upper. The list for the three models in size 41 EUR was gathered, further refined and considered in the upstream processes of the footwear's life cycle. Moreover, the shoe manufacturer has a database with the percentage of waste generated per material during the cutting process, e.g. waste rate from the cutting of leather is on average 25%, while for the cotton fabric the average is 20%. To ensure accuracy and completeness of the results, the database with the percentages of losses was used to calculate the waste produced per material. The waste disposal for each materials loss was defined based on the waste management plan of the shoe manufacturer, in which all types of waste produced within the facilities are classified and the disposal methods from each type of material are established. Furthermore, since most of the materials are measured and controlled in m^2 by the shoe manufacturer, during the visit a 10 cm^2 piece of each material was weighted to convert the consumptions from m^2 to grams. The footwear components with similar composition or made from the same material were grouped into clusters in order to assist the analysis and understanding.

In the manufacturing of the rubber components, three different formulas are used. Their composition changes according to the component that will be produced and whether the footwear will be vulcanized or not. The first formula is to produce the outsole of the V-10, the second is to produce outsole of the Esplar and Wata, while the last is to produce the welt, toe welt, rubber toe cover, and the V detail stitched to the upper. For the study, the three formulas are gathered, and the quantities required to produce the rubber components determined. Moreover, the excesses produced after the outsoles are pressed and trimmed were weighted during the author's visit to the shoe manufacturer. To facilitate the interpretation of the data collected, only the aggregated values of the rubber products are shown in the LCIs, however, all detailed data and formulas are presented in the APPENDIX D – Life Cycle Inventory for rubber products.

The core and downstream processes encompass the impact of transports, thus suppliers of materials used in the footwear and of substances to produce the rubber products were contacted to gather their addresses. Regarding downstream processes, the different distribution channels and modes of transport were collected with VEJA's logistics team, whereas the location of each waste management facility was compiled from the shoe manufacturer's waste management plan. In the study, the distribution of the finished product is only considered until the warehouse in Bonneuil-sur-Marne, from which VEJA distributes its products to shops all over France. The distances traveled from supplier to shoe manufacturer, and from shoe manufacturer to distribution platforms were calculated using Google Maps, except for the distance from Port Rio Grande to Port Le Havre which was determined by the website Ports.com. Similarly, the distance from the shoe manufacturer to the different options of waste treatment was also determined using Google Maps. Due to the limited time to investigate the different types of vehicle fleet used and its usual load, the same scenario was assumed for all road transport. The transport by truck and single trip was chosen since most suppliers hire freight companies to deliver the products to their clients and usually carry a load of economic value in their return trip.

Most materials and substances needed to produce the footwear or rubber products are made of a combination of different materials or elements. Suppliers of materials and substances were requested to specify the main materials and substances in their products. Therefore, in order to increase transparency only the main components of each material are considered. Moreover, due to a confidentiality agreement, some substances used in the rubber products cannot be disclosed and are represented by numbers. Although the author's attempt to contemplate all the inputs of the footwear's life cycle, the security threads, tape used in the cutting and sewing phase, secondary packaging, and some substances used to produce the rubber products have been excluded due to a lack of data, mixed composition or due to its low representativeness towards the footwear's total weight. The excluded materials represent an average of 2,56% of the total incoming flow of materials in each model.

The manufacturing of footwear involves around 360 process steps and machinery (Cheah et al., 2013); thus, energy and wood consumption were calculated based on the energy consumption and footwear manufactured from June 2017 and May 2018. For heat consumption, it is known by the shoe manufacturer that 30% of the heat produced by the wood log boiler is used in the oven to vulcanize some specific footwear models, like the Esplar and Wata. The remaining 70% is used by machinery in the rubber sector, such as the press. To calculate the amount of heat used during the production of each footwear, the following information was gathered: the wood log consumption from June to May 2018 (1.572 m^3), number of vulcanized shoes (525.932 pairs) and the total amount of shoes produced during the same period (1.591.032 pairs). With these numbers it was possible to calculate the cubic centimeters of wood log consumed to produce a vulcanized model with rubber outsole (1.588,32 cm^3, being 691.63 cm^3 to produce the outsole and 896,69 cm^3 in the vulcanization oven) and to produce a footwear with cupsole, where the outsole is stitched to the upper (691.63 cm^3). To calculate the energy produced by the boiler, the density and calorific value of the acacia magnium consumed by the shoe manufacturer was assumed to be of 510 kg/m^3 and 20,25 MJ/kg respectively (Rossi et al., 2003).

The total amount of footwear produced during the period was also used to calculate the amount of energy used per footwear. The energy consumption in the manufacturing factory is powered by grid electricity, and 3,25 GWh was consumed from June 2017 and May 2018. Therefore, on average a pair of footwear produced by VEJA's shoe manufacturer requires 2,04 kWh of energy. The water consumption during the shoe manufacturing is limited to a closed loop system boiler that typically operates in a stable system in which the water is fairly constant. Moreover, due to the high number of workers the greatest water consumption is in the toilets, cafeteria and for drinking. Therefore, since the study focuses on the environmental performance of the footwear and the machinery and processes are different from one manufacturer to another, specific data on water consumption was not included within the study. Further, data associated with infrastructure, building machinery and its maintenance are not considered due to time restriction and lack of data availability to support a credible assessment.

VEJA's does not give recommendations or sell shoe-care products. Furthermore, footwear cleaning, repair and product's application vary immensely from consumer to consumer. Therefore, the use phase was excluded from the study. The end of life scenario, according to PCR for footwear, must be calculated for both landfill and incineration. However, due to time constraint, only the incineration scenario is discussed since in Europe landfilling is the least preferable option in the waste management hierarchy and most municipal solid waste produced in France is incinerated (Council Directive 1999/31/EC, 1999; Ministère de la Transition écologique et solidaire, 2018).

The LCIs for the three models selected for the study are presented together with the specific aspects of the production systems.

5.1.2 Model V-10

One model chosen for this study is the V-10 (Figure 15). The upper of V-10 is comprised of a combination of suede, recycled PET and leather, the lining is made with agro-ecological cotton twill, whereas its outsole has 23,3% of FDL coming from the Amazon forest. In this model, the outsole is a cupsole, where the "sidewalls" are taller allowing the outsole to be stitched to the upper during the assembly, thus this model is not vulcanized. The inputs and outputs of all three processes of V-10's life cycle can be found in Table 1.

Figure 15: Model V-10 and its external components. Source: VEJA, 2018.

Although the quantities of materials entering the process were collected from the shoe manufacturer, the background data for most materials were compiled from articles and Ecoinvent 3.4. An exception is the data used for rawhide production which it was used from a different database. In Brazil, beef and dairy cattle are distinct production systems, where beef cattle are usually slaughtered at younger ages (Ferraz & Felício, 2010). Due to the lack of available data for beef cattle in the Ecoinvent database, data from Agri-footprint 4.0 database was used for this process. Moreover, the inputs and outputs from the slaughterhouse and tannery were based on the findings from Kurian & Nithya (2009). Due to the similarity between production processes and because both suede and leather used in V-10 come from the same animal, the quantities of these materials were combined and assumed to be the same material.

The recycled PET fabric used in the V-10 is produced from plastic bottles that would usually go to garbage dumps or controlled landfills in Brazil (IBGE, 2010). In this case, the delineation between the plastic bottle and the recycled fiber systems should be, according to EPD International (2017), the point at which the waste has its "lowest market value". Based on the paper from Huijbregts et al. (2006), in which their findings confirm that non-renewable energy use (NREU) is a suitable proxy for many impact categories, the savings (86,31%) in NREU from mechanical recycling of PET bottles in comparison with the production of virgin PET fibers were applied for the production of recycled fibers (L. Shen et al., 2010). Data used for the yarn spinning and weaving of the recycled PET was gathered during the visit and further contact with the suppliers.

Table 1: Inventory V-10 divided per different life cycle stages.

	UPSTREAM		CORE		DOWNSTREAM	
INPUT	Quantity	Unit	Quantity	Unit	Quantity	Unit
Quarter and vamp - recycled PET	18,47	g	20,59	kgkm		
Upper components - leather and suede*	149,86	g	4,92	kgkm		
Lining - agro-ecological cotton twill	50,09	g	1,90	kgkm		
Shoelaces - conventional cotton	24,16	g	0,22	kgkm		
Midsole - EVA	21,75	g	0,70	kgkm		
Insole, eyestay reinforcement, counter and toe puff - polyester	61,67	g	13,11	kgkm		
V Detail - rubber	17,76	g	21,83	kgkm		
Footbed - EVA, FDL, agro-ecological cotton twill	95,40	g	3,12	kgkm		
Outsole V-10 - rubber	538,50	g	785,15	kgkm		
Assembly glue, adhesive and foam padding - polyurethane	46,70	g	1,82	kgkm		
Threads and counter lining - polyamide	8,77	g	10,00	kgkm		
Silica gel sachet	1,00	g	0,03	kgkm		
Packaging - kraft	45,68	g	0,66	kgkm		
Packaging - tissue paper	10,20	g	0,28	kgkm		
Shoe box	255,00	g	4,11	kgkm		
Electricity			2,04	kWh		
Heat, central or small-scale - Outsole production			7,14	MJ		
Transport V-10 - Brazil					449,73	kgkm
Transport V-10 - Transoceanic ship					15 924,74	kgkm
Transport V-10 - France					267,95	kgkm
Transport - Excesses V-10 - cement kiln					2,75	kgkm
Transport - Excesses V-10 - recycling					1,57	kgkm
Transport - Excesses V-10 - landfill					0,21	kgkm
OUTPUT	Quantity	Unit	Quantity	Unit	Quantity	Unit
Materials V-10	1 345,01	g				
1 pair of V10 size 41 EUR			1 207,00	g		
Excesses V-10 - cement kiln			25,03	g		
Excesses V-10 - recycling			48,04	g		
Excesses V-10 - landfill			2,14	g		
Outsole V-10 excesses			62,80	g		

*Tongue, puller, toebox, eyestay, heel counter

As previously mentioned, the data used for the lining in all three models was collected from the farmers and different actors within VEJA's supply chain. The footbed produced for V-10 and Wata has the same composition, in which its main materials are EVA (70,4%), FDL (15,3%) and agro-ecological cotton twill (14,3%). For the database of this component, the materials percentage and the distance from the dyeing house and Amazon forest were considered. Therefore, in the core processes of the footbed only the distance from the supplier to the shoe manufacturer was included.

5.1.3 Model Esplar

The second model analyzed is the Esplar, which has its upper in white leather, lining made of agro-ecological cotton twill, and outsole with 18,3% of FDL coming from the Amazon forest (Figure 16). The Esplar's sole is comprised of the outsole, rubber welt and toe welt, thus the model must go through the vulcanization oven to ensure all rubber parts are bound together. To ensure an optimal vulcanization, the welt and toe welt do not have FDL in their materials composition.

Figure 16: Model Esplar and its external components. Source: VEJA, 2018.

The same article, database and premises adopted for the suede and leather used on V-10 were considered for the Esplar. The toe puff in this model is made 75% of EVA and 15% of polyester, while the counter is made of a mixture of rubber excesses, such as the outsoles excesses after pressed and trimmed or the excesses of rubber after the V details are cut. Furthermore, Esplar's footbed is different from the other models, where apart from being heavier, it has a different composition: 77,8% EVA, 17% FDL and 5,2% agro-ecological cotton twill.

The Esplar's life cycle, including the inputs and outputs, can be found in the table below.

Table 2: Inventory Esplar divided per different life cycle stages.

	UPSTREAM		CORE		DOWNSTREAM	
INPUT	Quantity	Unit	Quantity	Unit	Quantity	Unit
Upper - leather	218,96	g	6,35	kgkm		
Lining - agro-ecological cotton twill	40,09	g	1,52	kgkm		
Shoelaces - conventional cotton	24,16	g	0,22	kgkm		
V Detail - rubber	17,76	g	21,83	kgkm		
Insole and eyestay reinforcement - polyester	8,25	g	9,95	kgkm		
Toe puff - EVA and polyester	7,21	g	0,19	kgkm		
Counter - recycled rubber	16,05	g	0,00	kgkm		
Footbed Esplar - EVA, FDL, agro-ecological cotton twill	261,40	g	8,55	kgkm		
Welt and toe welt - rubber	168,11	g	206,60	kgkm		
Outsole Esplar - rubber	319,20	g	420,93	kgkm		
“Pre-Sewing" glue and foam padding - polyurethane	22,77	g	0,93	kgkm		
Assembly glue - polychloroprene	36,00	g	1,41	kgkm		
Threads - polyamide	0,50	g	0,03	kgkm		
Silica gel sachet	1,00	g	0,03	kgkm		
Packaging - kraft	45,68	g	0,66	kgkm		
Packaging - tissue paper	10,20	g	0,28	kgkm		
Shoe box	255,00	g	4,11	kgkm		
Electricity			2,04	kWh		
Heat, central or small-scale - Vulcanization			9,26	MJ		
Heat, central or small-scale - Outsole production			7,14	MJ		
Transport Esplar - Brazil					480,24	kgkm
Transport Esplar - Transoceanic ship					17 004,98	kgkm
Transport Esplar - France					286,13	kgkm
Transport - Excesses Esplar - cement kiln					4,74	kgkm
Transport - Excesses Esplar - recycling					1,79	kgkm
Transport - Excesses Esplar - landfill					0,17	kgkm
OUTPUT	Quantity	Unit	Quantity	Unit	Quantity	Unit
Materials Esplar	1 452,34	g				
1 pair of Esplar size 41 EUR			1 288,88	g		
Excesses Esplar - cement kiln			43,09	g		
Excesses Esplar - recycling			54,74	g		
Excesses Esplar - landfill			1,79	g		
Outsole Esplar excesses			63,84	g		

5.1.4 Model Wata

Lastly, Wata is the third model chosen and it’s one of VEJA’s vegan model. The Wata is very similar to Esplar because it must also be vulcanized due to its rubber components – welt, toe welt and rubber toe cover –, its lining is made with agro-ecological cotton twill, and the rubber components used in both models have the same composition. Nonetheless, Wata’s upper is comprised of agro-ecological cotton canvas instead of leather and Wata has a rubber toe cover which is not present in Esplar (Figure 17).

Figure 17: Model Wata and its external components. Source: VEJA, 2018.

Differently from the other models, the Wata has washer and eyelets. The washer is made of aluminium, whereas the eyelet is made of brass. The counter is also made of recycled rubber from outsole excesses (91,7%), however in this model a piece of agro-ecological twill is applied on top of the rubber (8,3%). The toe puff is the same as used on Esplar and the footbed is the same as used on the V-10.

The inputs of all three processes of Wata’s life cycle can be found in Table 3.

Table 3: Inventory Wata divided per different life cycle stages.

	UPSTREAM		CORE		DOWNSTREAM	
INPUT	Quantity	Unit	Quantity	Unit	Quantity	Unit
Quarter - agro-ecological cotton canvas	71,22	g	2,71	kgkm		
Washer - aluminium	1,44	g	0,01	kgkm		
Eyelet - brass	7,20	g	0,07	kgkm		
Lining - agro-ecological cotton twill	67,82	g	2,58	kgkm		
Shoelaces - conventional cotton	24,16	g	0,22	kgkm		
V Detail - rubber	17,76	g	21,83	kgkm		
Counter - recycled rubber and cotton twill	36,00	g	0,11	kgkm		
Toe puff - EVA and polyester	7,66	g	0,20	kgkm		
Insole - polyester	7,15	g	8,62	kgkm		
Footbed - EVA, FDL, agro-ecological cotton twill	95,40	g	3,12	kgkm		
Welt, toe welt and rubber toe cover - rubber	197,44	g	242,65	kgkm		
Outsole Wata - rubber	319,20	g	420,93	kgkm		
"Pre-Sewing" glue and adhesive - polyurethane	28,95	g	1,01	kgkm		
Assembly glue - polychloropene	36,00	g	1,41	kgkm		
Threads - polyamide	0,50	g	0,03	kgkm		
Silica gel sachet	1,00	g	0,03	kgkm		
Packaging - kraft	45,68	g	0,66	kgkm		
Packaging - tissue paper	10,20	g	0,28	kgkm		
Shoe box	255,00	g	4,11	kgkm		
Electricity			2,04	kWh		
Heat, central or small-scale - Vulcanization			9,26	MJ		
Heat, central or small-scale - Outsole production			7,14	MJ		
Transport Wata - Brazil					410,47	kgkm
Transport Wata - Transoceanic ship					14 534,65	kgkm
Transport Wata - France					244,56	kgkm
Transport - Excesses Wata - cement kiln					6,74	kgkm
Transport - Excesses Wata - landfill					0,29	kgkm
OUTPUT	Quantity	Unit	Quantity	Unit	Quantity	Unit
Materials Wata	1 229,78	g				
1 pair Wata size 41 EUR			1 101,64	g		
Excesses Wata - cement kiln			61,27	g		
Excesses Wata - landfill			3,03	g		
Outsole Wata excesses			63,84	g		

5.1.5 Background data

The background data used for components not mentioned above were chosen based on the closest match, that is:

- The process of woven cotton was selected for the shoelaces used in the three models;
- The process of ethylene vinyl acetate copolymer was chosen for all components with EVA in its composition, or entirely made of EVA, such as V-10’s midsole;
- The processes of unbleached kraft paper, newsprint paper – as a substitute of tissue paper –, activated silica and folding boxboard/chipboard were used for the packaging materials;
- Due to the great variety of products made of polyester and lack of specific data, all components made of this material or that has polyester in its composition had the polyester resin process used.
- The process of polyurethane – flexible foam, was selected for the assembly and “pre-sewing" glue, adhesive and foam padding;
- Since polyamide and nylon are the same product and Nylon 6-6 is the most frequent type of nylon used by the fashion industry, the process of Nylon 6-6 was chosen for polyamide products (Kothari, 2008);
- Polychloroprene, also known as chlorobutadiene rubber, lacks process data. Therefore, for the assembly glue used in the models Wata and Esplar, butadiene rubber process was selected since polychloroprene is produced in the further processing of butadiene (White, 2007).

The materials inventory for each component, service and the respective process data used from the ReCiPe and Agri-footprint database can be found in

APPENDIX E – Process materials inventory used for each component.

5.2 Life Cycle Impact Assessment

The data regarding the potential environmental impact of the three footwear models, calculated in accordance with the impact method defined in Section 3.2.5, are reported in the following charts.

Table 4: Potential environmental impact of the three models of footwear analyzed.

Impact Category	Unit	V-10	Esplar	Wata
Global warming	kg CO_2 eq.	16,6	21,5	5,63
Ozone depletion	kg CFC-11 eq.	9,83E-05	1,38E-04	1,69E-05
Ozone formation	kg NOx eq.	0,0836	0,114	0,0217
Acidification	kg SO_2 eq.	0,206	0,29	0,0232
Eutrophication	kg P eq.	0,00396	0,00535	0,00141

In all five impact categories analyzed, the model Esplar ranks as the most polluting footwear. In total, from materials extraction to its incineration a pair of Esplar size 41 EUR releases 21,5 kg of CO_2 equivalent. This amount is 1,29 times greater than the total amount of CO_2 released during V-10's life cycle, and 3,82 times the emissions of Wata.

In the other impact categories, namely ozone depletion, ozone formation, acidification and eutrophication, Esplar's environmental performance in comparison with the model V-10 is 35–40% more polluting. The biggest difference comes when comparing Wata – the footwear model with the highest amount of alternative materials and best performance – with the two other models. The environmental impact of Wata in ozone depletion represents only 12,2% of Esplar's emissions and is nearly 6 times smaller than V-10's impact. Furthermore, for ozone formation, Wata's total NOx eq. emissions are 5,25 times lower than Esplar's and 3,85 smaller than V-10's. The biggest contrast between the models is in the acidification impact category, where Wata's cradle to grave results are of 0,0232 kg SO_2 eq., i.e. 12,5 smaller than the impact of Esplar and 8,9 times less than the model V-10 (Figure 18). Ultimately, for eutrophication, Wata's emissions are 3,8 times inferior to Esplar's and are nearly 3 times smaller than V-10.

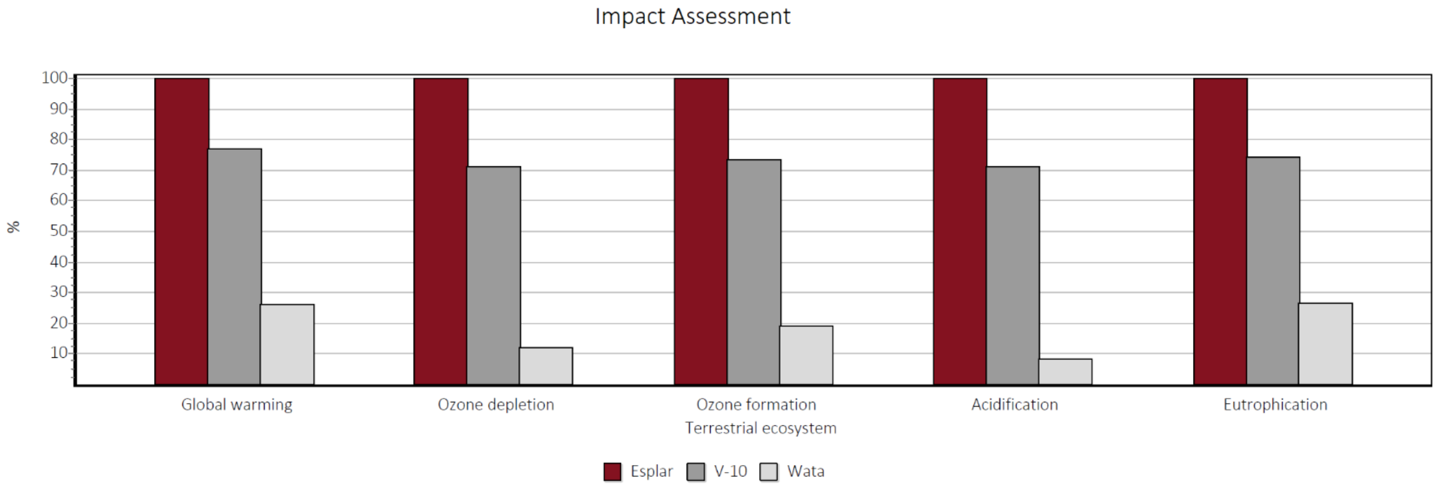

Figure 18: Impact assessment of the three footwear models.

The difference among the environmental performance of the models can be partly explained by the contrast in weight, since Esplar is 6,8% (81,88 grams) heavier than V-10 and 17% (187,24 grams) than Wata. Moreover, the final weight of the models is directly related to the amount of waste generated during the production and assembly. Thus, the impact of transport and disposal of the waste is greater for Esplar than for the lighter models. Considering the downstream processes are the same for all three models, i.e. transport from shoe manufacturer to the port, shipment, deliver to warehouse and incineration, the disparity between the weight of the models is the main determinant for the difference among the environmental performances.

Although the quantity and typology of the materials entering the production processes contribute to the results, the distance traveled from supplier to shoe manufacturer it is not a determinant aspect of the footwear's performance. The payload distance in kilogram-kilometer of V-10's core process is the longest with 868,45 kgkm, followed by Wata's (710,57 kgkm) and Esplar's (685,62 kgkm). Furthermore, energy and heat consumption are not determinant factors to the results, since all three models have the same energy consumption and both Esplar and Wata require the same amount of heat energy to be manufactured.

Foremost, the greatest difference between the footwear models analyzed are the upstream processes, which comprises the extraction and preparation of raw and semi-finished materials. Based on the findings from other authors, the nature of the materials used, as well as their production processes are likely to be the major contributors to the results of the LCIA. To investigate the aspects that contribute the most to the environmental performance of the models and validate the assumptions above, the life cycle of each footwear is be analyzed separately in the coming sections.

5.2.1 Model V-10

The impact assessment conducted for model V-10, in agreement with previous studies, indicates the upstream processes as the most impactful phase of the footwear’s life cycle. In all five categories assessed, the extraction of raw material, its acquisition and refinement, and production of intermediate components account for more than 90% of the total impact (Figure 19). Hereafter, the determinant aspects and largest contributors to V-10's environmental performance are investigated according to the life cycle phases and the impact categories analyzed.

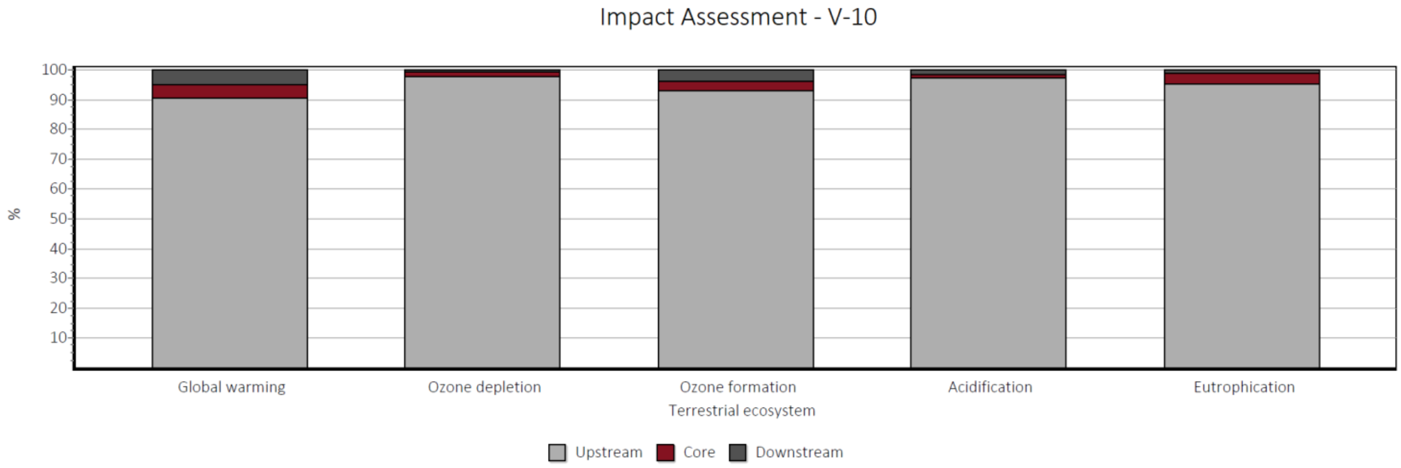

Figure 19: Contribution analysis of V-10's life cycle stages.

Global warming

Throughout V-10's life cycle, 16,6 kg of CO_2 eq. emissions is released. Out of this total, the upstream processes contribute to 90,6% of the shoe's emissions, the core processes to 4,2%, whereas the downstream processes contribute to 5,2% of the total emissions. From the CO_2 eq. emissions discharged during the upstream processes (15 kg), the upper components made of leather and suede represent 76,0% of the total, where most of the impact occurs during cattle raising (71,3%) and disposal of waste produced during leather tanning (9,7%). Other components that contribute to V-10's environmental performance are: the outsole (7,8%) – polybutadiene is responsible for nearly half its emissions –, followed by shoelaces made of conventional cotton (3,8%) and agro-ecological cotton twill (2,5%).

In the core processes, the electricity use during production and assembly accounts for 73,0% of the total emissions. The remaining come from the transport of materials to shoe manufacturer (17,6%), heat production (9,1%), and from landfilling the waste generated during production of the footwear (0,24%). Moreover, in the downstream processes, the waste management, i.e. incineration of V-10, releases 72,0% of the emissions, whereas the transport of the finished footwear contributes to 28,0% of the impact on this phase.

Ozone depletion

In the impact category ozone depletion, V-10 releases during its life cycle 9,83E-05 kg of CFC-11 equivalent (Table 5). It is estimated that upstream processes emit 97,5% of this total, the core processes 1,8%, while the downstream process contributes to 0,7% of total emissions. In the upstream processes, the leather and suede represent 94,3% of emissions, where nearly all impact comes from cattle raising (90,5%). Other components that contribute to the upstream emissions are: the shoelaces made of conventional cotton (1,9%) – mainly from the use of tetrafluoroethylene as soil and water repellent – and polyester components (1,9%).

During the core processes it is estimated that 1,73E-06 kg of CFC-11 eq. are released to air. In this phase, electricity use contributes to 78,0% of the emissions, heat production to 19,9% and the transport of materials from suppliers to shoe manufacturer contributes to 2,1%. With regards to downstream processes, the transport from shoe manufacturer to the warehouse in France releases 86,7% of the emissions, and V-10's incineration releases 13,3%.

Table 5: Potential environmental impact of V-10 divided per life cycle stages.

Impact Category	Unit	Total	Upstream	Core	Downstream
Global warming	kg CO_2 eq.	16,6	15	0,687	0,865
Ozone depletion	kg CFC-11 eq.	9,83E-05	9,58E-05	1,73E-06	7,46E-07
Ozone formation	kg NOX eq.	0,0836	0,0775	0,00266	0,00336
Acidification	kg SO_2 eq.	0,206	0,2	0,00255	0,00343
Eutrophication	kg P eq.	0,00396	0,00378	0,000132	4,62E-05

Ozone formation

Along the three stages of V-10's life cycle, it is estimated that 8,36E-02 kg of NOX eq. is released. The upstream processes are responsible for 92,8% of this total, the core processes to 3,2% and downstream processes for 4%. In the upstream process, the leather and suede represent 85,5%, in which much of the materials' impact comes from slaughtering and tanning processes (81%). Next, V-10's outsole is the second biggest contributor (3,8%) – nearly 50% is from the use of polybutadiene –, followed by the agro-ecological cotton twill (3,8%). Other components with smaller contributions are: polyester components (1,5%), shoelaces (1,4%) and footbed (1,4%).

The core process emits 2,66E-03 kg of NOX eq., in which the heat produced by burning the wood logs is responsible for 41,2% of the emissions, transport of materials for 33,4%, whereas the electricity use by the shoe manufacturer contributes to 25,4% of the impact of this phase. Additionally, in the downstream processes, 89,2% of emissions are released during the transport of the finished product to the warehouse and the V-10's end of life releases 10,8% of emissions.

Acidification

From cradle to grave, it is estimated that V-10 releases a total of 0,206 kg of SO_2 equivalent. Nearly all of it is emitted during upstream processes (97,1%), with minor contributions from core and downstream processes (1,2% and 1,7%, respectively). Most of the impact from upstream processes comes from the leather and suede components (92,8%), where agricultural phase of the material's life cycle is responsible for more than ¾ of the material's impact (79,5%). The next components with biggest contribution to the upstream emissions are the outsole (2,8%) – mainly from the use of polybutadiene and silica (38,2% and 33,0%) –, and shoelaces (1,1%).

Throughout the core processes, the electricity use releases 61,9%, heat production emits 20,5%, while the transport of materials accounts for 17,6% of the emissions. Furthermore, the majority of emissions released during downstream processes come from the transport of the footwear to the warehouse (94,7%), while the remaining emissions come from the disposal of V-10 (5,3%).

Eutrophication

Lastly, 3,96E-03 kg of P eq. is released throughout V-10's life cycle. The upstream processes account for 95,5% of emissions, the core processes for 3,3%, whereas the downstream processes represent only 1,2%. As in the other impact categories analyzed, the leather and suede are the main contributors to the environmental impact of the upstream processes (80,0%). From the leather and suede production system, 87,8% of the emissions are due cattle raising. Moreover, shoelaces account for 6,4% of the emissions, the outsole for 4,7% – where more than one third of the impact is due to the use of silica –, and shoe box is responsible for 3,2%. Other components with a minor contribution are the polyester components (1,9%) and the agro-ecological cotton twill (1%).

Out of the total emissions released along the core processes, the electricity consumption accounts for 88,2%, whereas heat production and transport for the footwear account for 10,8% and 1,0%, of the emissions, respectively. Finally, the impact from V-10's incineration represents 94,7% of downstream emissions, while the remaining 5,3% are released from the transport of the footwear from shoe manufacturer to warehouse.

5.2.2 Model Esplar

In accordance with the findings of V-10's impact assessment, the upstream processes, and especially leather, are the foremost determinant of the product's environmental performance (Figure 20). In the same manner as in the previous analysis, the aspects and biggest contributors to Esplar's environmental performance will be investigated. Nevertheless, for both Esplar and Wata, the downstream processes will not be commented. This is due to the fact that although the amount of pollutants released in this phase changes from one model to the other, the percentages in which the transport and incineration accounts for the emissions are the same for all three models, since both inputs and outputs of downstream processes are calculated based on final weight of the product.

Furthermore, the leather and suede components of V-10 and the leather in Esplar share the same database. Thus, the aspects of the material's life cycle that contribute the most to the impact category will not be detailed, as it is the same as described in V-10.

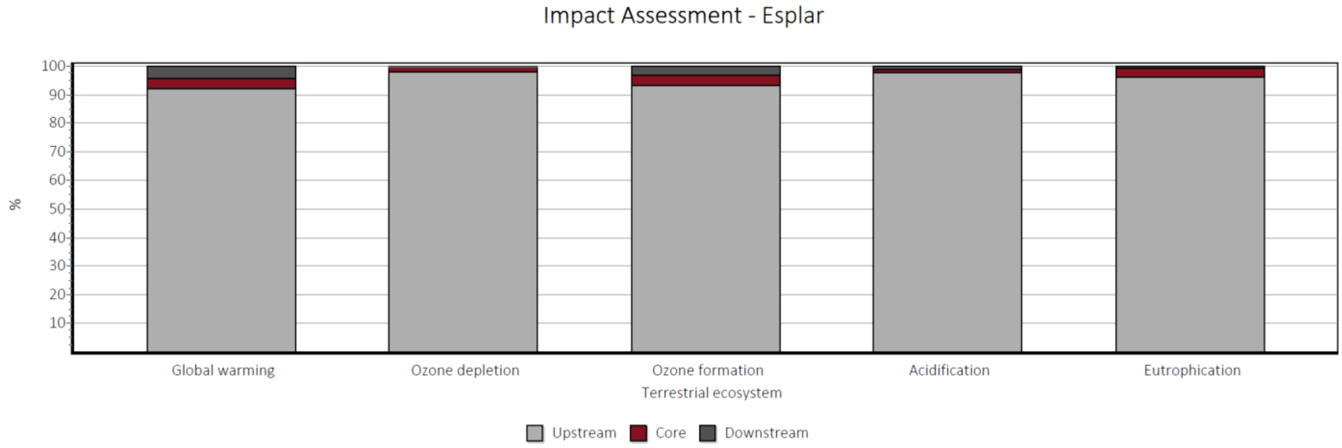

Figure 20: Contribution analysis of Esplar's life cycle stages.

Global warming

Throughout its entire life cycle, Esplar releases a total of 21,5 kg of kg CO_2 equivalent. Similar to V-10, the upstream processes contribute to 92,3% of emissions, whereas the core and downstream processes contribute to 3,4% and 4,3% of the total. Out of the CO_2 eq. emissions released during the upstream processes, the use of leather accounts for 83,9%. The next components that contribute the most to Esplar's environmental performance is the outsole (3,3%) – due to the use of polybutadiene (37%) and product 1 (23,47%) –, shoelaces made of conventional cotton (2,9%), footbed (2,8%) and shoe box (1,9%).

The estimated CO_2 eq. emissions produced by the core processes come from the electricity use during production and assembly (67,5%), heat production (19,4%) and from the transport of materials to shoe manufacturer (12,9%).

Ozone depletion

Considering the impact category ozone depletion, Esplar releases around 1,38E-04 kg of CFC-11 eq., in which roughly all emissions are discharged during the upstream processes (97,9%). The core processes represent merely 1,5% of emissions and downstream processes account for 0,6% of the total impact. In the upstream phase of Esplar's life cycle, the leather accounts for nearly all emissions (97,3%), followed by the shoelaces made of conventional cotton (1,3%) – where 50% of the impact its due to the use of tetrafluoroethylene as soil and water repellent – and agro-ecological cotton twill (0,5%).

Moreover, along the core processes, the electricity used by the shoe manufacturer represents 62,3% of the emissions, the heat production to 36,4% and the transport of materials from suppliers to shoe manufacturer is responsible for the remaining 1,3%.

Ozone formation

Along the three phases of Esplar's life cycle, it is estimated that 0,114 kg NOX eq. (Table 6) is released to the air. The upstream processes are responsible for 93,4% of this total, the core processes for 3,4% and downstream processes for 3,2% of total emissions. During the upstream processes, the leather accounts for 91,1% of the impact, the agro-ecological cotton twill is responsible for 2,2% and the outsole for 1,6% – 37,6% the use of from polybutadiene and 20,4%

from product 1. Other important components that contributed to the upstream results are: footbed (1,6%) and shoelaces (1%). Additionally, the share in which each core process contributed to the impact of this phase is: heat production (64,6%), transport of materials (18,0%) and electricity consumption (17,4%).

Table 6: Potential environmental impact of Esplar divided per life cycle stages.

Impact Category	Unit	Total	Upstream	Core	Downstream
Global warming	kg CO_2 eq.	21,5	19,8	0,74	0,923
Ozone depletion	kg CFC-11 eq.	1,38E-04	1,36E-04	2,15E-06	7,96E-07
Ozone formation	kg NOX eq.	0,114	0,106	0,00388	0,00359
Acidification	kg SO_2 eq.	0,29	0,283	0,00312	0,00367
Eutrophication	kg P eq.	0,00535	0,00515	0,00015	4,93E-05

Acidification

In the impact category acidification, Esplar's life cycle emits approximately 0,29 kg of SO_2 eq., mostly coming from the upstream processes (97,7%), with minor contributions from the core (1,1%) and downstream (1,3%) phases. From all materials used in Esplar, the leather alone accounts for 95,6% of the emissions released during the upstream phase of the product life cycle, followed by the outsole (1,1%), where ⅔ of the impact is from the use of polybutadiene and silica, and shoelaces (0,8%). In the core processes, electricity use is responsible for 50,3% of emissions, heat production accounts 38,4%, and the transport of materials to shoe manufacturer is responsible 11,3%.

Eutrophication

Finally, from cradle to grave it is estimated that Esplar emits 5,35E-03 kg of P eq., being 96,3% from the upstream phase, 2,8% from core and 0,9% from downstream phase of the product's life cycle. Out of the 5,15E-03 kg P eq. released during the upstream processes, leather represents 85,8% of the emissions, shoelaces account for 4,7% of the impact and outsole for 2,4% – nearly half of it is due to the use of product 1. Other components that contribute to upstream emissions are: shoe box (2,4% each), welt and toe welt (1,6%), and footbed (1,3%). In Esplar's core processes, the electricity consumption is responsible for 77,4% of emissions, heat production for 21,9% and transport of materials for 0,7%.

5.2.3 Model Wata

Differently from V-10 and Esplar, Wata does not have any material of animal origin in its composition. However, regardless the materials used, the upstream processes are still the main contributor to the footwear's environmental performance (Figure 21). Following the analysis of the other models above, the same investigation will be conducted to understand the aspects and biggest contributors to Wata's environmental performance.

Since the outsole used in Wata and Esplar are of same composition, the detailed description of the materials that contribute the most to the impact category will not be repeated, as they are the same as described in Esplar's outsole.

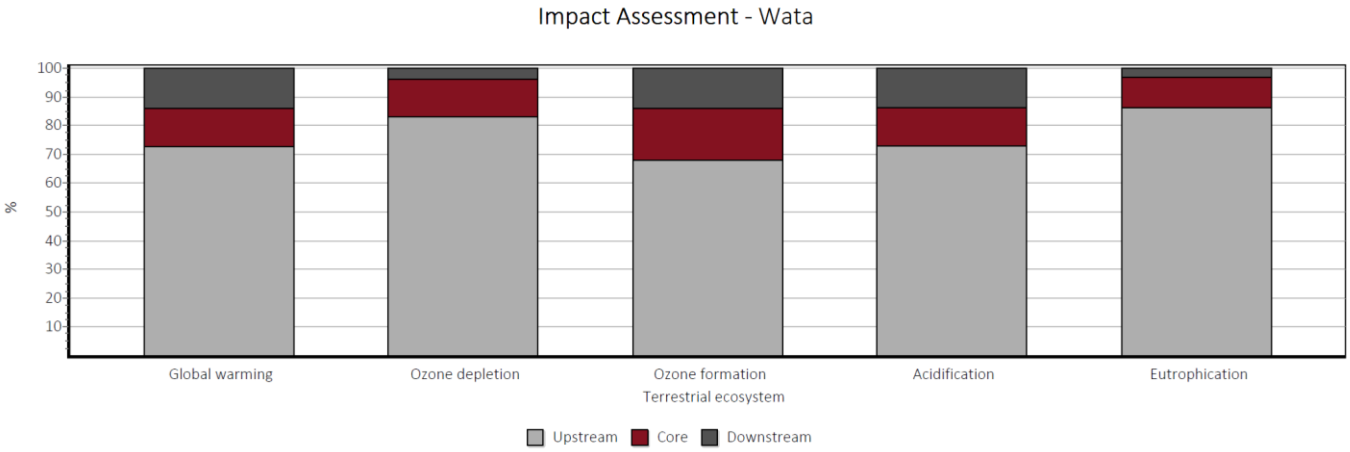

Figure 21: Contribution analysis of Wata's life cycle stages.

Global warming

Along its life cycle, Wata releases around 5,63 kg of CO_2 eq., in which the upstream processes contribute to 72,7% of the impact, the core processes to 13,2%, whereas 14,0% of emissions are released during downstream processes. Out of the total CO_2 eq. emissions emitted in the upstream processes, the agro-ecological cotton canvas used in the quarter is responsible for 20,9%, where nearly 50% is from the process of washing and dyeing it. Furthermore, the other components that contribute the most to Wata's environmental performance are: outsole (15,9%), shoelaces made of conventional cotton (14,0%), agro-ecological cotton twill (12,4%), the additional rubber components – welt, toe welt and rubber toe cover – (10,5%), shoe box (9,1%) and footbed (6,2%).

During the core processes it is estimated that 0,744 kg of CO_2 eq. were emitted. From this total, electricity use accounts for 67,1% of total emissions, followed by heat production (19,3%) and transport of materials (13,3%).

Ozone depletion

Considering the impact category ozone depletion, Wata releases during its life cycle 1,69E-05 kg CFC-11 equivalent. The upstream processes are responsible for 83,3% of this total, the core processes for 12,7%, while the downstream process accounts for 4,0% of total emissions. In the upstream phase, the emissions discharged from the canvas production system represent 70,2% of the total, whereas the shoelaces account for 12.9% of the impact. For both products, the main responsible for the impact is the use tetrafluoroethylene as soil and water repellent. Other components that contribute to the upstream emissions are the agro-ecological cotton twill (7,8%) and footbed (1,7%). Additionally, the contributors to the emissions produced in the core processes are: the electricity use (62,2%), heat production (36,4%), and from the transport of materials from suppliers to shoe manufacturer (1,4%).

Ozone formation

From cradle to grave, Wata releases approximately 0,0217 kg NOX eq., in which the upstream phase is responsible for 67,8% of the emissions, the core processes for 18,0% and downstream phase accounts for 14,2%. Among the upstream processes the agro-ecological cotton twill represents 26,8% of the total impact, and the cotton canvas represents 24,5% – in both cases mainly due to heat production. The next materials that contribute to Wata's environmental performance are: outsole (11,4%), shoelaces (7,5%), footbed (7,4%), additional rubber products

(6,9%) and the shoe box (5,7%). During the core phase, the greatest contribution comes from heat production (64,2%), followed by the transport of materials (18,6%) and the use of electricity (17,2%).

Acidification

Throughout its life cycle, Wata releases 0,0232 of kg SO_2 equivalent (Table 7). Nearly ¾ of the emissions are released in the upstream phase (73,1%), while the rest is divided between the core (13,4%) and downstream phase (13,5%). Out of the upstream processes, the outsole accounts for 18,9% of the impact, the shoelaces are responsible for 13,1% and the agro-ecological cotton canvas for 13,0%. Moreover, other components that contribute to Wata's environmental performance are: agro-ecological cotton twill (12,9%), other rubber products (10,4%), eyelet made of brass (9,6%), shoe box (8,7%) and footed (4,7%). Furthermore, during the core processes the electricity use is responsible for half of the emissions, followed by heat production (38,2%) and the transport of materials from supplier to shoe manufacturer (11,7%).

Table 7: Potential environmental impact of Wata divided per life cycle stages.

Impact Category	Unit	Total	Upstream	Core	Downstream
Global warming	kg CO_2 eq.	5,63	4,09	0,744	0,789
Ozone depletion	kg CFC-11 eq.	1,69E-05	1,41E-05	2,15E-06	6,81E-07
Ozone formation	kg NOX eq.	0,0217	0,0147	0,00391	0,00307
Acidification	kg SO_2 eq.	0,0232	0,017	0,00313	0,00314
Eutrophication	kg P eq.	0,00141	0,00122	0,00015	4,22E-05

Eutrophication

Finally, in the eutrophication impact category, it is considered that a total of 1,41E-03 kg of P eq. is emitted. From this total, the upstream processes contribute to 86,4%, the core processes to 10,6% and the downstream processes (3,0%). Differently from the other impact categories, the main contributor to the upstream emissions is the production system of the eyelet made of brass (34,7%). Other great contributors are: shoelaces (19,8%), outsole (9,9%), shoe box (9,9%), rubber products (8,1%), agro-ecological cotton canvas (4,9%) and cotton twill (4,1%). Lastly, in the core processes electricity use accounts for 77,5%, heat production is responsible for 21,8%, whereas transport accounts for only 0,7% of the total impact of this life cycle phase.

5.3 Interviews and online survey

During the study, interviews with the founders of VEJA, and with the customer service and communication departments were conducted. During the interview with the founders of VEJA, it became clear that sustainability is not a marketing tool due to their continuous pursuit for projects that either minimize the environmental impact of VEJA's footwear or reduce social inequity. For instance, the company is currently conducting a project to cultivate staple food, produce alternative fibers and raise animals in deforested areas in the Amazon forest. The idea is to create systems that are similar to agroforestry and silvopasture. The primary goal of the project is to create a new model of income for the communities by supplying fibers that will be used in VEJA's footwear. Furthermore, the vision of the company is to be recognized worldwide as the most sustainable footwear in the market and to be the frontrunner in developing alternative and sustainable materials.

The interviews and meeting with the customer service and communication departments aimed at identifying the topics regarding sustainability that are of highest concern to clients. In terms of inquiries, VEJA's team receives frequent questions about rubber's composition and chemicals used during the manufacturing processes. VEJA is extremely transparent about the use of natural rubber, thus the company shares in its website the exact percentage of natural rubber used in all their footwear. However, since its use has technical limitations and usually represents less than ¼ of the outsole, consumers are interested to know the other materials that comprise the outsole and the purpose of their use. Concerning the chemicals used, most of the inquiries are not related to the chemicals that are dangerous to people, wildlife and the environment, e.g., phthalate, azo dyes, chlorophenols, and organotin compounds (Brigden et al., 2012). In fact, most customers are concerned about chemicals and components that might cause allergic reactions, such as rubber chemicals, adhesives, and agents used in the tanning of leather (Hulstaert et al., 2017; Nedorost, 2009).

The customer service and communication teams mainly receive messages concerning the use of leather and requesting vegan options in VEJA's models. The founders of VEJA are aware of the meaningful impacts coming from the use of leather and petrol-based products, thus VEJA recently released some of its footwear with the upper made with a new type of artificial leather produced with bio-based polyurethane. However, although the founders and VEJA's customers are engaged in sustainability and interested in the social and environmental aspects of the company's supply chain, according to the founders more than 75% of the revenue comes from leather products, whereas half of the collection has materials of animal origin in its composition.

To conclude the research on the main drivers of stakeholder value an online survey was conducted during two weeks of August 2018. The survey was shared in social media with a focus on consumers that are concerned with sustainability or buy products from eco-friendly brands – the profile most of VEJA's consumers fit in. From the total number of responses (39), 66% of the respondents declared to be concerned or very concerned about sustainability and/or are likely or very likely to buy sustainable products within the next 12 months. For them, the most important aspects of sustainable footwear in the purchase decision are Fairtrade – payment of fair prices to the producers – and other certifications, followed by vegetable tanned leather and sustainable design (Figure 22). The use of natural rubber, alternative materials, and vegan footwears are the least important aspects. The questions and other results can be found in APPENDIX B – Online survey and results.

The results show that although VEJA frequently has many inquiries about vegan models and claims about the use of leather, the vegan aspect of footwear is crucial for only one-third of the respondents. This might be due to the advocacy of the vegan movement that pressure companies and government towards improving animal rights. Furthermore, the fact that Fairtrade and other certifications appeared as the most critical aspects of sustainable products show the need for companies to prove compliance with sustainable practices through third-party audits.

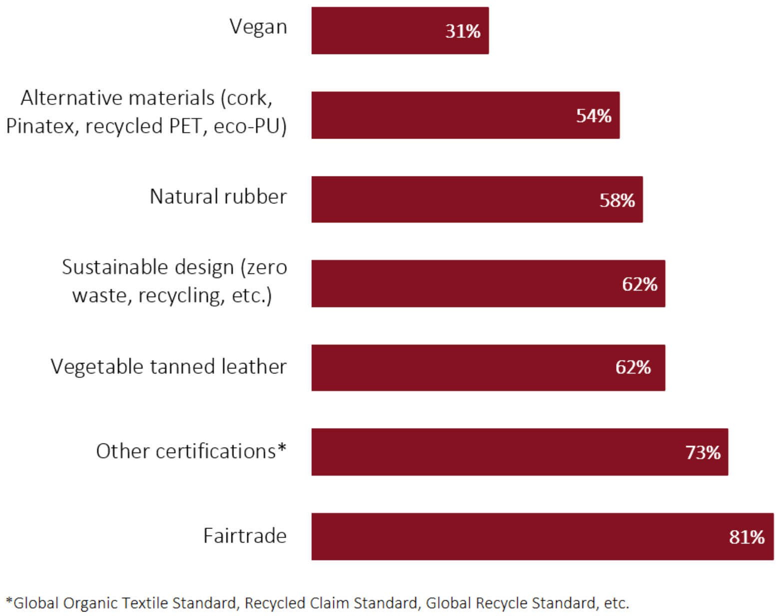

Figure 22: Importance of aspects of sustainable products in the purchase decision.

The outcomes of the survey are consistent with the findings of the study commissioned by Fashion Revolution, in which 5.000 people from the five largest European markets answered to a systematic survey. Their study focused on understanding how supply chain transparency and sustainability impact consumers' purchasing decisions when shopping for clothing, accessories, and footwear. When shopping fashion items, it is important for 39% of consumers surveyed to buy items made by workers paid a fair price or living wage. The other topics covered by the survey included environmental protection (37%), safe working conditions (31%), animal welfare (30%), local production (10%) and use of recycled materials (6%) (Fashion Revolution, 2018). Although the payment of fair prices to workers was identified as the most critical aspect in both surveys, the study from Fashion Revolution embraced other items such as clothing and accessories and the general fashion market.

DISCUSSION

Based on the presented results, the guiding question of this study "What is the environmental performance of footwear made with alternative materials and which recommendations can be drawn to enhance the sustainable value of an eco-friendly company?" can be answered. In the following sections, the research question is addressed, and subsequently, the limitations of the study are specified.

6.1 Environmental performance and recommendations

6.1.1 Upstream processes

In line with previous studies, the results of the LCIA indicate the extraction of raw material, its refinement, and the production of intermediate components as the phase of the life cycle with the most significant impact on the environmental performance of footwear. Nevertheless, the use of alternative materials, such as in the case of Wata, contributes to lower the emissions released during the upstream processes and consequently, reduces the overall environmental impact of the footwear. Thus, since VEJA has total control over the materials used in its designs, the company should strengthen its pursuit for alternative and locally produced materials as the company has already done for agro-ecological cotton, natural rubber, and fabric made of recycled PET.

From an environmental point of view, VEJA should cease the use of leather in their models, since in the models V-10 and Esplar, the material is responsible for not less than 70% of the total impact in all categories analyzed. Although the tanning industry is considered to be a significant source of pollution and alternative tanning methods, such as vegetable tanning and other tanning agents, might decrease the environmental burden of the process, the impact of tanning was relevant only in the impact category ozone formation. In fact, the agricultural aspect of the life cycle of leather is the main responsible for the impact in 4 out of 5 categories. Nevertheless, as identified during the interview with the founders of the company, VEJA's revenue is heavily dependent on leather products. Therefore, VEJA should gradually expand the vegan collection and raise awareness of consumers regarding the impact of the use of leather. On the other hand, leather products are known for its durability and resistance, thus a study assessing the lifespan of footwear according to its materials should be conducted to understand the real benefits of the change.

Other two materials that are frequently ranked as one of the components with the most significant contribution to the environmental impact of the footwear are the outsole and shoelaces. In all three models the outsole is the heaviest part of the footwear, and despite the percentage of FDL in its composition (from 18 to 23%), the component has a significant impact on global warming, ozone formation, acidification, and eutrophication. The outsole used in the model V-10 has a different composition from the one used in the models Wata and Esplar, thus, the materials with the most significant impact differ among the models. In model V-10, polybutadiene is the main responsible for the impact followed by the use of silica. These materials represent half of the total weight of the outsole, however, in some impact categories such as global warming, the polybutadiene alone accounts for half of the impact. Concerning the outsole used in the other two models, the polybutadiene, even in smaller concentration, is also responsible for a significant part of the environmental impact of the outsole. Nevertheless, the use of "product 1", which is only 6,4% of the outsole's content has important impacts on global warming, eutrophication and ozone formation. Therefore, VEJA should establish a partnership with the shoe manufacturer, who has the expertise regarding rubber products, to increase the environmental performance of the outsole. The aim of the collaboration should be to investigate alternative materials that could substitute the use of polybutadiene, silica, and "product 1", as well as to increase the amount of FDL since despite its high percentage use the material had minimal contributions to the environmental impact of the outsole.

The social and environmental benefits of using agro-ecological cotton are undeniable. For this reason, VEJA should partner with the shoelaces manufacturer and supply the agro-ecological cotton harvested in Northeast of Brazil to produce it. Nonetheless, the production of agro-ecological cotton by small farmers is restricted, and with the steady growth in sales and VEJA's increasing demand for agro-ecological cotton, the company should seek for other associations in Brazil that could supply the material. Furthermore, to improve the environmental performance of the VEJA's footwear, the company should engage the management team of the dyeing house to assist VEJA in finding more sustainable options for the use of tetrafluoroethylene. The chemical is used in both cotton canvas and shoelaces to repel soil and water, and its use has a high impact in ozone depletion. Some alternatives are the use of short-chain fluorinated and silicone-based repellents, which are recognized for their favorable health and environmental properties (Holmquist, 2016; ZDHC, 2012).

The cotton twill and canvas often perform as the materials with the most significant impact, especially on the performance of the model Wata. To achieve significant improvements, it would be necessary investments in new machinery or the identification of new suppliers with better performance. Other options would be to adopt simpler weave construction that requires less energy to be produced or to shift to the use naturally colored lint and cotton fabric in its original color, avoiding the energy intensive processes stages in the dyeing house. These options, however, are not feasible since the investment in machinery would have to be done by the suppliers and working with new suppliers involves financial and logistics aspects of the business. Moreover, the use of different fabric constructions or change the color of textiles according to the varieties of naturally colored lint available would modify the design and characteristics of the footwear, which could affect the sales. Anyhow, VEJA should investigate customer's response to the use of naturally colored lint and its availability in agro-ecological systems. Nonetheless, it is essential to understand that materials will always have an environmental impact and to acknowledge when all feasible solutions to reduce it have been implemented.

Still regarding the use of materials, VEJA should cease the use of eyelets made of brass used in the model Wata. The eyelets represent less than 0.6% of the model's total weight and account for more than 34% of the impact in eutrophication and contribute to acidification, mostly due to its copper content. A simple alternative is to substitute the eyelet made of brass to ones made of aluminum or preferably, made of recycled content. Lastly, new regulations concerning packaging are in place or under development, such as the VerpackG – English, Packaging Act – in Germany. Therefore, to take responsibility for the environmental impacts of their product and to reduce its obligations, VEJA should reconsider the packing materials currently used and explore alternative solutions, such as biodegradable and recycled materials. Moreover, the development of lighter packaging with a secondary use, such as "Clever Little Bag" designed by Yves Béhar of Fuseproject and commissioned by Puma, would reduce the use of resources and avoids waste disposal.

6.1.2 Core and downstream processes

Although the core and downstream processes represent a small portion of the environmental performance of the footwear, some initiatives can assist the sustainable value creation. To minimize the impact of the core and downstream processes, VEJA should prioritize the acquisition of materials produced in the region of Vale dos Sinos, and when responsible for contracting freight to deliver the materials, VEJA should prioritize companies with a newer fleet. Furthermore, to reduce energy consumption throughout the core phase, VEJA should encourage the shoe manufacturer to contact an energy service company (ESCO) and invest in energy efficiency. In this manner, the ESCO would evaluate the production and assembly facilities and would identify points of improvement to provide comprehensive solutions for energy and cost savings. Through this model, the ESCO would provide expert advice to the shoe manufacturer and the benefits of improved energy efficiency would be shared between the two companies.

Regarding the waste generated during the production and assembly of footwear, the shoe manufacturer is carrying out excellent initiatives to avoid landfilling. However, both companies should explore new and more sustainable solutions to transform these co-products into new materials or products – i.e., upcycling – as it is currently done with the leather waste to produce insoles. Furthermore, according to the waste hierarchy, energy recovery and disposal are the least preferable options. Thus, VEJA should create tools and systems to increase the lifespan of their footwear. To improve the durability of the footwear, an option to VEJA is the development of a guide on how customers can take proper care of their footwear, as well as sell sustainable shoe-care products, such as banana oil to clean leather products. The company should also consider the development of a service where customers could send their footwear from VEJA to be renewed. Some companies in France, such as Hello Sneakers Atelier, Sneaker and Chill and L'atelier de la basket, have developed different business models in which footwear can be cleaned, renovated or customized. Thus, VEJA could establish a partnership with one of these companies to extend the life of their clients' footwear. Moreover, in cases which the customer does not want the product anymore, but it is still in good condition and can be worn longer, VEJA could sanitize and renovate the footwear and create a second-hand shop to sell these models for lower prices.

Once there are no more options to avoid the end of life of the footwear, its recycling should be prioritized. Nevertheless, footwear recycling requires either machinery that is specific and expensive to separate its materials or footwear made of few components, and that is easy to be disassembled. In June this year, SOEX, a global leader in the field of used textiles and recycling, together with I:Collect, an international specialist for the collection, reuse, and recycling of textiles and footwear, launched the first shoe recycling plant in Wolfen, Germany. VEJA should discuss the possibility to establish a collaboration with SOEX and I:Collect to reduce waste and use the secondary raw materials derived from the recycling plant into VEJA's products. This project would lead to a closed production cycle and would enable a circular economy. Moreover, VEJA should evaluate the possibility to reduce the number of components in the footwear in order to simplify its recycling, without compromising its design and characteristics.

6.1.3 Stakeholder value

In terms of increasing stakeholder value, VEJA should first certify the agro-ecological cotton and FDL as Fairtrade – or equivalent certification – and as organic. This would legitimize the company's effort to ensure more equitable and dignified commercial transactions. The certification process might be costly and time-consuming, but as it was shown in both surveys, the payment of fair prices and other certifications are the most important aspect of products in the purchase decision. Furthermore, the purchase of certified recycled PET fabric would add further value to the company, since currently its origin is based on the supplier's declaration.

Regarding the use of materials and its composition, VEJA should increase transparency by sharing in its website sheets with the detailed information of each material used. Furthermore, concerning the chemicals used that are dangerous to people, wildlife and the environment or that might cause allergic reactions, the company should create a Restricted Substances List (RSL) and develop a program to ensure compliance with VEJA’s RSL requirements. The RSL document should be based on environmental and health & safety risk assessments and should be used to reduce the use and impact of harmful substances in VEJA’s supply chain. In this case, VEJA would be responsible for training their suppliers about the company’s RSL requirements and procedures. Documents published by the AFIRM Group, Greenpeace and ZDHC Foundation could be used as a starting point to understand some substances risk, where they are used in the supply chain, the reasons they are restricted, as well as safer alternatives.

6.2 Limitations

The materials used in the manufacturing of footwear usually have mixed composition. Due to time limitation and confidential information some components had to be restricted to its main materials. Furthermore, the lack of specific data and literature required the use of generic and proxy data for different materials and components. For example, there are five different products made of polyester in which the extraction and preparation of the raw materials are the same, but the manufacturing processes of the semi-finished materials are not. By excluding these processes some relevant contributions might have been neglected.

Considering that most of the phases of the product’s life cycle take place in Brazil and the fact that ReCiPe's database is primarily of European origin, nearly all data chosen for the inputs and outputs are from generalized global averages. The exceptions are data from the electricity grid in Brazil and from the end of life of the footwear in France. The use of proxy and generic data, as well as global averages, decrease the confidence in the results, thus an uncertainty analysis is needed to determine whether the differences between the results are significant or not. However, the license of SimaPro used in the study limits some of the software's features and the uncertainty analysis could not be carried out.

Although the packaging materials are most likely to be recycled in France, the author opted to follow PCR's guidelines and not consider recycling as an end of life scenario. Furthermore, by adopting the transport by truck and a single trip for all road transportation, its contribution to the total environmental performance of the footwear might have been reduced since some fleet might be older than the process data selected and for some suppliers, a round trip should have been adopted. Lastly, the sensitivity analysis to evaluate the influence of the most critical assumptions on the results, e.g., economic allocation, was not conducted due to lack of time.

Regarding the online survey carried out to identify the most important aspects of sustainable footwear in the purchase decision, the outcomes are restricted by the limited number of responses and the possibility that not all topics regarding sustainability in footwear companies might have been covered by the survey. Furthermore, the concept of stakeholder includes a list of different groups, some of which are employees, suppliers, shareowners, lenders, and society (Freeman, 2010). The online survey conducted had its focus on only one of these groups, i.e., customers. Therefore, in-depth research with a broader audience from different groups of stakeholders should be conducted to validate the findings.

CONCLUSION

The present study provides recommendations to enhance the sustainable value of an eco-friendly footwear company. In this regard, the supply chain of the was characterized, and three LCA were conducted to identify the life cycle phases and materials with most relevant impact on the environmental performance of the footwear. Moreover, the main drivers of stakeholder and shareholder value were identified through interviews and an online survey.

The findings are in line with previous studies that indicate the extraction and refinement of raw materials, as well as the production of intermediate components as the life cycle phase with the most significant impact on the environmental performance of footwear. By carrying out this study, the materials and processes with particularly high impacts were identified. In fact, the use of leather was identified as having the most significant impact on the environmental performance of two models analyzed, accounting for more than 70% of the total impact. Other materials identified as having relevant impacts on the environmental performance of footwear were the outsole and shoelaces. The transport of materials to the shoe manufacturer, the production and assembly of footwear, its distribution and end of life have a minor contribution to the overall impact. Moreover, the footwear model with the highest amount of alternative materials demonstrated to have the best environmental performance – on average 88% lower than the other two models analyzed. The interviews and online survey identified the payment of fair prices to producers and the adoption of certifications as the most important aspect of products. Transparency regarding the materials composition and the chemicals used during the manufacturing processes are also topics of high concern for stakeholders.

Nevertheless, future research focusing on specific footwear components and on its sustainable alternatives is needed to identify improvements in the environmental performance of footwear. Regarding the use of new and sustainable materials, it is important to investigate the real environmental benefits of its use in comparison with the material to be substituted. Finally, further research encompassing other groups of stakeholders would increase sustainable value creation of the company.

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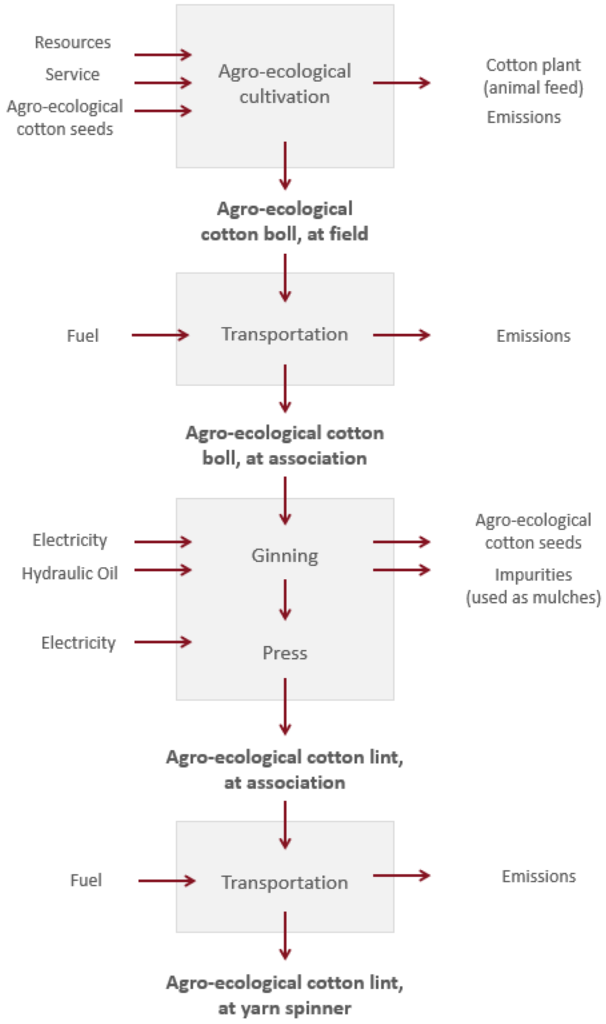
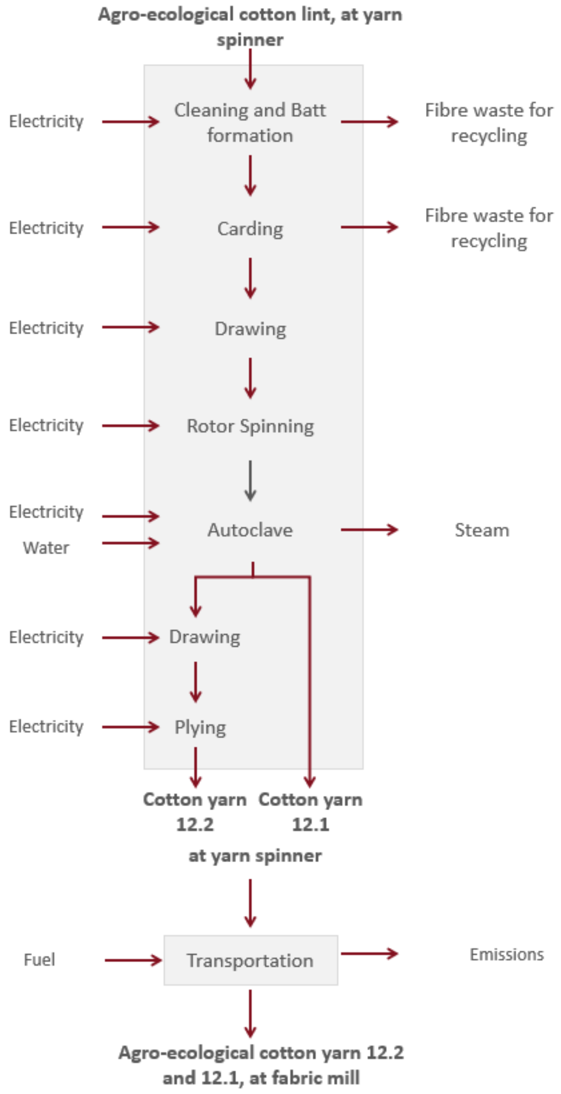
APPENDIX A – Additional product system and life cycle inventories

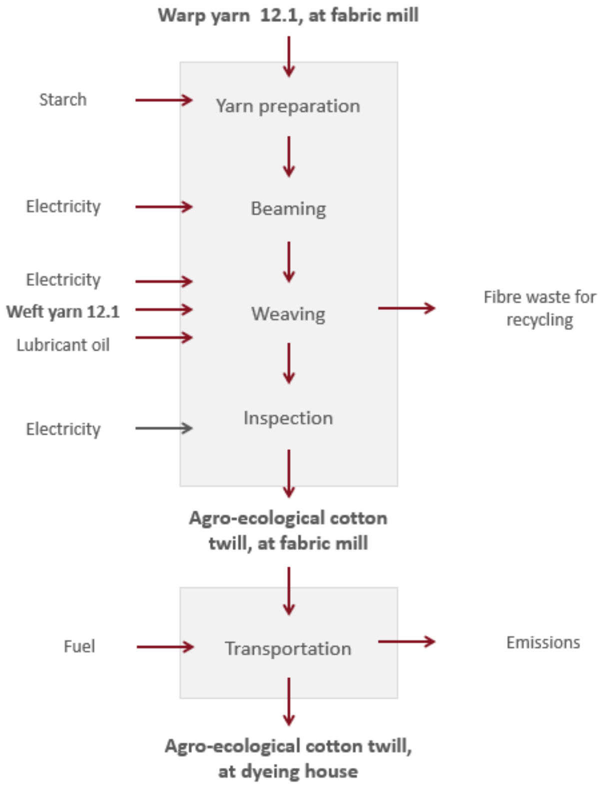
1. Agro-ecological cotton lint unit process chain

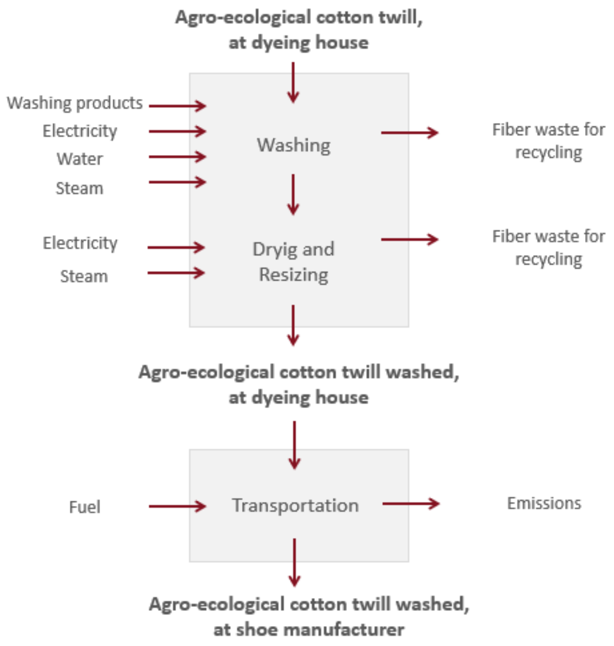


2. Agro-ecological cotton yarn unit process chain

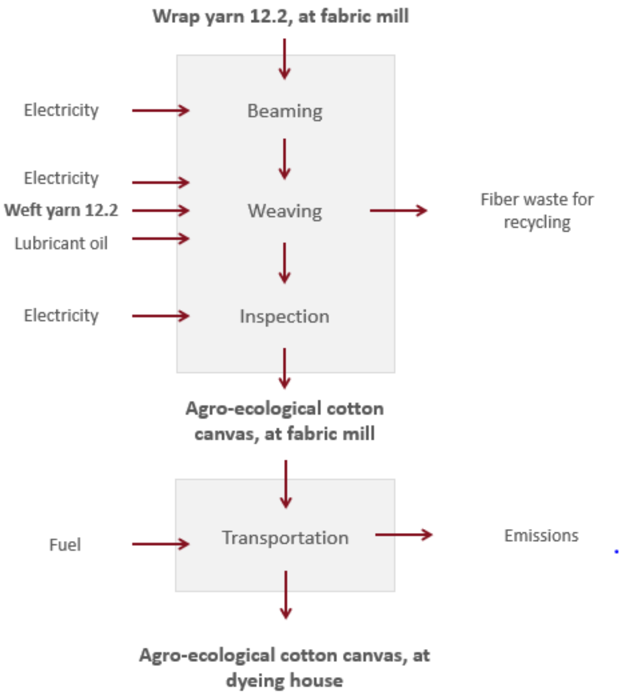


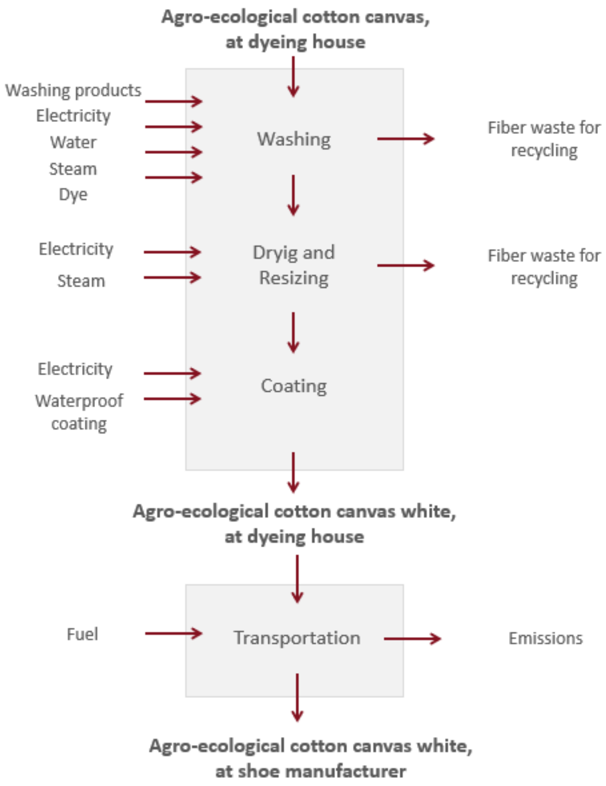
3. Agro-ecological cotton twill unit process chain



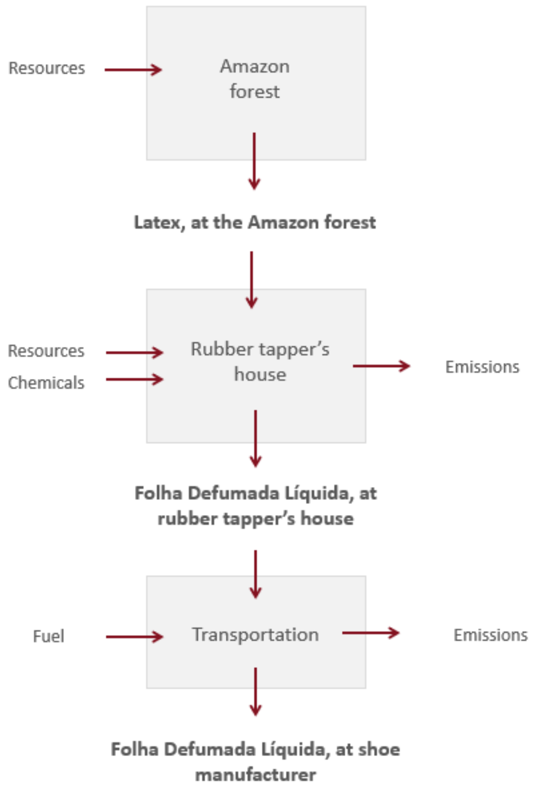


4. Agro-ecological cotton canvas unit process chain





5. Folha Defumada Líquida unit process chain



6. Life Cycle Inventory Analysis of agro-ecological cotton canvas

AGRO-ECOLOGICAL COTTON CULTIVATION (Product - cotton boll: 1.000,00 kg)			
INPUT	Quantity	Unit	Comment
Tillage, ploughing	1,10	ha	
Occupation, annual crop, organic	1,10	ha year	
Transformation, from annual crop	1,10	ha	
Transformation, to annual crop, organic	1,10	ha	
Energy, gross calorific value, in biomass	19 392,81	MJ	cotton production RoW
Carbon dioxide, in air	1 721,36	kg	cotton production RoW
Agro-ecological cotton seeds	6,60	kg	6 kg of cotton seed / hectare
Rain water	4 030,40	m^3	Funceme, 2018 - Based on historical data from January to June 2017
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton boll, at field	**1 000,00**	**kg**	
Agro-ecological cotton plant, at field	3 401,67	kg	Pedroza et al. 2003
Water	792,00	ton	Murugesh & Selvadass, 2013

TRANSPORTATION (from farmer to association)			
INPUT	Quantity	Unit	Comment
Agro-ecological cotton boll, at field	1	ton	
Transport	38	tkm	Google Maps
OUTPUT	Quantity	Unit	Source
Cotton boll agro-ecological, at ginning	1	ton	

COTTON ASSOCIATIONS - AGRO-ECOLOGICAL COTTON GINNING (Product - cotton lint: 1.000,00 kg)

INPUT	Quantity	Unit	Comment
Agro-ecological cotton boll, at ginning	2 710,03	kg	
Electricity, cotton gin (*descaroçadeira*)	93,45	kWh	2.710,03 kg (Cotton boll) / 87 kg/h (Capacity) x 3 kW (Power)
Lubricating oil	0,87	kg	2.710,03 kg (Cotton boll) x 36,9% (Cotton lint) x 0,001 liters of Hydraulic Oil / kg of Cotton lint x 0,87 g/cm^3
Electricity, press (*prensa*)	20,56	kWh	1.000,00 kg (Cotton lint) / 180 kg/h (Capacity) x 3,7 kW (Power)
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton lint, at ginning	**1 000,00**	**kg**	Cotton lint (10,90 R$/kg)
Agro-ecological cotton seeds, at ginning	1 709,49	kg	Waste from ginning (63,08%)
Impurities like leaves, dust, stones	0,54	kg	Waste from ginning (0,02%)

TRANSPORTATION (from association to yarn spinner)

INPUT	Quantity	Unit	Comment
Agro-ecological cotton lint, at ginning	1,00	ton	
Transport	2 703,00	tkm	Goggle Maps
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton lint, at yarn spinner	1,00	ton	

YARN SPINNER (Product - yarn 12.2: 1.000 kg)

INPUT	Quantity	Unit	Comment
Cotton lint, at yarn spinner	1 098,90	kg	
Electricity, cleaning and batt formation (*sala de abertura)*	316,48	kWh	1.098,90 kg (Cotton lint) / 500 kg/h (Capacity) x 144 kW (Power)
Electricity, carding (*carda*)	237,36	kWh	1.098,90 kg (Cleaned cotton) / 500 kg/h (Capacity) x 12 kW (Power) x 9 (Units)
Electricity, drawing (*passadeira*)	48,00	kWh	1.000,00 kg (Carded cotton) / 250 kg/h (Capacity) x 12 kW (Power)
Electricity, rotor spinning (*filatório a rotor open end*)	428,57	kWh	1.000,00 kg (Drawed cotton) / 140 kg/h (Capacity) x 60 kW (Power)
Electricity, autoclave	48,00	kWh	1.000,00 kg (Spinned cotton) / 1.000 kg/h (Capacity) x 48 kW (Power)
Water	171,00	m^3	spinning, bast fibre RoW
Electricity, drawing 12.1 (*binadeira*)	100,00	kWh	1.000,00 kg (Yarn 12.1) / 4 kg/h (Capacity) x 0,4 kW (Power)
Electricity, plying (*retorcedeira*)	1 207,55	kWh	1.000,00 kg (Yarn 12.1 drawed) / 53 kg/h (Capacity) x 64 kW (Power)
Packaging box	5,00E-07	p	spinning, bast fibre RoW
Soybean oil	12,50	kg	spinning, bast fibre RoW
Lubricating oil	12,50	kg	spinning, bast fibre RoW
OUTPUT	Quantity	Unit	Comment
Yarn 12.2, agro-ecological cotton, at yarn spinner	**1 000,00**	**kg**	
Fibre waste	98,90	kg	9% of losses
Steam	34,00	m^3	spinning, bast fibre RoW
Water	137,00	m^3	spinning, bast fibre RoW
Waste graphical paper	160,12	kg	yarn production, kenaf RoW

TRANSPORTATION (from yarn spinner to fabric mill)

INPUT	Quantity	Unit	Comment
Yarn 12.2, agro-ecological cotton, at yarn spinner	1,00	ton	
Transport	81,00	ton.km	Google Maps
OUTPUT	Quantity	Unit	Comment
Yarn 12.2, agro-ecological cotton, at fabric mill	1,00	ton	

FABRIC MILL (Product - cotton canvas: 1.000,00 kg)

INPUT	Quantity	Unit	Comment
Warp - Yarn 12.2, agro-ecologico cotton, at fabric mill	655,98	kg	
Electricity, beaming canvas (*urdideira + transferência para rolo*)	9,84	kWh	655,98 kg (Wrap - Yarn 12.2) / 200 kg/h (Capacity) x 3 kW (Power)
Weft - Yarn 12.2, agro-ecologico cotton, at fabric mill	388,08	kg	
Lubricating oil	0,41	g	0,446 ml of lubrificant oil / ton of Yarn 12.2 (Warp and Weft) * 0,87 g/cm³
Electricity, weaving canvas (*tear*)	596,64	kWh	1.044,06 kg (Wrap and Weft - Yarn 12.2): 132 (132h) x 4,52 kW (Power)
Electricity, inspection canvas (*revisadeira*)	2,02	kWh	1.000,00 kg (Cotton Canvas): 3,81 (3h49) x 0,53 kW (Power)
Packaging box	5,22E-07	p	weaving, bast fibre RoW
OUTPUT	**Quantity**	**Unit**	**Comment**
Agro-ecological cotton canvas, at fabric mill	**1 000,00**	**kg**	
Fibre waste	44,06	kg	
Waste graphical paper	20,15	kg	textile production, kenaf RoW

TRANSPORTATION (from fabric mill to dyeing house)

INPUT	Quantity	Unit	Comment
Agro-ecological cotton canvas, at fabric mill	1,00	ton	
Transport	1 264,00	ton.km	Google Maps
OUTPUT	**Quantity**	**Unit**	**Comment**
Agro-ecological cotton canvas, at dyeing house	1,00	ton	

DYEING HOUSE (Product - white canvas: 1.000 kg)

INPUT	Quantity	Unit	Comment
Agro-ecological cotton canvas, at dyeing house	1 062,85	kg	
Hydrogen peroxide	10,63	kg	10 g of Hydrogen Peroxide 130V / kg of Cotton Canvas
Sodium hydroxide	5,31	kg	5 g of Sodium Hydroxide/ kg of Cotton Canvas
Detergent	5,31	kg	5 g of Detergent / kg of Cotton Canvas
Tap water	7 971,38	l	7,5 l of Water / kg of Cotton Canvas
Bleach (cyanuric chloride)	75,00	kg	textile production, knit cotton, batch dyed GLO
Electricity, jigger	296,54	kWh	1.062,85 kg (Cotton Canvas) / 10 kg/h (Capacity) x 2,79 kW (Power)
Electricity, dryig and resizing (*rama*)	295,32	kWh	1.024,59 kg (Cotton canvas) / 0,36495 kg/m² (grammage) / 1,5 m (width) / 600 meters/h x 94,67 kW (Power)
Electricity, waterproof applicator (*"aplicador" de impermeabilizante*)	7,22	kWh	1.000,00 kg (Cotton Canvas washed) / 0,36495 kg/m² (grammage) / 1,5 m (width) / 600 meters/h x 2,37 kW (Power)
Waterproof agent - tetrafluoroethylene	32,53	l	32,53 ml of Waterproof agent / kg of Cotton canvas
Heat, central or small-scale	158 423,85	MJ	15,34 m³ x 510 kg/m³ x 20,25 MJ
OUTPUT	**Quantity**	**Unit**	**Comment**
White agro-ecological cotton canvas, at dyeing house	**1 000,00**	**kg**	
Fibre waste	24,59	kg	2,4% of losses
Waste water treatment	7,97	m³	treatment of wastewater, average, capacity 1E9l/year RoW
Sludge	39,52	m³	
BOD5, Biological Oxygen Demand	430,45	g	
COD, Chemical Oxygen Demand	1 275,42	g	
Phenol	0,64	g	
Iron	1,67	g	
Phosphorus, total	0,64	g	
Nitrogen, total	41,45	g	
Solids, inorganic	6,38	g	
Suspended solids, unspecified	310,88	g	
Surfactants	8,77	g	

TRANSPORTATION (from dyeing house to shoe manufacturer)

INPUT	Quantity	Unit	Comment
White agro-ecological cotton canvas, at dyeing house	1,00	ton	
Transport	38,00	ton.km	Google Maps
OUTPUT	**Quantity**	**Unit**	**Comment**
White agro-ecological cotton canvas, at shoe manufacturer	1,00	ton	

7. Life Cycle Inventory Analysis of agro-ecological cotton twill

The cotton production and ginning are the same for cotton twill and cotton canvas. Therefore, the life cycle inventory for cotton twill starts from the yarn spinner.

YARN SPINNER (Product - yarn 12.1: 1.000 kg)

INPUT	Quantity	Unit	Comment
Agro-ecological cotton lint, at yarn spinner	1 098,90	kg	
Electricity, cleaning and batt formation (*sala de abertura)*	316,48	kWh	1.098,90 kg (Cotton lint) / 500 kg/h (Capacity) x 144 kW (Power)
Electricity, carding (*carda*)	237,36	kWh	1.098,90 kg (Cotton lint) / 500 kg/h (Capacity) x 12 kW (Power) x 9 (Units)
Electricity, drawing (*passadeira*)	48,00	kWh	1.000,00 kg (Carded cotton) / 250 kg/h (Capacity) x 12 kW (Power)
Electricity, rotor spinning (*filatório a rotor open end*)	428,57	kWh	1.000,00 kg (Carded cotton) / 140 kg/h (Capacity) x 60 kW (Power)
Electricity, autoclave	48,00	kWh	1.000,00 kg (Carded cotton) / 1.000 kg/h (Capacity) x 48 kW (Power)
Water	171,00	m³	spinning, bast fibre RoW
Packaging box	5,00E-07	p	spinning, bast fibre RoW
Soybean oil	12,50	kg	spinning, bast fibre RoW
Lubricating oil	12,50	kg	spinning, bast fibre RoW
OUTPUT	Quantity	Unit	Comment
Yarn 12.1, agro-ecological cotton, at yarn spinner	**1 000,00**	**kg**	
Fibre waste	98,90	kg	
Steam	34,00	m³	spinning, bast fibre RoW
Water	137,00	m³	spinning, bast fibre RoW
Waste graphical paper	160,12	kg	yarn production, kenaf RoW

TRANSPORTATION (from yarn spinner to fabric mill)

INPUT	Quantity	Unit	Comment
Yarn 12.1, agro-ecological cotton, at yarn spinner	1,00	ton	
Transport	81,00	ton.km	Google Maps
OUTPUT	Quantity	Unit	Comment
Yarn 12.1, agro-ecological cotton, at fabric mill	1,00	ton	

FABRIC MILL (Product - cotton twill: 1.000,00 kg)

INPUT	Quantity	Unit	Comment
Warp - Yarn 12.1, at fabric mill	610,31	kg	
Maize Starch	31,23	kg	3,1% of the weight of the yarn entering the process
Electricity, beaming twill (*urdideira + transferência para rolo*)	17,98	kWh	610,31 kg (Wrap - Yarn 12.1) + 18,84 kg (Starch on Wrap) / 105 kg/h (Capacity) x 3 kW (Power)
Weft - Yarn 12.1, at fabric mill	399,58	kg	
Lubricant oil	0,88	g	0,975 ml of lubrificant oil / ton of Yarn 12.1 (Warp, Weft + Starch) x 0,87 g/cm³
Electricity, weaving twill (*tear*)	1 318,53	kWh	610,31 kg (Wrap - Yarn 12.1) + 31,23 kg (Starch) + 399,58 kg (Weft - Yarn 12.1): 291,71 (291h43) x 4,52 kW (Power)
Electricity, inspection twill (*revisadeira*)	2,81	kWh	1.00,00 kg (Cotton Twill): 5,31 (5h19) x 0,53 kW (Power)
Packaging box	5,05E-07	p	weaving, bast fibre RoW
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton twill, at fabric mill	**1 000,00**	**kg**	
Fibre waste	41,12	kg	
Waste graphical paper	20,15	kg	textile production, kenaf RoW

TRANSPORTATION (from fabric mill to dyeing house)

INPUT	Quantity	Unit	Comment
Agro-ecological cotton twill, at fabric mill	1,00	ton	
Transport	1 264,00	ton.km	Google Maps
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton twill, at dyeing house	1,00	ton	

DYEING HOUSE (Product - washed twill: 1.000 kg)			
INPUT	Quantity	Unit	Comment
Cotton twill, at dyeing house	1 062,85	kg	
Hydrogen peroxide	10,63	kg	10 g of Hydrogen Peroxide 130V / kg of Cotton Twill
Sodium hydroxide	5,31	kg	5 g of Sodium Hydroxide/ kg of Cotton Twill
Detergent	5,31	kg	5 g of Detergent / kg of Cotton Twill
Water	7 971,38	l	7,5 L of Water / kg of Cotton Twill
Electricity, jigger	296,54	kWh	1.062,85 kg (Cotton Twill) / 10 kg/h (Capacity) x 2,79 kW (Power)
Electricity, dryig and resizing (*rama*)	411,89	kWh	1.024,59 kg (Cotton Twill washed) / 0,26166 kg/m^2 (grammage) / 1,5 m (width) / 600 meters/h x 94,67 kW (Power)
Heat, central or small-scale	221 008,50	MJ	21,40 m^3 x 510 kg/m^3 x 20,25 MJ
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton twill washed , at dyeing house	**1 000,00**	**kg**	
Fibre waste	24,58	kg	2,4% of losses
Waste water treatment	7 971,38	l	treatment of wastewater, average, capacity 1E9l/year RoW
Sludge	40,03	kg	
Ashes	3,82	kg	
BOD5, Biological Oxygen Demand	430,45	g	
COD, Chemical Oxygen Demand	1 275,42	g	
Phenol	0,64	g	
Iron	1,67	g	
Phosphorus, total	0,64	g	
Nitrogen, total	41,45	g	
Solids, inorganic	6,38	g	
Suspended solids, unspecified	310,88	g	
Surfactants	8,77	g	

TRANSPORTATION			
INPUT	Quantity	Unit	Comment
Agro-ecological cotton twill washed , at dyeing house	1,00	ton	
Transport	38,00	ton.km	Google Maps
OUTPUT	Quantity	Unit	Comment
Agro-ecological cotton twill washed , at shoe manufacturer	1,00	ton	

8. Life Cycle Inventory Analysis of FDL

FDL PRODUCTION (Product - FDL: 1.000,00 kg)			
INPUT	Quantity	Unit	Comment
Latex Amazonia	2 333,33	kg	
Water, rain	9 523,81	l	
Folpet	23,81	kg	
Pyroligneous acid (water + acetic acid)	238,10	kg	
Occupation, tropical rain forest	280,28	ha a	Souza et al., 2005
OUTPUT	Orign	Source	Comment
Folha Defumada Liquida, rubber tapper's house	1 000,00	kg	
Water	1 106,23	l	
Chemically polluted water	5,67	kg	Estimated

TRANSPORTATION (rubber tapper's dwelling to shoe manufacturer)			
INPUT	Quantity	Unit	Comment
FDL, at rubber tapper's house	1,00	ton	
Transport	3 448,00	kg.km	Google Maps
OUTPUT	Quantity	Unit	Comment
FDL, at shoe manufacturer	1,00	ton	

9. Life Cycle Inventory Analysis of Recycled PET fabric

YARN SPINNER (Product - yarn Recycled PET: 1.000 kg)

INPUT	Quantity	Unit	Comment
Recycled PET fiber, at yarn spinner	1 075,27	kg	13,68% considered
Electricity, cleaning and batt formation (*sala de abertura)*	309,68	kWh	1.075,27 kg (PET fiber) / 500 kg/h (Capacity) x 144 kW (Power)
Electricity, carding (*carda*)	232,26	kWh	1.075,27 kg (Cleaned cotton) / 500 kg/h (Capacity) x 12 kW (Power) x 9 (Units)
Electricity, drawing (*passadeira*)	48,00	kWh	1.000,00 kg (Carded PET) / 250 kg/h (Capacity) x 12 kW (Power)
Electricity, rotor spinning (*filatório a rotor open end*)	428,57	kWh	1.000,00 kg (Drawed PET) / 140 kg/h (Capacity) x 60 kW (Power)
Electricity, autoclave	48,00	kWh	1.000,00 kg (Spinned PET) / 1.000 kg/h (Capacity) x 48 kW (Power)
Water	171,00	m^3	spinning, bast fibre RoW
Electricity, drawing 12.1 (*binadeira*)	100,00	kWh	1.000,00 kg (PET Yarn) / 4 kg/h (Capacity) x 0,4 kW (Power)
Electricity, plying (*retorcedeira*)	1 207,55	kWh	1.000,00 kg (Yarn PET drawed) / 53 kg/h (Capacity) x 64 kW (Power)
Packaging box	5,00E-07	p	spinning, bast fibre RoW
Soybean oil	12,50	kg	spinning, bast fibre RoW
Lubricating oil	12,50	kg	spinning, bast fibre RoW
OUTPUT	Quantity	Unit	Comment
Recycled PET yarn, at yarn spinner	**1 000,00**	**kg**	
Fibre waste	75,27	kg	7% of losses
Steam	34,00	m^3	spinning, bast fibre RoW
Water	137,00	m^3	spinning, bast fibre RoW
Waste graphical paper	160,12	kg	yarn production, kenaf RoW

TRANSPORTATION (from yarn spinner to fabric mill)

INPUT	Quantity	Unit	Comment
Fibre waste	1,00	ton	
Transport	73,00	ton.km	Google Maps
OUTPUT	Quantity	Unit	Comment
Yarn 12.1, agro-ecological cotton, at fabric mill	1,00	ton	

FABRIC MILL (Product - Recycled PET: 1.000,00 kg)

INPUT	Quantity	Unit	Comment
Warp - B Mesh	270,66	kg	
Electricity, beaming recycled PET (*urdideira + transferência para rolo*)	11,36	kWh	270,66 kg (Wrap - Yarn 12.2) / 71,5 kg/h (Capacity) x 3 kW (Power)
Weft - B Mesh	773,33	kg	
Lubricant oil	0,69	g	0,828 ml of lubrificant oil / ton of Recycled PET (Warp and Weft) * 0,87 g/cm^3
Electricity, weaving recycled PET (*tear*)	906,09	kWh	1.043,99 kg (Wrap and Weft): 200,46 (200h27) x 4,52 kW (Power)
Electricity, inspection recycled PET (*revisadeira*)	2,30	kWh	1.000,00 kg (Recycled PET): 4,34 (4h20) x 0,53 kW (Power)
Packaging box	5,21E-07	p	weaving, bast fibre RoW
OUTPUT	Quantity	Unit	Comment
Recycled PET fabric, at fabric mill	**1 000,00**	**kg**	
Fibre waste	43,99	kg	
Waste graphical paper	20,15	kg	textile production, kenaf RoW

TRANSPORTATION (from fabric mill to shoe manufacturer)

INPUT	Quantity	Unit	Comment
Recycled PET fabric, at fabric mill	1,00	ton	
Transport	1 115,00	ton.km	Google Maps
OUTPUT	Quantity	Unit	Comment

APPENDIX B – Online survey and results

Total answers: 39

1. What gender do you identify? (Female, Male, Prefer not to say, Other)

Result: 72% female, 28% male

2. How old are you?

Result: Average 29 years old (from 24 to 37 years old)

3. How likely is that you will buy sustainable products within the next 12 months? (not likely at all, slightly likely, moderately, likely, very likely)

Result: not likely at all (3%), slightly likely (10%), moderately (46%), likely (31%), very likely (10%).

4. What is your level of concern regarding sustainability? (not concerned, somewhat concerned, concerned, very concerned)

Result: not concerned (3%), somewhat concerned (31%), concerned (51%), very concerned (15%)

5. Regarding sustainable footwear, please rate the level of importance of the following information to your purchase decision (not important at all, slightly important, important, fairly important, very important):
   - Fairtrade;
   - Vegetable tanned leather;
   - Sustainable design (zero waste, recycling, etc.);
   - Alternative materials (cork, Pinatex, recycled PET, eco-PU);
   - Natural rubber;
   - Vegan;
   - Other certifications (Global Organic Textile Standard, Recycled Claim Standard, Global Recycle Standard, etc.)

Overall importance for purchase decision:

Information:	Not important at all	Slightly important	Important	Fairly important	Very important	Importance for purchase decision:
Fairtrade	5%	28%	21%	26%	21%	67%
Other certifications	13%	33%	18%	23%	13%	54%
Vegetable tanned leather	21%	31%	23%	15%	10%	49%
Sustainable design	36%	15%	28%	15%	5%	49%
Alternative materials	28%	31%	21%	13%	8%	41%
Natural rubber	41%	23%	18%	13%	5%	36%
Vegan	56%	23%	13%	5%	3%	21%

Importance for purchase decision of costumers concerned or very concerned about sustainability and/or are likely or very likely to buy sustainable products:

Information:	Not important at all	Slightly important	Important	Fairly important	Very important	Importance for purchase decision:
Fairtrade	4%	15%	27%	35%	19%	81%
Other certifications	4%	23%	27%	31%	15%	73%
Vegetable tanned leather	15%	23%	27%	23%	12%	62%
Sustainable design	23%	15%	38%	15%	8%	62%
Alternative materials	15%	31%	35%	12%	8%	54%
Natural rubber	19%	23%	38%	15%	4%	58%
Vegan	50%	19%	19%	8%	4%	31%

APPENDIX C – Definitions

Binding: the reinforcement of the edge of the collar and eyestay of the footwear – e.g., on the model Wata;

Counter and toe puff: material embedded at the heel of the footwear or inside the upper to shape the toe box and the vamp. It is usually placed between the upper and the lining and it is used to protect and reinforce the footwear;

Eyelet and washer: the reinforcement of the hole punched into the footwear's eyestay which allows shoelaces to be threaded through. It is usually made from metal or plastic – e.g., on the model Wata;

Eyestay: the patch of perforated material attached to the upper where the laces are threaded through;

Foam padding: foam placed around the collar to improve comfort;

Footbed: the removable sole worn inside the footwear to improve the fit;

Heel counter: the patch of material attached to the outside of the heel area on the footwear's upper. It is used to stiff the heel, as well as an element of design – e.g., on the model V-10;

Insole: material sewn to the bottommost of the upper. It gives structure to the footwear before the sole is attached to the upper;

Lining: the material on the inside that the foot will be in contact with. It is used to extend the economic lifespan of the footwear while improving comfort;

Midsole: the layer of material between the insole and outsole of the footwear. It is applied to absorb shock;

Outsole: the outer sole of the footwear that comes in direct contact with the ground;

Puller: the patch of material attached to the outside of the heel area on the footwear's or upper beneath the collar. It is used to stiff the collar, as well as an element of design – e.g., on the models Esplar and V-10;

Quarter: the patch of material attached to the sides of upper – e.g., on the models Esplar and Wata;

Rubber toe cover: a patch of material that reinforces the outside area over the toes – e.g.: on the model Wata;

Shoelaces: the string used for fastening the shoes;

Sole: the parts of the footwear bellow the upper. It can be a single piece, or it can comprise many pieces glued together;

Toe box: the patch of material that covers the front of the footwear as far as it joins the quarter – e.g., on the model V-10;

Toe welt: the reinforcement made of rubber applied on top of the welt in the front part of the footwear – e.g.: on the models Esplar and Wata;

Tongue: the flap of upper material that covers the instep of the foot underneath the shoelaces;

Upper: the parts of the footwear above the sole. It can be a single piece, or it can comprise many pieces stitched together.

Vamp: the patch of material attached that covers the toes and its shape can be irregular, square, pointed or round – e.g.: on model V-10;

Welt: strip of rubber material that encircles the entire footwear and secures the joint where the upper and sole meet – e.g., on the models Esplar and Wata.

APPENDIX D – Life Cycle Inventory for rubber products

1. Inventory – V-10 outsole

	UPSTREAM			CORE	
INPUT	Quantity	Unit	%	Quantity	Unit
Silica	146,442	g	27,2%	185,8965	kgkm
Polybutadiene	125,289	g	23,3%	3,9892	kgkm
FDL	125,289	g	23,3%	445,1368	kgkm
Synthetic rubber	74,848	g	13,9%	86,6829	kgkm
Product 1	15,295	g	2,8%	48,6984	kgkm
Product 2	10,251	g	1,9%	0,3601	kgkm
Product 3	10,251	g	1,9%	0,5597	kgkm
Product 4	10,088	g	1,9%	11,8238	kgkm
Product 5	1,627	g	0,3%	1,8642	kgkm
Product 6	1,627	g	0,3%	0,0890	kgkm
Product 7	1,627	g	0,3%	0,0519	kgkm
Product 9	6,997	g	1,3%	--	kgkm
Product 10	6,997	g	1,3%	--	kgkm
Product 11	1,058	g	0,2%	--	kgkm
Product 12	0,814	g	0,2%	--	kgkm
OUTPUT	Quantity	Unit	%	Quantity	Unit
Outsole rubber V-10	538,50	g	100%		

2. Inventory – Wata and Esplar outsole

	UPSTREAM			CORE	
INPUT	Quantity	Unit	%	Quantity	Unit
Silica	71,674	g	22,5%	91,56	kgkm
FDL	58,471	g	18,3%	209,05	kgkm
Polybutadiene	56,585	g	17,7%	1,81	kgkm
Outsole excesses	47,154	g	14,8%	0,00	kgkm
Synthetic rubber	35,837	g	11,2%	41,77	kgkm
Product 1	20,371	g	6,4%	65,26	kgkm
Product 3	4,998	g	1,6%	0,27	kgkm
Product 4	4,715	g	1,5%	5,56	kgkm
Product 8	4,715	g	1,5%	5,49	kgkm
Product 7	1,886	g	0,6%	0,06	kgkm
Product 6	1,415	g	0,4%	0,08	kgkm
Product 10	3,395	g	1,1%	--	kgkm
Product 9	3,301	g	1,0%	--	kgkm
Product 13	1,698	g	0,5%	--	kgkm
Product 14	1,245	g	0,4%	--	kgkm
Product 15	0,754	g	0,2%	--	kgkm
Product 11	0,566	g	0,2%	--	kgkm
Product 12	0,377	g	0,1%	--	kgkm
Product 16	0,042	g	0,0%	--	kgkm
OUTPUT	Quantity	Unit	%		
Rubber Outsole V10	319,20	g	100%		

3. Inventory – V Detail in rubber used in all three models

	UPSTREAM			CORE	
INPUT	Quantity	Unit	%	Quantity	Unit
Synthetic rubber	6,818	g	38,4%	7,97	kgkm
Calcium carbonate	3,814	g	21,5%	5,93	kgkm
Silica	3,814	g	21,5%	4,89	kgkm
Product 8	1,192	g	6,7%	1,39	kgkm
Product 1	0,372	g	2,1%	1,20	kgkm
Product 7	0,358	g	2,0%	0,01	kgkm
Product 3	0,353	g	2,0%	0,02	kgkm
Product 4	0,296	g	1,7%	0,35	kgkm
Product 5	0,057	g	0,3%	0,07	kgkm
Product 13	0,171	g	1,0%	--	kgkm
Product 10	0,167	g	0,9%	--	kgkm
Product 11	0,157	g	0,9%	--	kgkm
Product 12	0,129	g	0,7%	--	kgkm
Product 7	0,031	g	0,2%	--	kgkm
Product 14	0,031	g	0,2%	--	kgkm
Product 8	0,001	g	0,0%	--	kgkm
Product 9	0,000	g	0,0%	--	kgkm
OUTPUT	**Quantity**	**Unit**	**%**		
V detail	17,76	g	100%		

4. Inventory – welt and toe welt used in the model Esplar

	UPSTREAM			CORE	
INPUT	Quantity	Unit	%	Quantity	Unit
Synthetic rubber	64,533	g	38,4%	75,46	kgkm
Calcium carbonate	36,103	g	21,5%	56,15	kgkm
Silica	36,103	g	21,5%	46,27	kgkm
Product 8	11,282	g	6,7%	13,18	kgkm
Product 1	3,520	g	2,1%	11,31	kgkm
Product 7	3,385	g	2,0%	0,11	kgkm
Product 3	3,339	g	2,0%	0,18	kgkm
Product 4	2,798	g	1,7%	3,31	kgkm
Product 5	0,542	g	0,3%	0,63	kgkm
Product 13	1,616	g	1,0%	--	kgkm
Product 10	1,579	g	0,9%	--	kgkm
Product 11	1,489	g	0,9%	--	kgkm
Product 12	1,218	g	0,7%	--	kgkm
Product 7	0,298	g	0,2%	--	kgkm
Product 14	0,293	g	0,2%	--	kgkm
Product 8	0,010	g	0,0%	--	kgkm
Product 9	0,002	g	0,0%	--	kgkm
OUTPUT	Quantity	Unit	%	Quantity	Unit
Welt and toe welt - Esplar	168,11	g	100%		

5. Inventory – welt, toe welt and rubber toe cover used in the model Wata

	UPSTREAM			CORE	
INPUT	Quantity	Unit	%	Quantity	Unit
Synthetic rubber	75,792	g	38,4%	88,62	kgkm
Calcium carbonate	42,401	g	21,5%	65,94	kgkm
Silica	42,401	g	21,5%	54,34	kgkm
Product 8	13,250	g	6,7%	15,48	kgkm
Product 1	4,134	g	2,1%	13,29	kgkm
Product 7	3,975	g	2,0%	0,13	kgkm
Product 3	3,922	g	2,0%	0,22	kgkm
Product 4	3,286	g	1,7%	3,89	kgkm
Product 5	0,636	g	0,3%	0,74	kgkm
Product 12	1,897	g	1,0%	--	kgkm
Product 9	1,855	g	0,9%	--	kgkm
Product 10	1,749	g	0,9%	--	kgkm
Product 15	1,431	g	0,7%	--	kgkm
Product 17	0,350	g	0,2%	--	kgkm
Product 18	0,345	g	0,2%	--	kgkm
Product 19	0,012	g	0,0%	--	kgkm
Product 20	0,003	g	0,0%	--	kgkm
OUTPUT	Quantity	Unit	%	Quantity	Unit
Welt, toe welt and rubber toe cover - Wata	197,44	g	100%		

APPENDIX E – Process materials inventory used for each component

Category	Component	Materials	SimaPro process
Upper	Various	Polyester	market for polyester resin, unsaturated GLO
	Various	Polyurethane	market for polyurethane, flexible foam GLO
	Threads and counter lining	Polyamide	market for nylon 6-6 GLO
	Quarter and vamp	Recycled PET	L. Shen et al., 2010 and specific data
	Various	Leather and Suede	Beef co-product, hides and skins, from beef cattle, at slaughterhouse; Kurian & Nithya, 2009
	Upper	Agro-ecological cotton canvas	Specific data
	Lining	Agro-ecological cotton twill	Specific data
	Assembly glue	Polychloroprene	market for butadiene GLO
	Washer	Aluminium	market for aluminium alloy, metal matrix composite GLO
	Eyelet	Brass	market for brass RoW
	Toe puff - Wata and Esplar	EVA	market for ethylene vinyl acetate copolymer GLO
		Polyester	market for polyester resin, unsaturated GLO
	Counter - Wata	Recycled rubber	Waste from rubber products
		Agro-ecological cotton twill	Specific data
	Counter - Esplar	Recycled rubber	Waste from rubber products
Sole	Outsole	Silica	market for activated silica GLO
		Polybutadiene	market for polybutadiene GLO
		FDL	Specific data
		Synthetic rubber	market for synthetic rubber GLO
		Outsole excesses	Waste from rubber products
	Welt, toe welt, rubber toe cap and V detail	Synthetic rubber	market for synthetic rubber GLO
		Calcium carbonate	market for calcium carbonate, precipitated GLO
		Silica	market for activated silica GLO
	Midsole V-10	EVA	market for ethylene vinyl acetate copolymer GLO
	Footbed	FDL	Specific data
		EVA	market for ethylene vinyl acetate copolymer GLO
		Agro-ecological cotton twill	Specific data
Others	Shoelace	Conventional cotton	market for textile, woven cotton GLO
	Packaging	Carboard box	market for folding boxboard/chipboard GLO
		Silica gel	market for activated silica GLO
		Kraft paper	market for kraft paper, unbleached GLO
		Tissue paper	market for paper, newsprint RoW
	Electricity		market for electricity, medium voltage BR
	Road Transport		market for transport, freight, lorry 16-32 metric ton, EURO3 GLO
	Transoceanic ship		market for transport, freight, sea, transoceanic ship GLO
	Heat, central or small-scale		heat production, mixed logs, at furnace 100kW RoW
	Incineration		Municipal solid waste (waste scenario) {FR}| treatment of municipal solid waste, incineration