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Environmental Impact of Textile Fibers

A case study of Nextiili-paja

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ABSTRACT

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These days cloth and clothing are not limited to the basic need of human rather use as a standard of living and lifestyle. As the demand for clothing and textile products are increasing continuously, the production of eco-friendly textile materials and textile products are getting popular around the world. The aim of this study was to investigate an environmental impact caused by most common textile fibers during its raw fiber production stage. Six most common textile fibers were selected based on an interview with personnel working at Nextiili-paja, Tampere based recycling center. Our main concern was on the fiber production level rather than the textile production level. The information and data were gathered from a literature review and an interview with the personnel working in the recycling facility. An impact caused by the cotton, wool, viscous, polyester, polyamide and acrylic fibers during raw fibers production was studied using ecological sustainability measure, carbon footprint, water footprint, energy footprint, and land footprint.

It was found that each textile fiber raw materials have an impact on the environment whether they are from natural or artificial fibers. However, the impacts levels vary with raw materials. Cotton and wool fiber production have the highest land and water footprint compared to other fibers. While artificial fibers have more energy, footprint compared to natural fibers. Thus, the author recommends maximizing the recycling and reusing of textile fibers to minimize the environmental impacts caused by textile raw fibers.

Keywords: textile, raw fiber, fiber production, cotton, wool, polyamide, polyester, viscous, acrylic

CONTENTS

1 INTRODUCTION

An immediate basic need of human being are food, shelter, and clothing without this, one cannot imagine about the survival of humanity. Other needs such as healthcare, education, sanitation, and entertainment come after these immediate needs. It is widely believed that food production and clothing production are two old business since the civilization of human being. In ancient time people used to cover their body with tree leaves and animal skins with no processing or minimum processing. However, the situation has changed dramatically now. Nowadays, cloth and clothing are not only limited to the basic need of human connected to fashion and apparel industries.

In developed countries, the fashion industry is one of the key players in the country economy as often the concern of government. While talking about fashion industries, textile raw material production, processing, textile designing, and manufacturing take part in it. Cloths are the final product of a lengthy process starting from the harvesting of raw material to the finalization in the manufacturing plant. The population relies on the earth for the food, shelter, clothing, and other needs. The production of food and textile are two major activities that have the second most impact on the environment after the industrialization and urbanization. Often, they are related to industrialization and urbanization.

The aim of this thesis project is to study the environmental impact caused by textile raw materials during the raw fiber extraction process. The environmental impacts such as carbon footprint, water footprint, land footprint and energy footprint caused by textile fiber extraction are studied based on article review and data studies. The primary intention is to investigate the different textile raw materials and examine various environmental impacts caused by these materials. Author interest for this thesis research is to figure out energy footprint, land footprint, carbon footprints and water footprints of these raw materials. The choice of raw materials is based upon the textile waste collected in Nextiili, from a private household in the Tampere region. This helps to get an insight into the type of textiles that are mostly produced in the textile industry and ended up in recycling facilities. Additionally, this will supply information about the textile materials that are disposed into the environment and ideas to mitigate those impacts. Most importantly, the research question is to figure out how the literature review of environmental impacts of textile fibers in fiber production stage information helps textile recycling facility, Nextiili to understand textile fibers impacts so that they put their focus on recycling and reusing such textile products more efficiently.

This thesis is based on author practical work done in Tampere based textile recycling facility “Nextiili- paja”. The research approach is to investigate recent articles, research papers, and publications. The data collection is based on this article reviews and publications. An environmental impact assessment is performed based on the collected data and visualizes the findings. Secondarily, onsite visit to the local textile collection and recycle facility is done to study the status of textile recycling in general. In addition to that, a face-to-face interview with the personnel working on textile recycling center is done in order to get the board understanding of current situations and the problems.

The whole part of this thesis paper is structured as follows. In the second chapter, the background of these studies is presented in detail. Textile business in general, in the context of Finland and the textile recycling facility, Nextiili in Finland are presented there. Third chapter deals with the textile, textile raw fibers, classification of fibers based on source and origin are presented in detail. Answers to questions of what textile is raw fiber, what are the common textile fibers are addressed there.

The fourth chapter contains the research work methodology applied for the data collection and literature review. In the fifth chapter of this thesis, the results from the theoretical findings are given. The findings from data collection are compared and analysed there. The summary of theoretical findings, limitation of this research work together with the possible ideas for the improvement of the textile recycling process and future work are described in the concluding chapter.

2 BACKGROUND

In this chapter, the textile business, in general, is described in brief. In addition to that, a brief history of Finnish textile industries and current scenarios are discussed here. Textile waste and recycling practice in general for the textile are discussed. Textile recycling and reuse practice applied on Tampere based recycling facility 'Nextiili' is presented in a later part.

2.1 Textile Business

The textile industry refers to the places where the textile products are made starting from the raw material to the end products. In other word, textile industries produce the cloth and clothing product from raw materials to fibers, fibers into fabrics and other consumable product. Textile production is one of the oldest business that started with human civilization. However, the industrialization of textile production was done in the industrial revolution era in the 1700s. Before industrialization people used to produce the cotton, wools in their home and farm, sell it to the local community in an exchange of other goods. The production of cloth and clothing was based on handcraft machine or small machinery hence it was slow and unable to fulfill the demand of a growing population. (Textile manufacturing in the industrial revolution n.d)

Today, textile industries together with apparels (clothing) industries are one of the top contributors in the world economy. About 60 to 75 million people are employed by global textile and garment industries (Global Garment and Textile Industries 2015). According to the world trade organization (WTO) statistical review 2018, the market value of textile is 296.1 billion dollars and clothing is 454.5 billion dollars in 2017. The value and volume of the total business in textile industries and clothing is growing linearly. The economy powerhouse countries are both involved in textile importing and exporting. China, EU countries, India followed by the USA and Turkey are the top textile importers in the world. In the other hand, EU countries, USA, China followed by Vietnam and Bangladesh are top importers of textiles products. (World Trade Statistical Review 2018)

2.1.1 Textile Business in Finland

The textile industry has a long history in Finland, the knitting machine was already invented in the 16th century. In 1740, Finland first tricot factories were established in Tampere and started making coats and socks. At that time the demand for those clothes was very few as people were using self-made clothes. By the end of the 19th century, there were various specialty machines developed to process and made the textile product that helped to increase clothing factories in Finland. The golden time of Finnish textile industry was at the beginning of 1980 when the export of textile clothes was on the highest level and nearly 50,000 people were employed in that sector (Jukarainen 2018). (Clothing and textile sector in Finland 2017)

There were more than 500 clothing and textile companies in Finland including large, medium and small industries. During the 1980s, many textile companies from Sweden were transferred in Finland for the sake of a cheaper workforce compared to Sweden. At that time Finland exported textiles and clothing products with the Soviet Union in exchange of oil to Finland. The fall in Finnish textile industries began immediately after the Soviet Union dissolution in 1991. The increased cost of workforce reduced the profitability of the industry while in the other hand the trade with eastern Europe collapsed, many industries went bankrupt, many relocated their industry to the cheaper workforce countries including middle east countries. (Eynde & Wiinamäki 2012)

Finnish textile industry mostly consists of small and medium-sized companies and most of their workforce from the locality. In recent years, the Finnish textile industries focus mainly on high-quality product development and designing. There are approximately 700 companies and 5,000 workforces working in manufacturing of textile and clothing in Finland. The number of Finnish textile industries and workforce involving is decreased numerously compared over the last few decades. The implementation of automation technology and production plant relocation are two major factors for this declination. Finnish industries produce both clothes and footwear and home textiles. Finnish fashion and textile industry are subcategories by functions such as manufacturing and production of clothing and textiles (manufacturing), wholesale of textiles and fashions, retails of textile and fashion, and maintenance of clothing and textiles. Nowadays, most of the textile workforce is working in wholesale and retails than in manufacturing and production compared to the 20th century. (Clothing and textile sector in Finland 2017)

2.2 Textile Waste and Recycling

Textile recycling is the process of using textile wastes to reuse or recover materials to make other products. Based on the source, textile wastes are classified into two major category post-consumer and pre-consumer textile waste. Pre- consumer textile waste is the by-products or left-over from the textile production process as well as post-industrial scrap from industries. Post-consumer waste is the waste from the products that have been gone through consumer use. This category includes used clothes, garments, household items and other textile products that were used by the primary consumer. (Sandin & Peters 2018)
The demand for textile recycling is increasing high as textile industries are growing and the environmental impacts from these industries are increasingly high. Nowadays, the need for efficient recycling technique is the height in order to use produced textile materials to its full extent before it is sent to incineration rather than producing new. Depending on the materials involved in textile, textile recycling can be classified as mechanical and chemical recycling. In mechanical recycling, textile materials are mechanically transformed into new textile products. In chemical recycling, materials are gone through the chemical process to produce new raw materials such as yarns and fabrics. (Textile Recycling n.d)

2.2.1 Nextiili

Nextiili, officially named as “Nextiili-paja” is a textile recycling facility established and maintained by Pirkanmaa´s Recycling and Work Association (Pirkanmaan Kierrätys ja työtoiminta ry). It is a non-profitable organization established in October 2015 in Vihiojantie 30, Tampere, Finland. It differs from other similar recycling facilities in terms of social services, professional guidance, public awareness and sharing domain knowledge in the field of textile recycling and reuse. It was started as a pilot project to fill the gap between industrial recycling and textile waste going to either incineration or landfill. Nextiili mostly receives funds from its employment projects and some percentage from its own sales. In general, Nextiili collects textile waste from its customers, reuse and recycle them. About 80 percentages of textile waste come from private household and rest comes from small enterprises. The textile waste consists of clothing, home textiles, shoes, fabric, handicrafts, and other reusable waste. (Käppi 2019)

The first stage in the recycling process in Nextilli involves sorting of the collected textile materials. Textile products are sorted based on their quality, usability, and material used. Textiles that are in good shape and has no stains go to their own shop for sales, meaning that they are going to sell those items to customers from their second-hand shop. The clothes that are wearable but are not in the best shapes are sent to the partnering companies or charity. Soft textiles such as wool are sent to Dafecor, a company that recycles recycled soft textiles, mechanically and produce environmentally friendly products such as oil stop fabrics. Handicraft and hand knitted item is gathered in the vintage department of their shop for sales. Nextiili plays an important part in the social aspect of the community by donating clothes to some Baltic region. For instance, it has been collecting apparel textiles for children and women in Latvia and net fabrics and shorts for men and children in the Gambia. In this thesis, the environmental impacts of different raw material will be discussed based upon the textile raw materials mostly used these days. The prior information to get the ideas of common textile materials and selecting that raw material is based upon the textiles received in Nextiili. As textiles in Nextiili comes from a wide range of population, it gives an idea about the textile fibers that are mostly consumed by people in everyday life. (Käppi 2019)

3 TEXTILE

This chapter explains the details about the raw materials of textile fibers. The theoretical aspect of textile fibers, classification of fibers based on their source are described in detail. The terminologies involved in sustainable environmental measures such as carbon footprint, water footprint, land footprint, and energy footprint are presented in this chapter.

3.1 Textile Fibers

Textile fiber is the primary materials require to produce the textile product. Fibers are a small and threadlike structure that can be obtained directly from nature or through technology. However, all fibers cannot be categorized as textile fiber due to lack of essential qualities such as strength, flexibility, usability, and length. (Collier, Bide, Tortora 2009)

Textile fiber is identified as long, thin, flexible and strong raw material build up by twisting together which are submitted to production processes that can be converted into thread or yarn used in textiles or industrial products. Based on nature and origin textile fiber are classified into two major categories natural and artificial fiber. These two can be further divided into subcategories as shown in Figure 1. The source of fibers is not limited to these lists rather board. The aim is to focus mainly on common and widely used textile fibers. (Lord 2003)

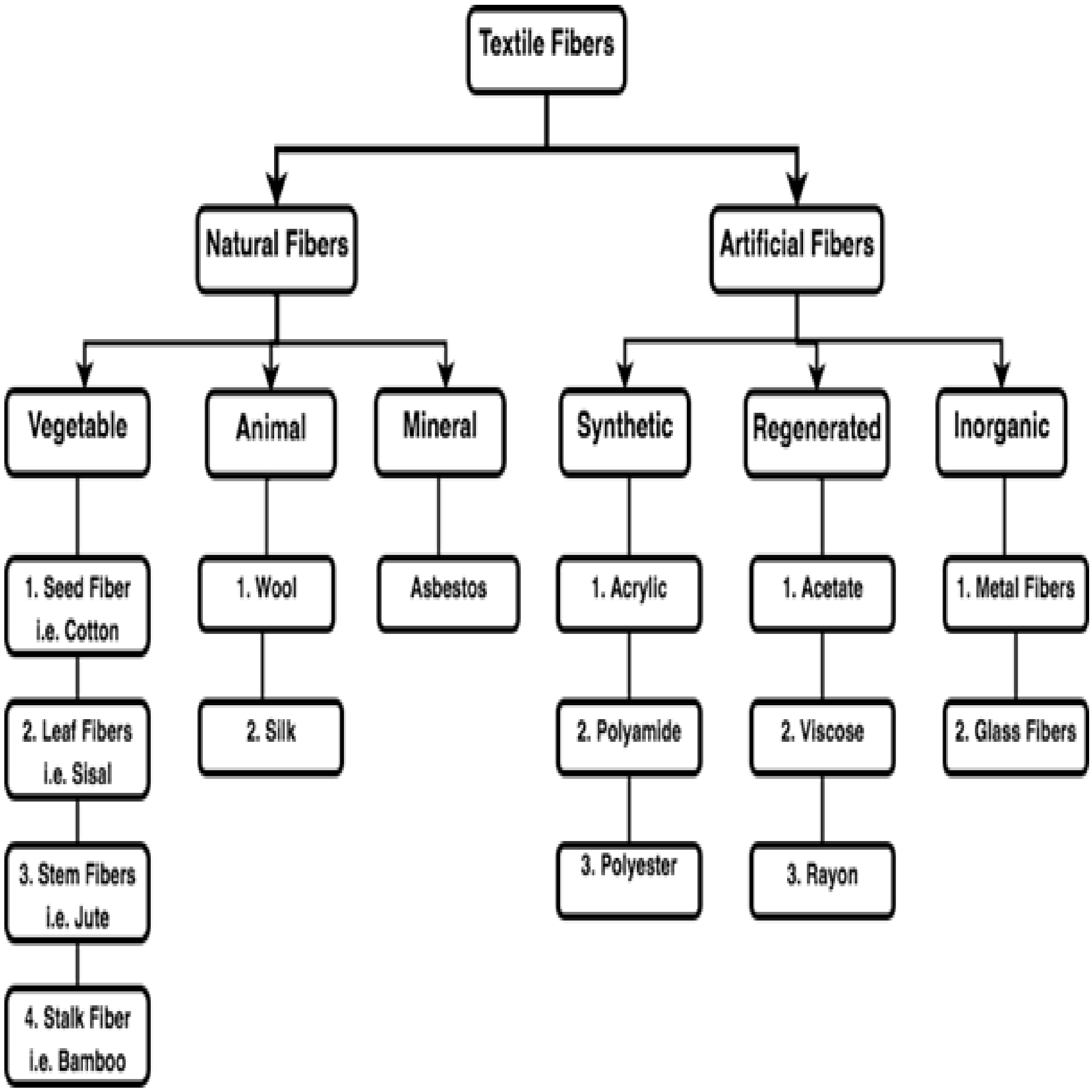

Fig. 1 Classification of textile fibers. (Lord 2003, Cook 2004 modified)

3.1.1 Natural Fibers

Fibers that are naturally available in our environment are known as natural fibers. They are non-synthetic hair-like materials of continuous filament that comes from natural growing sources. These fibers are further sub-categories based on their source of origin i.e. vegetable, animal and geological. Natural fibers are biodegradable over time. (Lord 2003)

3.1.1.1 Vegetable Fibers

Fibers achieved from plants and vegetables are known as vegetable fibers. They are cell walls that occur in the stem, wood and leaf parts of plants. These fibers are based on cellulose, hemicellulose, and lignin. Cotton, jute, flax, ramie are some common fibers from plants. (Cook 2004)

Cotton

Cotton is known to be one of the oldest textiles fiber in the world recorded and traced back to 3000 BC (Cook 2004, 35-38). Throughout the industrial revolution, Cotton holds remarkable durability and significant economic importance as a fiber in the Textile Industry. Cotton is a natural fiber categorized under vegetable fiber which is grown in the seed within the seed pod. It is a member of the mallow family. Among the various species of cotton, selection of cotton fibers for textile production is strictly based on the strength and durability of fiber (Lord 2003). Cotton is grown in warm and dry climate zone. For the optimal growth, the plant needs enough moisture and plenty of water throughout the growing season. It takes about 130 to 190 days before the cotton fiber is ready to be harvested. The process of harvesting of cotton fiber influence an essential role in the quality of fiber. Advanced technology made the harvesting process easier in the USA. However, most other cotton producers still use the traditional way to plant, cultivate and harvest the cotton fiber. Around 25 million tonnes of cotton are produced every year among which 45-50% accounts for clothing, household goods, and other commercial products. (Cleaner, Greener Cotton: Impacts and Better Management Practices 2013)

A major issue in cultivating cotton is the susceptibility of the plant to insect pest such as the boll weevil. To maximize the production, strong pesticides are used to get rid of pests, causing environmental impacts as reduced soil fertility, loss of biodiversity and other toxicity problem (Fletcher 2008). Another environmental concern is the need and use of land for cotton cultivation which may lead to soil erosion, and groundwater contamination from pesticides (Collier et al. 2009, 61-64). According to World Wildlife Fund (WWF) cleaner, greener cotton report, cotton cultivation takes up about 2,5% of global fertile land and consume around 8-10% of the world´s pesticide, 50 % accounted to be used in developing countries.

To produce one kilogram of cotton lint, about 8,506 liters of water is needed including irrigation and rainfall with a range of 4,710 liters per kg in China to 20,217 liters per kg in India. However, the amount of water needed for cultivation strongly depends upon the cultivation practices and local conditions. Due to traditional harvesting practice, poor infrastructure a huge amount of water is lost before it reaches the field causing waste of water (Fletcher 2008). (Cleaner, Greener Cotton: Impacts and Better Management Practices 2013)

3.1.1.2 Animal Fibers

Fibers achieved from the animal by-product or part of bodies are known as animal fibers. These fibers are based on the specific protein. Wool, silk, hair are some common fibers from the animal. Sheep, rabbit, fox, and beaver are commonly known as a good source of animal fibers. Often these animals are cultivated as fiber source as well as a source of leather and meat. (Cook 2004)

Wool

Wool is formed of a protein substance called keratin which is composed of eighteen different amino acid connected by a peptide bond. According to U.S wool production labelling Act of 1939, wool is termed as “the fiber from the fleece of the sheep or lamb or hair of the angora or cashmere goat (and may include so-called specialty fibers from the hair of camel, alpaca, llama, and vicuna)” (Federal Trade Commission 1986). However, the most common and widely used and produced wool fiber comes from the fleece of sheep. More than 1.163 billion of sheep (2015) produce around 1.160 million kg (2015) of clean raw wool. The production number changes slightly every year depending upon the number and breeds of sheep’s and other variables that determine the quantity, quality, and specifications of wool. (Wool Production 2019)

The wool comes with excellent insulating quality due to which it is widely used for cold weather clothing. Apparels such as winter coats, woolen socks, hosiery, warm sweaters are some commonly made of wool fabrics. Wool is also used for home textiles such as carpets, blankets, draperies and upholstery fabrics. Depending upon its quality, wool gives an advantage of durability and flame resistance. However, it comes with a disadvantage of shrinking at high temperature

and susceptibility to moth damage. Extensive care is needed during the handling and use of woolen fabric to minimize the problem. (Collier et al. 2009, 90-101)
Wool, being a natural protein fiber contain elements such as carbon, nitrogen, hydrogen, and oxygen as every other protein fiber. However, it also contains sulfur as well. The amount of pure carbon present in wool makes up to 50% of its total weight. This carbon comes from the plant wool sheep consume. The plants and herbs consumed by the sheep undergo photosynthesis meaning that the plants convert carbon from the atmosphere into organic compounds which helps the sheep to grow wool. Therefore, wool is a natural and renewable fiber. Wool fiber is the most recycled biodegradable fiber with a long lifespan. It claims 5% of market share within the recycled fibers market that holds a share of 1.3% of all other textile fibers, making wool a suitable recycling fiber. (Green Wool Facts: The Wool Industry & The Environment 2014)
Wool production is based on the cultivation of the animals that are a good source of wool such as sheep and rabbit. Wool is the secondary product from these animals after meat and followed by other products from there their body parts such as leather and bone. It is difficult to point out the exact environmental impact caused for wool production rather we generalize these figures. Land, water, energy, and chemicals as supplements are needed to cultivate these animals and shearing the wool from their body. Mostly the impacts of animal cultivation are on land, water as well as air in farm and surroundings. However, their food and supplements in other had had carbon emission together with the impacts on land and water ecosystem. (Barber & Pellow 2006) (Beverley 2012)

3.1.1.3 Mineral Fibers

Mineral fibers are another form of natural fibers produces from the naturally occurring minerals. Minerals fibers are of limited importance in the textile production. Asbestos is the naturally occurring mineral fiber used in textiles to made special fireproof and industrial fabrics. (Cook 2004)
Asbestos occurs in fibrous crystalline form which is resistant to different chemicals and heating. It does not degrade in normal usage and is not attackable by organisms. Due to this complex quality, asbestos fibers were used in fireproof clothing, conveyor belts, industrial packaging, and soundproofing materials. How-

ever, inhaled asbestos fibers showed some serious health hazards like lung cancer, fatal malignant tumor, and other fatal health conditions. The toxic behaviors asbestos ultimately led to the banning of its usages from the textile market. It is known as health hazardous fibers and the use is highly regulated by United State Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA) (Asbestos n.d). (Textile School 2019)

3.1.2 Artificial Fibers

Man-made fibers also are known as artificial fibers or synthetic fibers produced by reacting compounds and chemicals. These fibers are often non-biodegradable and are further subclassified based on the source of fiber-forming substance from which they are made i.e., Regenerated fibers, Synthetic fibers, and Inorganic fibers. (Cook 2004)

3.1.2.1 Regenerated Fibers

Regenerated fiber is produced mainly from natural cellulose getting dissolved into the chemical. Basically, the cellulosic area of natural fiber is made in contact with some chemicals to regenerate new fiber. (Cook 2004)

Viscose

Viscose is a regenerated or semi-synthetic fiber made from the cellulose of wood pulp, cotton lint or bamboo, obtained by the viscose process. The pulp used as raw material to manufacture viscous fiber contains more than 90% cellulose and are suitable for fiber manufacture. Viscous, also termed as Rayon or Rayon Viscose in some parts of the world, was the first man-made fiber known. In order to manufacture viscous, water is needed in huge amount along with different chemicals. To produce 1 kg of viscous fiber nearly more than 1600 kg of water, 2 kg of sulphuric acid, 1 and a half kg of caustic soda, 1 kg of wood pulp or cotton lint, 4 kg of carbon disulfide and a smaller amount of other chemicals are needed. (Cook 2005, 9-11)

The basic manufacturing process of Viscose involves 6 major steps; steeping or slurring, aging, xanthation, dissolving and ripening, filtration, and extrusion. However, the possibility of modification in different steps of process changes the quality of basic viscous fiber to other types of rayon fibers made from viscose so, it is difficult to generalize all rayon fibers. Viscose counts as the third largest share of the total fiber market after polyester and cotton. Global viscous production capacity grew at an average of 7.7% annual rate during the first decade of the 21st century. China has become the largest country in producing viscose by 2013. About 85% of total viscose fiber production is produced as staple fibers and about 15% as filaments (Freitas & Mathews 2017). Viscose is used in fashionable wearing apparel ranging from suits, dresses, lingerie, and sportswear and is also, suitable for home textiles such as curtains, chair coverings, table cloths and so on (Collier et.al 2009, 127-133).

The viscous extraction process uses a substance such as sodium hydroxide, carbon disulfide, sulphuric acid and sodium sulfate that are extremely toxic to both environment and human health. In the case of viscous fiber, the major environmental impacts happen during the extraction of viscous from source plant rather than growing source plants. The extraction process of viscous fiber has significant impacts on water, air, and land due to the use of a huge amount of water and mentioned chemicals. Cleaner alternative for the viscous is lyocell, which is obtained from the renewable natural sources and is biodegradable fiber. (Fletcher 2008)

3.1.2.2 Inorganic Fibers

Inorganic fibers are a fiber that is produced from inorganic compounds. These fibers can be further classified into mineral fibers, metallic fibers and carbon fibers based on the composition compounds. (Cook 2005)

3.1.2.3 Synthetic Fibers

Synthetic fibers are categorized under synthetic fibers that are based on chemical synthesis. They are generated by extruding fiber-forming materials through spinnerets into air and waters to form thread. (Cook 2005)

Polyester

Polyester is one of the most widely used and produced synthetic fiber. It is a polymer made by a condensation reaction between a small molecule in which the linkage of molecules occurs through the formation of ester groups. Polyester is commonly made by reacting dicarboxylic acid with a di-hydric acid (Cook 2005, 328-329). Market share of around 49% of global fiber production, polyester is one of the widely used synthetic fiber in textile industries. Around 63,000 million tonnes of polyester fiber is produced annually and the number is linearly increased as the demand for polyester made products is increasing. Demand for polyester has been increasing over the years overtaking cotton as the single most popular textile (Fletcher 2008). (Preferred Fiber and Materials Market Report 2018)

Certain physical and chemical properties of polyester fiber had made polyester irreplaceable in the market. However, extraction of this synthetic fiber from petrochemicals involves significant quantities of chemicals such as terephthalic acid (TA), and ethylene glycol. The by-products of the extraction process are toxic and can pollute water, land, and air causing serious health issues. A large amount of energy consumption and toxic emission from the extraction process are major environmental impacts of polyester. (Fletcher 2008)

Polyamide

Polyamide is artificial fiber made from caprolactam. It is marketed as Nylon which was developed to substitute the demand of silk fiber. Among different variants, polyamide 6 known as Nylon 6 is the most commonly used textile fiber. Nylon, a trading name of polyamides is a synthetic fiber made of polymers that contain carbon, oxygen, nitrogen, and hydrogen. The solid form of a compound called nylon salt which is formed from acid and amine undergoes polymerization in the air-free atmosphere. After the process, it depends on the manufacturer to adjust the basic manufacturing process of polyamide to produce different quality polyamide fibers. Globally, polyamide production has increased from 3.74 million tonnes in 1990 to 5.73 million tonnes until 2017 while the global consumption of polyamide fiber was about 5 % in 2015 (Preferred Fiber and Materials Market Report 2018). The possibility and availability of a wide variety of polyamide fibers have resulted in polyamide being used in a large range of products for the apparel, home, and industry. Due to its resilient, abrasion resistance, wrinkle resistance, high melting point, and other such properties, it has replaced polyester for high-quality products. (Collier et.al 2009, 147-153)

The process of polyamide formation from petrochemicals is energy intensive, about 150 MJ energy is required to produce 1 kg of polyamide fiber. Polyamide formation process produces emission of nitrous oxides a potent greenhouse gas. The by-products of these processors have a serious impact on the air, water, and land ecosystem if it is discharged to the environment without treatment. (Fletcher 2008)

Acrylic

Acrylic fibers are another popular synthetic fibers after polyester and polyamide. It is described as "a manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85% by weight of acrylonitrile units". The raw materials of acrylic are made from mineral oil or other hydrocarbons. The manufacturing process involves a lot of hazardous chemicals such as dimethyl-formamide, ammonium persulfate, styrene, iron, and vinyl acetate. (Collier et.al 2009)

Acrylic fibers possess an aesthetic appeal, are lightweight, elasticity, resilient, have excellent resistance to Ultraviolet (UV) degradation, weak alkalis, laundry bleach, and microbiological attack. It also characterized in warmness and softness like wool. The largest producer of acrylic in today date is China and about 60% of global production capacity is concentrated in Asia. Consumption of acrylic fiber was at a height of 2.8 million tons in the year 2004. However, the competition with polyester resulted in the reduction of acrylic fiber consumption reaching around 1.9 million tons. Acrylic fiber production is high energy and water intensive compared to polyester fiber. The by-products of the acrylic manufactured process such as acrylonitrile create environmental effects if exposed to environmental without treatment (Fletcher 2008). (Acrylic and Modacrylic Fibers 2016)

3.2 Environmental Aspects

In this chapter, the environmental aspects of textile raw materials production are discussed. Ecological footprints are a commonly used method to measure ecological sustainability. Impact based on the ecological footprints including carbon footprint, water footprints, land footprint and energy footprints for raw material production is a major concern in textile production. In simple words, the family of footprints indicators are used to measure the impacts on nature and natural resources by various standard methods including usages, pollution, and other effects. Footprints are becoming the standard common benchmark for impacts assessments. Cotton, wool, viscous, polyester, nylon and acrylic are selected for these studies. (Global Footprint Network n.d)

3.2.1 Carbon Footprint

Carbon footprint is a measure of the total amount of emission of carbon dioxide (CO2) caused by an individual, event, action, or production. Carbon footprint measure is a globally accepted method to calculate the amount of carbon dioxide emission over time. Due to global warming and climate changes, the carbon footprint is on the top priority of environmental impact assessment. It is impossible to calculate the exact amount of carbon produced in some activity because of inadequate information about complex interaction and chemical process including natural processes that store or release CO2. Carbon footprint is commonly known as greenhouse emission. (Dev 2009)
In 2011, Wright, Kemp, and Williams have suggested the following definition for carbon footprint:

> “A measure of the total amount of carbon dioxide (CO) and methane (CH4) emissions of a defined population, system or activity, considering all relevant sources, sinks, and storage within the spatial and temporal boundary of the population, system or activity of interest. Calculated as carbon dioxide equivalent (CO2e) using the relevant 100-year global warming potential (GWP100)”. (Wright, Kemp & Williams 2011)

3.2.2 Energy Footprint

There is a need for a certain form of energy to produce some material from another material. Energy footprint focuses on the issue of the environmental issue of the energy consumption and energy required in each stage of product production. Energy footprint is the number of energy requirements in order to produce product, service or business. The assessment of energy consumption by energy footprint can consider renewable energy source (electricity, solar, wind) and non-renewable energy (fossil fuel, nuclear energy) source. (Srinivas n.d)

3.2.3 Land Footprint

The land footprint is another member in the family of ecological footprint indicators that deal with the amount of land consumed for particular action or event including its consequences. This is a production-based indicator that deals with the resources used within a region. As we are considering raw material production, our goal is to measure the amount of land needed to produce a fixed amount of natural and artificial fibers. The land footprints are not limited to the land used to grow the products but also include other land used in association with this product such as irrigation, transportation and storing. (Giljum, Lutter, Bruckner & Aparcana 2013)

3.2.4 Water Footprint

The water footprint is another member of the ecological footprint family assessment (Giljum et al. 2013). The water footprint is the total volume of freshwater used directly or indirectly to produce goods and services consumed by the individual or community and water pollution done during these stages. Inside water footprint measure, there are multiple ways to measure the use of direct and indirect use of water for some action or production process named green water footprint, blue water footprint, and grey water footprint. Some measures are right for some purpose while inappropriate for others. Water footprint became a popular measure of water usage and sustainability measurement in recent years. The water footprint is commonly used to refer the water consumption by individual, community, business, state or nation together with the pollution caused by water resources by them. Our focus is to find the water footprint used to produce natural and artificial textile raw materials together with the amount needed to concentrate the toxic chemicals to a safe level. (What is a water footprint? n.d)

4 METHODS

In this chapter, methods used to conduct this research work are described. The methodology to conduct the literature review and source of materials are presented here. The data collected from books, articles, scientific papers and other sources are discussed here.

4.1 Methodology

The method used to conduct this research is a literature review and interview with the personnel working at Nextiili. TAMK library system and services were extensively used to collect the thesis manual, research guidelines, and materials. An interview was conducted with Helena Käppi, supervisor of raw sorting team in Nextiili to know the major textile waste products they are dealing in day to day operation at Nextiili. The ideas were to sort and identify the most common textile fibers found in textile waste that comes to Nextiili and do extensive research on environmental impact caused to cultivate or produce them.

4.2 Data Collection

Data collection and analysis is the core way of any research and study to figure out the pros and cons of some action. The data collection was done by reviewing field specific recent news, articles, research papers, recently published books and other materials found on the internet. The gathered information consists of ranges from the theory of textiles, a textile business, textile recycling, and different textile raw fibers. The environmental impact measure data is of the numerical type representing a measurement of specific impact assessment parameters.
The primary source of the data is recent scientific papers in the textile field especially focused on the environmental aspects of textile raw materials. As scientific papers are more academic and updated in a timely manner, it is more likely to get recent results from these. The knowledge gained from TAMK information

searching workshop were extensively used to collect related books, journals, scientific papers, and news. Hard copies of books were collected from Tuni library. E-books, journals and scientific papers were gathered from Knovel (online library), google books, google scholar, and Springer. In addition to abovementioned sources, some of the popular articles and trusted web pages are used as a reference for gathering the required information. Related information from GDRC, IWTO, OSHA, and WTO websites were collected.

The secondary source of data is the interview with the Supervisor of raw sorting team in Nextiili, Helena Käppi. She is also known as the Mother of Nextiili- Paja and similar facilitates in Forssa and Loimaa (Turku). She is the best person to interview with and get an expert view about the recycling process in Nextiili and identifying textile fibers. Based on the interview with her and author practical involvement in the sorting process, popular top six textile fibers were selected for the study of their environmental impacts.

Textile lifecycle assessments topic has been widely discussed in recent years. There are many pieces of research by Laursen, Hansen, Bagh, Jensen & Werther 1997, Barber & Pellow 2006, Sustainable Agriculture and books are written such as “Assessing the Environmental Impact of Textiles and the Clothing Supply Chain” by Muthu and “Sustainable Fashion and Textiles Design Journeys” by Fletcher discuss the textile lifecycle assessment in brief and footprints of raw fibers. However, it is quite arduous to find out the information about how they measure and got those data. Here author aim is to compare the theoretical findings rather than explaining all the small details behind the results.

5 RESULTS

The analytical results based on the data collected from recent books and articles are described in this chapter. Environmental impacts of six fibers mentioned in chapter three are compared and discussed briefly.

5.1 Impact Assessments

An environmental impact assessment of most common textile raw fibers during fiber production stage are compared here. Table 1 shows the number of different resources needed to produce 1 kilogram of each textile raw fiber from zero stage to the raw fiber i.e. all stages including cultivation/harvesting, raw material extraction, and processing. Data are presented as gathered from resources hence have inconsistency in amount and units. For the sake of simplicity, they are shown in a single table even in cases where some requirement is not valid for some fiber type.

Table 1. Environmental impacts of raw fibers during production

Raw Fibers	**Carbon Footprint (CO2-eq/Kg)**	**Water Footprint (litre/kg)**	**Land Footprint (kg/hectare)**	**Energy Footprint (MJ/Kg)**
Cotton	2.6	20,000	600	55-60
Wool	1.8	125	15	63
Viscous	3.43	640	-	100
Polyester	2.31	n/a	-	104-125
Polyamide (6)	5.5	185	-	250
Acrylic	5	210	-	175

Source: (Laursen, Hansen, Bagh, Jensen & Werther 1997), (Barber & Pellow 2006), (Fletcher 2008), (Muthu 2014), (Sustainable Agriculture n.d)

5.1.1 Cotton

Cotton fiber production consists of sowing cotton seeds, growing plant, harvesting, ginning, and bailing process. All these processes are considered on the raw fiber production impact assessment. The production of cotton needs a massive amount of water, land, energies from renewable and non-renewable sources followed by chemicals like fertilizers and pesticides. According to Laursen et.al 1997, 600 kg of cotton is produced in 1 hectare of land. The water footprint of cotton is the second highest among the selected fibers. The amount of water required for the irrigation and pollution caused to water resources are considered as water footprint. Water footprint to produce 1 kg of cotton is about 20,000 liters (Sustainable Agriculture). This is commonly considered the amount of water required for irrigation, and pollution on land water. Often rainfall is taken part as water requirement for cotton plant harvesting. Plants are using natural sunlight to grow and harvest, the energy footprint of 1kg of cotton fiber is 55-60 MJ (Laursen et.al 1997), (Barber & Pellow 2006), (Fletcher 2008), (Muthu 2014). The amount of energy requires varies based on the harvesting location and climate. The CO_2 emission also varies depending on the location. For example, US organic cotton has 2.35 kg CO_2 emission per ton while Indian organic cotton has 3.75 kg CO_2 emission per ton for cotton fiber. The case for conventional cotton is much worse compared to organic cotton, i.e. US conventional cotton has 5.89 kg CO_2 emission for the same amount of raw fiber production (Muthu 2014).

5.1.2 Wool

In most of the wool-producing country from sheep, wool is the secondary product after meat production (Laursen et.al 1997). It is hard to measure the exact amount of resources such as land and water used to produce a certain amount of wool separately rather it is considered together with the meat production of wool producing animals. This applies to the carbon footprint measure as well; it is considered that 1 kg wool production from sheep produces emission of 1.8 kg CO_2 (Muthu 2014). A large amount of land and water is used in animal cultivation, wool shearing, and cleaning. It has been estimated that 125 liters of water are used to produced 1 kg of wool considering 4.5 litres of water is needed for a sheep for a day. In addition to this, the scouring process needs more water. Raw wool scouring needs about 10-15 litres of water for a kg of raw wool (Laursen et.al 1997). According to the Laursen at.al 1997, 15 kg of wool is produced in a hectare land. Vitamins, minerals including other supplements contain different amount of chemical used for these animals that are considered as chemical footprints for wool production. Shearing and cleaning the wool might leave some chemical footprint to the environment together with the water and land pollution. The energy footprint of wool is at the same level of cotton, 63 MJ/Kg (Barber & Pellow 2006) (Muthu 2014).

5.1.3 Viscose

The viscous extraction process uses a substance like carbon disulfide that is extremely toxic to both the environment and human health. The carbon footprint of viscous fiber extraction is approximated as 3.43 CO_2 equivalent per kg (Muthu 2014). Viscous fibers are often considered as carbon neutral as their source plants absorb almost the same amount of carbon during their harvesting as it produces during the harvesting process (Fletcher 2008). To manufacture 1 kg of viscous fiber, 640 litres of water is needed together with various chemicals such as sodium hydroxide and carbon disulfide (Laursen et.al 1997) (Muthu 2014). Production of viscous fiber undergoes various steps and uses an intensive amount of energy, about 100 MJ/kg is required depending upon the process used and resource type (Barber and Pellow 2006) (Muthu 2014). The land usage to harvest the resource for viscous is negligible and not discussed in the research.

5.1.4 Polyester

As polyester fiber is extracted from the by-product of petroleum products, the direct land and water footprints are much less compared to other natural fibers and often not calculated separately rather discussed with other stages of textile manufacturing from polyester fiber. The amount of energy requirement and carbon emission is lower compared to other synthetic fibers. The carbon footprint of polyester fiber production is 2.31 kg CO_2 emission equivalent to per kilogram fiber (Muthu 2014). However, the carbon footprint during the yarn and fabric production phase is much more compared to the fiber production phase. The amount of direct water used in the process of producing a kilogram of polyester fiber is negligible, strictly depends on the manufacturer (Laursen et.al 1997) (Muthu 2014) (Fletcher 2008). However, the environmental impact on land and water caused during other process associated to produce this fiber are rather big. The energy requirement is in the range of 104-125 MJ/Kg to extract polyester fiber from petrochemical products (Laursen et.al 1997) (Barber and Pellow 2006) (Fletcher 2008) (Muthu 2014).

5.1.5 Polyamide

The carbon footprint of 1 kg polyamide fiber during its formation phase is equivalent to 5.5 kg of carbon emission (Muthu 2014). Land footprints only for the fiber production stage is negligible in the case of artificial fibers. Water requirement for one-kilogram polyamide 6 fiber extraction phase is about 185 liters together with some amount of chemicals (Fletcher 2008). The energy requirement for the 1 kg polyamide 6 is the highest among the compared fiber, 250 MJ/Kg which is used in different stages of fiber production from the petrochemicals (Barber and Pellow 2006) (Muthu 2014).

5.1.6 Acrylic

As acrylic is an artificial fiber that is produced from polyacrylonitrile (PAN), again the land footprint is not measured separately for the fiber productions stage. The process involved in producing a kg of acrylic fiber produced carbon footprint equivalent to the emission of 5 kg of CO2 emission (Muthu 2014). Acrylic is considered as the most water-intensive artificial fibers, it is also required more energy compared to polyester fiber. The water footprint of acrylic fiber is 210 liter per kg (Laursen et.al 1997). The amount of energy to produce a kilogram of acrylic is 175 MJ which is in between the range of polyester and polyamide (Barber and Pellow 2006) (Muthu 2014).

5.2 Comparison

The comparison based on high and low impacts caused during the production of these six raw fibers is shown in Table 2. This comparison is based on the collected data from resources and measures from above Table 1 and (Niinimäki n.d) online lecture materials. It is difficult to calculate the exact amount of carbon emission, land, water, and energy footprint. The goal is to generalize the amount in the best possible way. The impacts are placed in decreasing order, means that one appears in front is the higher than the next one. As the process of producing different raw fibers are unrelated the comparison between these fiber production stages does not make sense. Hence, the impact of individual fiber production on various aspects are compared here.

Table 2. Comparison of impact assessment of raw fibers production based on high and low environmental impacts

Fiber	**Big Impact**	**Low Impact**
Cotton	Water, Land, Energy	Carbon
Wool	Water, Land, Energy	Carbon
Viscous	Water, Carbon, Energy	Land
Polyester	Carbon, Energy	Water, Land
Polyamide	Energy, Carbon	Water, Land
Acrylic	Water, Carbon, Energy	Land

Source: (Niinimäki n.d, modified)

As shown in tables, cotton production has big environmental impacts on water, land as well as required more energy. Being a plant, it has less carbon emission. Wool production from sheep harvesting have a substantial impact on water and land footprints and often required a large amount of energy to harvest sheep while carbon emission is comparatively low.

Artificial fibers are known to have more energy and carbon footprint. Viscous fiber extraction required a huge amount of water resulting in higher water footprint followed by carbon, energy, and land footprints. Polyester fiber production has a higher carbon footprint followed by energy, water, and land. Polyamide fiber production has high energy footprint followed by carbon, water, and land footprints.

Acrylic fiber production has a high-water footprint followed by carbon, energy, and land.

In general, artificial fibers required more energy, and have more carbon emission on fiber production stage, comparatively higher than natural fibers. As artificial fiber are produced in the laboratory, the direct use of land is often not considered for at fiber production stage. However, there is a direct or indirect impact on land from every stage of the fiber production process.

6 CONCLUSIONS

The need for textile in human life is inevitable, we cannot live without clothing and textile products. As the demand for clothing and other textile products are linearly increasing, the concern toward the eco-friendly textile is growing too. It is a crucial challenge to reduce the textile product as that is the only way to mitigate the environmental impacts. The use of environmentally friendly fibers, implementation of the eco-friendly production methods together with the recycling and reuse process will help to minimize the impacts on mother nature.

The information about the most common fibers was gathered during author practical training at Nextiili-paja and having an interview with the Nextiili personal. Six most popular textile fibers were selected based on textile waste from different fibers collected in Nextiili recycling center, Tampere.

Textile fiber possesses an enormous impact on the environment already from the raw fiber production stage and there is no single such fiber which has zero impact on our environment. The amount of impact on different areas varies from each other. Interestingly, natural fibers are not always the best alternatives while it comes to life cycle assessment. This has limitation while selecting raw fiber for textile production eventually as we need to consider the life and recycling and reuse of products made from these raw fibers. Calculating impact based on raw fiber production stage itself is not enough to generalize the overall impact of textile formed from this fiber we need to consider all stages of textile manufacturing, recycling, and reusing.

All fibers cause an impact in the environment during their production stage, the best way to mitigate environmental impacts and the problem of global warming is to focus more on eco-friendly and sustainable alternatives for textile raw fiber and increase the concept of recycling and reusing of produced fibers rather than fully rely on virgin fibers. The production of organic cotton, recycled wool, lyocell, recycled polyester and reusing and recycling of fibers should be prioritized rather than the normal cotton, wool, viscous, polyester, polyamide, and acrylic. Also, the process and methods involved in producing, refining and manufacturing textile from these raw fibers can be improved by adopting sustainable techniques. It is worth to mention that reusing and recycling clothes, clothing's and textile products could be advertised more to reach out to more population and make them aware of its consequences.

Currently, the Finnish textile industry is import based and is small. However, due to fast fashion the consumption of textile and clothing is significantly increasing so as the amount of textile waste. The origin of textile products that enters the Finnish market are produced outside the European Union and follows a different guideline and regulation about the sustainability of production. The origin and production principles are unknown to the consumers thus risking the quality measures of the textile products. This study will help to enlighten the possible risks behinds common practices in raw fiber production. This impact assessment will aid facilities like Nextiili to recognise the board perspective of impacts caused by these textile fibers and their risk on environment. Hence, they could focus their work on effectively minimizing these fibers waste and maximize the reuse of textile products from these fibers.

6.1 Limitation

In this research work, the focus was mostly on the specific recycling facility in Finland, Nextiili. Even though the recycling facilities follow general waste recycling hierarchy for efficient textile recycling they might have different preferences for commonly used textile fibers. Due to the limitation in time and resource, the visit to another recycling facility in neighboring cities was not possible. This limit to collect data for the research as well as hear the experiences of the people involved in those places.

During data collection one of the main challenges was to find out the recent information on textile raw fibers. Most of the available resources concerned about the fibers in general, however, the focus was to figure out the environmental impacts caused by commonly used textile raw fibers. Due to insufficient skills of Finnish language, the information from Finnish textile industries was not utilized in full space. There was a problem in finding accurate information about the measure of the environmental impact caused by raw fibers in one place as this

information varies in a different country and different environment. Similarly, it was hard to conclude the exact amount of resource used in producing these fibers.
Data gathered from most of the mentioned resources are quite old and outdated. Often these resources linked to the same materials from decade-old research. Interestingly most of these sources followed the data from the late ’90s. As there have been improvements in the production process and technologies involvements, these references do not supply clear ideas about the recent practices in fiber production.

6.2 Future Work

The topic of efficient textile production, reuse and recycle is board and never-ending field of research. There are many aspects to further study from this point. Firstly, the research work could extend further to do an impact assessment on the textile manufacturing process including fiber to yarn production, yarn to fabric, and fabric to textile products considering other aspects of textile industries. This will help to gain a clear figure of environmental impacts of a single fiber from its production to its decomposition. Secondly, as reusing and recycling is getting on the hype of every single business in the world, it is worth to take a step ahead towards this hot topic. This will help us to know the potential life span of each raw fibers, techniques that could imply to maximize the reuse of already produced fiber rather than virgin fibers. It would be extremely beneficial to spread the pros of eco-friendly fibers to end user. This will help to increase the potential consumer of eco-friendly textile, reuse, and recycling of textiles as well as help to mitigate textile waste.

In the future, Nextiili-paja can expand their work as a core business in textile waste recycling and reusing. The major issues Nextiili-paja facing these days are the lack of manpower together with the consistency in the management. Since, it provides a good alternative social platform for the rehabilitative purpose, provides skills to the interested customer and opens for interns, most of the workforce is working there on a temporary basis which has a significant impact on longtime work management. This problem can be solved by considering some long-term positions such as internship and research work and partly paid regular jobs. Collaboration with the local government, academics and residents will benefit all parties equally and promote Nextiili-paja's business to grow at the industrial level. On the other hand, students will have a handful of knowledge and skill sets in this field via long term internship. This eventually increases the amount of skilled workforce in this specific area. The city will get helping hands for waste management and residents will have a chance to consume textile product economically and ecologically. Another potential collaboration Nextiili could benefit from is with a waste management company by selling textile waste to generate energy instead of paying for their waste handling. In Nextiili, current business is reusing rather than recycling which helps to reduce the textile waste from the consumer that is going to deposit into industrial recycling centers. It could prioritize the core business as recycling facility like Finnish company Dafecor. In this way, the textile waste can be utilized and turn it into a treasure by processing textile raw materials from industry surplus and developing products out of these materials.

REFERENCES

Acrylic and Modacrylic Fibers: Chemical Economics Handbook. 2016. IHS Markit. Read on. 09.02.2019. https://ihsmarkit.com/products/acrylic-and-modacrylic-chemical-economics-handbook.html

Asbestos. N.d. United State Department of Labours. Occupational Safety and Health Administration (OSHA). Read on 22.02.2019. https://www.osha.gov/SLTC/asbestos/

Barber, A. & Pellow, G. 2006. Life cycle assessment: New Zealand merino industry merino wool total energy use and carbon dioxide emissions. Report by The Agribusiness Group. New Zealand.

Beverley, H. 2012. Understanding the environmental impacts of wool: A review of Life Cycle Assessment studies. Agri Escondo Ptv Ltd.

Blackburn, R. S. 2009. Sustainable Textiles - Life Cycle and Environmental Impact. Woodhead Publishing. Read on: 23.01.2019. https://app.knovel.com/hotlink/toc/id:kpSTLCEI05/sustainable-textiles/sustainable-textiles

Cleaner, Greener Cotton: Impacts and Better Management Practices. 2013. World Wildlife Fund. Washington DC. Read on 16.02.2019. https://www.worldwildlife.org/publications/cleaner-greener-cotton-impacts-and-better-management-practices

Clothing and Textile Sector in Finland. 2017. Market Survey. Flanders Investment & Trade Helsinki. Read on 16.01.2019. https://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/Clothing%20and%20textile%20sector_Finland_2017.pdf

Collier, J. B., Bide, M. & Tortora, G. P. 2009. Understanding Textiles. seventh edition. Pearson Prentice Hall.

Cook, G.J. 2005. Handbook of Textile Fibers. Vol 2- Man-made Fibers. Fifth edition. Woodhead Publishing Limited. Cambridge England.

Cook, G.J. 2004. Handbook of Textile Fibers. Vol 1- Natural Fibers. Fifth edition. Woodhead Publishing Limited. Cambridge England.

Dahlbo, H., Aalto, K., Eskelinen, H. & Salmenperä, H. 2017. Increasing textile circulation-Consequences and requirements. Sustainable Production and Consumption 44-57. Helsinki: Finnish Environment Institute & the University of Helsinki. Consumer Society Research Centre.

Dev, V. 2009. Carbon Footprint of Textiles. Read on: 20.01.2019. http://www.domain-b.com/environment/20090403_carbon_footprint.html

Eynde, V. F. & Wiinamäki, W. 2012. Clothing and Textile Sector in Finland. Flanders Investment & Trade Helsinki. Read on 16.01.2019. https://www.flandersinvestmentandtrade.com/export/sites/trade/files/market_studies/875121107095326/875121107095326_1.pdf

Fletcher, K. 2008. Sustainable Fashion and Textiles Design Journeys. Earthscan.

Freitas, A. & Mathews, R. 2017. Viscose fibers production: An assessment of sustainability issues. water footprint network. https://waterfootprint.org/media/downloads/Viscose_fibres_Sustainability.pdf

Giljum, S., Lutter, S., Bruckner, M. & Aparcana, S. 2013. State of Play of National Consumption Based Indicators: A review and evaluation of available methods and data to calculate footprint-type (consumption-based) indicators for materials, water, land, and carbon. Sustainable Europe Research Institute (SERI). Read on 10.02.2019. http://ec.europa.eu/environment/enveco/resource_efficiency/pdf/FootRev_Report.pdf

Global Footprint Network: Advancing the Science of Sustainability. N.d. Read on 20.01.2019. https://www.footprintnetwork.org/faq/?fbclid=IwAR08zhuHznb9GGtwpjz11H9EijtNz-yszlSaGQGmBWwrEt43l6Z0eXdpBcw

Global Garment and Textile Industries. Workers, Rights and Working Conditions. 2015. Solidarity Center. Read on 15.02.2019. https://www.solidaritycenter.org/wp-content/uploads/2015/11/Global.Garment-Workers-Fact-Sheet.11.15.pdf

Green Wool Facts: The Wool Industry & The Environment. 2014. International Wool Textile Organisation (IWTO). Read on: 12.03.2019. https://www.iwto.org/sites/default/files/files/iwto_resource/file/Green%20Wool%20Facts_April%202014.pdf

Jukarainen, H. N.d. Radical restructuring of the Finnish textile and clothing industry. SAK. Read on 25.12.2018. http://netti.sak.fi/sak/englanti/articles/textile.htm

Käppi, H. Raw Sorting Supervisor. 2019. Interview on 17.01.2019. Interviewer Ranabhat, R. Nextiili-paja. Tampere.

Laursen, E. S., Hansen, J., Bagh, J., Jensen, K.O. & Werther, I. 1997. Environmental Assessment of Textiles. Life Cycle Screening of Textiles containing Cotton, Wool, Viscose, Polyester or Acrylic Fibers. Environmental Project No. 369. Denmark: Ministry of Environment and Energy. Danish Environment Protection Agency.

Lord, R. L. 2003. Handbook of Yarn Production. Woodhead Publishing Limited. Cambridge England.

Muthu, S.S. 2014. Assessing the Environmental Impact of Textiles and the Clothing Supply Chain. Woodhead Publishing Series in Textiles. Elsevier Science.

Niinimäki, K. Professor. N.d. Sustainable Fashion and Textile Design. Fashion Research. Online Lecture Material. Read on 03.03.2019 https://my-courses.aalto.fi/pluginfile.php/646899/mod_folder/content/0/Lecture%20slides.pptx?forcedownload=1

Preferred Fiber and Materials Market Report. 2018. Textile Exchange. Read on 02.02.2019. https://textileexchange.org/downloads/2018-preferred-fiber-and-materials-market-report

Sandin, G, & Peters, M. G. 2018. Environmental impact of textile reuse and recycling – A review. Journal of Cleaner Production. Volume 184. Pages 353-365. ISSN 0959-6526.

Srinivas, H. N.d. What is the Energy Footprint? Global Development Research Center (GDRC). Read on 15.02.2019. http://www.gdrc.org/uem/footprints/energy-footprint.html

Sustainable Agriculture. Cotton. N.d. World Wildlife Fund (WWF). Read on 16.01.2019. https://www.worldwildlife.org/industries/cotton

Textile Recycling. N.d. Swerea. Read on 16.02.2019. https://www.swerea.se/en/areas-of-expertise/materials-sciences-raw-materials/textiles/textile-recycling

Textile manufacturing in the industrial revolution. N.d. History Crunch. Read on: 16.02.2019. https://www.historycrunch.com/textile-manufacturing-in-the-industrial-revolution.html/

Textile School. 2019. Types of Textile Fibers: list of textiles fibers by its source. Read on 14.02.2019. https://www.textileschool.com/2782/comprehensive-list-of-textile-fibers/

Watson, D., Elander, M., Gylling, A., Andersson, A. & Heikkilä, P., 2017. Stimulating Textile-to-Textile Recycling. Nordic Council of Ministers. https://norden.diva-portal.org/smash/get/diva2:1161916/FULLTEXT01.pdf

What is a water footprint? N.d. Water Footprint Network. Read on 23.02.2019. https://waterfootprint.org/en/water-footprint/what-is-water-footprint/

Wool Production. 2019. International Wool Textile Organization (IWTO). Read on 01.02.2019. https://www.iwto.org/wool-production

World Trade Statistical Review 2018. World Trade Organization. Read on 15.02.2019.
https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018_e.pdf

Wright, A. L, Kemp, S. & Williams, I. 2011. 'Carbon footprinting': towards a universally accepted definition. Carbon Management. 2:1. 61-72.

APPENDICES

Appendix 1. Interview Questions

1. Can you introduce shortly about yourself? (like what's your name, study background or working background, position in Nextiili and years of experience in Nextiili)

2. Can you give a basic background of Nextiili?

3. How much textile waste was received in 2018? (in number)

4. Can you tell the type of major textile materials that are received as textile waste?

5. Is there any available statistical data on the type of material received?

6. If not, then maybe the amount to textile sorted during the process could help? (get number in kg)

7. How do you see the difference between reusing and recycling in terms of Nextiili or What Nextiili is doing?