Tampere University of Applied Sciences

Measuring Environmental Benefits for Nextiili ry

Suvi Tanni

MASTER’S THESIS
May 2022

Risk Management and Circular Economy Degree Programme

ABSTRACT

Tampereen ammattikorkeakoulu
Tampere University of Applied Sciences
Risk Management and Circular Economy Degree Programme

TANNI, SUVI:
Measuring Environmental Benefits for Nextiili ry

Master's thesis 73s pages, appendices 3 pages
May 2022

Negative environmental impacts are being produced during each life-cycle stage of textile products. Studies have shown that the stages having the most significant impact are use of textiles and the choice of the disposal method. At present, the primary treatment method for disposing textiles in Finland is to discard them among the mixed solid waste to be incinerated during energy production. Changes are taking place, as Finland is about to start a national separate collection of end-of-life textiles in 2023, with the recycling requirements set by the European Union. With the separate collection of end-of-life textiles, it becomes more achievable to utilise discarded textiles according with the waste hierarchy.

At the end of 2020, second-hand shop Nextiili Association, together with Pirkanmaan jätehuolto Oy, started a pilot period for separate collection and sorting of the end-of-life textiles for recycle. The more versatile utilisation of discarded textiles has been welcomed by many, but verifying the benefits of the operation was found to be challenging. The aim for this thesis was to identify the benefits of Nextiili Association’s operations, limited to deal with environmental benefits, and to form a concreate result on the benefits in sorting of the textiles to reuse and recycle fractions.

The mapping of the environmental benefits of Nextiili Association’s operations required information research on the current situation of end-of-life textiles, the requirements for organising separate collection, suitable environmental indicators and clarifying some key terms. Expressing the benefits also required familiarization with Nextiili Association’s operating environment and data on the sorting quantities in order to conduct the calculations. Literature review was used to find carbon footprint analysis of various textile products.

The concept of avoided environmental impacts was selected as a means of expressing the environmental benefits. The avoided impact consists of offering a reused and recycled option instead of a new textile product made of virgin material. This difference on the generated carbon footprints was seen as an effective and understandable way to express the positive effects of sorting operations. During 2021, avoided carbon footprint resulted in total of 6061 tonnes of CO_2e due to the sorting of end-of-life textiles. The calculations confirmed previous research results on that the reuse of textile is more beneficial than recycling according to the avoided carbon footprint indicator.

Key words: end-of-life textile, separate collection, carbon footprint, carbon handprint, reuse, recycle, textile waste, avoided environmental impact

TIIVISTELMÄ

Tampereen ammattikorkeakoulu
Risk Management and Circular Economy Degree Programme

TANNI, SUVI:
Ympäristöhyötyjen mittaaminen Nextiili ry:lle

Opinnäytetyö 73 sivua, joista liitteitä 3 sivua
Toukokuu 2022

Tekstiilituotteen jokaisesta elinkaarivaiheesta muodostuu negatiivisia ympäristövaikutuksia. Tutkimusten mukaan tekstiilien käyttö ja niiden loppusijoituksen valinta vaikuttavat merkittävästi syntyneisiin päästöihin verrattuna muihin elinkaarivaiheisiin. Tällä hetkellä Suomessa ensisijainen käsittelymenetelmä tekstiilien loppusijoitukselle on hävittää ne sekajätteen mukana polttolaitosten energiatuotannossa. Käytäntöön on tulossa muutoksia, sillä Suomi on aloittamassa valtakunnallisen poistotekstiilien erillisikäyksen vuonna 2023, EU:n asettamien kierrätysvaatimusten myötä. Poistotekstiilien erilliskeräyksen myötä tekstiileitä on mahdollista hyödyntää tehokkaammin jätehierarkian mukaisesti.

Tekstiilikierrätysyhdistys Nextiili ry, yhdessä Pirkanmaan jätehuolto Oy:n kanssa, aloitti vuoden 2020 lopussa testausjakson erilliskeräyksen ja poistotekstiilien kierrätyslajittelun prosessoinnille. Poistotekstiilien monipuolisempi hyödyntäminen on todettu suotuisaksi toiminnaksi, mutta toiminnan hyödyllisyyden todentaminen koettiin haasteelliseksi. Tämän tutkimuksen tavoitteena oli nimetä Nextiili ry:n toiminnan hyöty, joka työn alussa rajattiin koskemaan ympäristöhyötyä sekä muodostamaan konkreettinen tulos tekstiilien uudelleenkäyttö- ja kierrätysjakeisiin lajittelun hyödyllisyydestä.

Nextiili ry:n tekstiililajittelutoiminnan ympäristöhyötyjen kartoitus vaati tiedonhakua poistotekstiilien nykytilanteesta, erilliskeräyksen järjestämisen vaatimuksista sekä prosessivaiheista ja sopivista ympäristöindikaattoreista, lisäksi vaadittiin keskeisten termien avaamista. Hyötyjen ilmaiseminen vaati myös tutustumista Nextiili ry:n toimintaympäristöön sekä dataa lajittelumääristä, joiden avulla laskennat suoritettiin. Kirjallisuusselvitystä hyödynnettiin eri tekstiilituotteiden hiilijalanjälkiselvityksessä.

Ympäristöhyötyjen ilmaisukeinoksi valikoituivat toiminnan kautta vältetyt ympäristövaikutukset. Vältetty ympäristövaikutus muodostuu uudelleenkäyttö- ja kierrätysvaihtoehdon tarjoamisesta uuden, neitseellisestä materiaalista valmistetun tekstiilituotteen sijaan. Tämä hiilijalanjälkierotus koettiin tehokkaaksi ja ymmärrettäväksi tavaksi ilmaista Nextiili ry:n tekstiililajittelun positiivisia vaikutuksia. Vuoden 2021 aikana Nextiili ry:n vältetyksi hiilijalanjäljeksi kertyi yhteensä 6 061 tonnia CO_2e poistotekstiilien lajittelun myötä. Laskelmista todettiin tekstiilituotteiden uudelleenkäytön olevan hyödyllisempää kuin kierrättäminen vältetyn hiilijalanjäljen mukaan, mikä vahvistaa aikaisempia tutkimustuloksia aiheesta.

Avainsanat: poistotekstiili, erilliskeräys, hiilijalanjälki, uudelleenkäyttö, kierrätys, tekstiilijäte, vältetty ympäristövaikutus

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ABBREVIATIONS

CE	Circular Economy
CO	Cotton fibre
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CV	Viscose fibre
EIA	Environmental Impact Assessment
EOL	End-of-Life textile
EMS	Environmental Management System
ETS	Emission Trading System
EU	European Union
GHG	Greenhouse gases
GWP	Global warming potential
IR	Infrared
LCA	Life Cycle Assessment
LHV	Lower Heating Value
LSJH	Lounais-Suomen Jätehuolto Oy
Mixed MSW	Mixed municipal solid waste
NIR	Near infrared
PES	Polyester fibre
PET	Polyethylene terephalate
PJHOY	Pirkanmaan jätehuolto Oy
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
TAMK	Tampere University of Applied Sciences
TBL	Triple bottom line
WO	Wool fibre

1 INTRODUCTION

Whether it is through bikinis, power suit or warm wool sweater, clothes are a way of expressing yourself, having protection against forces of nature and a tool for communication. Clothes are essential for us, but their consumption has its disadvantages. Textile production, with its long supply chain, has its environmental impacts on water, air and land usage creating emissions each step of the production, its usages and during end of life stage. Manshoven et al. (2019) estimated that production of clothing, footwear and household textiles for EU citizen makes textile production the fifth largest source for CO_2 emissions among all household consumption groups. The production of those items also consumes the fourth of most raw materials and water after food, housing and transport. (Manshoven et al. 2019, 45). Not to mention the chemicals, land usage and social impacts that the textile production and distribution has.

In Finland, the estimated overall consumption of new textiles was 11,3 kg/capita according to 2019 figures. At the same time, 85 773 tons of end-of-life (EOL) textiles were formed from various sources of which 61% was utilized as energy, 18% as material recovery and 4% by reuse. (Dahlbo et al. 2021, 5, 23). When thinking how much resources go into textiles and how long the usage time is, utilizing the material afterwards as only as energy, seems wasteful which is not sustainable practise.

Changes in utilizing EOL textiles more effectively is about to happen. In 2018 the EU Parliament approved amendments to the Waste Directive 2008/98/EY with the aim of improving circular economy. In practise this means that EU requires Member States to set up separate collection systems by the year 2025 for textile waste and to increase recycling of municipal waste to 55 %. (Direktiivi (EU) 2018/851) In Finland the aim is to achieve national separate collection system already in 2023 (Ympäristöministeristö 2021).

Nextiili ry association has been working in Pirkanmaa, in western Finland, as a part of circular economy in handling used textiles dividing them to recoverable fractions and working as second-hand shop for a few years. Donated textiles have been divided into their own reuse and energy recovery fractions since January 2021, when Nextiili ry started pilot project together with Pirkanmaa jätehuolto Oy (PJHOY) (Regional Solid Waste Management Ltd.) to establish separate collection for EOL textiles and to sort suitable material for recycle. Suitable textile material for mechanical recycling gets further processed in Paimio, a pilot plant owned by Rester Oy and in which Lounais-Suomen Jätehuolto Oy (LSJH), a tenant, has a pilot processing line for household textile waste. The new pilot plant will produce recycled fibre out of the EOL textile which can be further processed into yarn, fabrics, acoustic panels, non-woven and other applications. (Lounais-Suomen Jätehuolto 2020).

The project established Nextiili ry as the official collection point for EOL textiles at the end of 2022 (Ojala 2022). During this time, information is collected to help construct the basics for the national separate collection starting in 2023. At the moment plans for the future are still open and the uncertainty of the situation was one of the impulses for Nextiili ry to review their operations more thoroughly. Previous participation and the good work of Telaketju-project on research development of end-of-life textiles collection and sorting models inspired to compare the benefits of sorting EOL textiles to recycle rather than energy fraction. Working as part of circular economy and providing new life for used textiles has environmental benefits. The study question was on how to communicate those benefits and what they actually are where the starting point for this thesis.

The aim for this thesis was to find suitable way to describe the environmental benefits of Nextiili ry operations now that the pilot project has been in action during the year 2021. The description should be understandable for several stakeholder groups, possibly reproducible by Nextiili ry in the coming years and appropriate in scope for thesis. The service provided by Nextiili ry, sorting of the donated textiles according to the waste hierarchy, could be seen forming the environmental benefits and form a measurable result. Although the social benefits of Nextiili ry is an interesting branch of research, it was not taken into closer consideration in this thesis.

The main method used to find a way of communicating benefits was a literature review of different sustainable indicators that are being used to describe environmental issues by companies. The literature review was conducted also in the calculation stages where the emissions factors and carbon footprints of different fibre and textile applications were needed. In this stage, the main sources for the review were searching the internet and the TAMK's online library. Nextiili ry provided collected data of the material volumes in 2021. The data described the sorting of donated textiles into different fractions and was written in MS Office Excel form. Interviews of the Nextiili ry operations were made during this thesis for Sari Tuomaala, Chairman of the Board and executive director of Nextiili ry, Helena Käppi and Emppu Nurminen, other members of Nextiili ry. Email interviews were conducted for Saana Ojala, Operating System Specialist at PJHOY to verity the information of the project and with Oskari Pokela, Collection and logistics Planner at LSJH to gain information of textile refining pilot plant in Paimio.

Because of the nature of textile diversity, the definition of different aspects was seen as good starting point for this thesis. After explaining key terms, the current situation of EOL textiles and its treatments, the focus turned to sustainability and the common indicators used to describe environmental impacts. The next topic was the company profile of Nextiili ry and the introduction of a same type of company, Wieland Textiles B.V, and their solution for environmental benefits. This was followed by calculations of avoided environmental impact by Nextiili ry in 2021. The final chapter contains a discussion of founded results during the thesis.

2 TEXTILE WASTE

2.1 Used terms

Defining different terms used in describing textiles leaving from the primary use stage is a good starting point. Since the talk of sustainability, recycling and reuse has increased over the years, some of the terms have been changed and new additions have been created. In the next table (Table 1) has a sort description of the terms used in this thesis and how they are to be understood.

TABLE 1. Definition of key terms

Textile	Assembly of fibres or yarns, either natural or manmade origin, produced by different techniques depending on the application. Common techniques of textile production are weaving, knitting, bonding, felting, tufting and braiding. Usually textile fabric is created by converting fibres into yarn and then converting yarn to fabric. Nonwoven, insulation and filling materials are produced straight from fibre to textile product. (Shaker et. al. 2016, 47) In this thesis composites, films, laminated products are not considered as textiles
Textile waste	Waste Act (646/2011, 5§) defines waste as a substance or an object which the owner has disposed of or is about to dispose of or is required to do so. Textile waste is the collected discarded material that is not suited for reuse, but can be recovered through energy or recycling (Salmenperä 2017, 3).
End-of-life textile	EOL textile is textile material that the owner is disposing of. Material contains both textile waste (e.g. ragged textile) and reusable textile products, which can be used as such for their original purpose. Without sorting the EOL textile material into different fractions, it is regarded as textile waste (Salmenperä 2017, 3). In this thesis, collected EOL textiles are sorted into reusable, recyclable textiles and energy recovery fractions
Pre-consumer waste	Pre-consumer textile waste is material that is a by-product from different phases of textile production (for example fibre, yarn or pattern cutting stage) (Maqsood & Nawab 2016, 169) or unsold clothing from stores or logistic centers. Note that in some cases cutting waste may meet the by-product criteria and is not considered as waste and therefore not a subject to administrative procedures of Waste Act. (Salmenperä 2017, 3)
Post-consumer waste	Post-consumer textile waste is more heterogenic, qualitatively and quantitatively, varying material from consumers when pre-consumers textile waste is more well-known type of material. It can be any type of home textile or garment discarded by its owner (Maqsood & Nawab 2016, 169)

Reuse	Using the product or a part of the product for same purpose that it was originally intended without any specific treatments. Selling used clothes for clothing purposes or fabrics to use as material for new products can be considered as reuse. (Salmenperä 2017, 4)
Recycle Textile-to-textile recycle	Commonly known textile recycling methods are divided according to the processing methods into mechanical, chemical and thermal recycling. Textiles are shredded into fibres in mechanical recycling method and the fibres are used as such or spun into yarn to be further woven into fabric. Chemical recycling is based on dissolution of cellulose and converting it back into fibres. Thermal recycling is a method of re-melting synthetic fibres and processing them back to fibres by different processing technologies. (Salmenperä 2017, 5)

2.2 End-of-life textiles

At the moment in Finland, textile waste is handled according to the landfill ban on organic waste 331/2013 which entered into force in 2016 and the application of the waste hierarchy introduced by the directive 2008/98/EC. As an organic material, textile waste is not allowed into landfills and is now processed mostly by incineration, creating energy. This is inconsistent with the waste hierarchy goal because according to it incineration is only the fourth solution after waste prevention, reuse and recycling. (Directive 2008/98/EC).

Responsibility of handling textile waste is partly on municipalities and partly on the waste holders. Since textile waste is part of municipal waste stream, most of it is collected in the mixed municipal solid waste (mixed MSW). (Salmenperä 2017, 7). There are about 30 waste management companies in Finland, covering the whole country and owned by municipalities (Heikkilä et al. 2021, 51). Energy recovery is the most commonly used form of proceeding for municipal waste stream. This recovery is based on combined production of electricity and heat, where the heat is further used in district heating (Findikaattori 2020).

Households have a key role in textile waste processing. Out of the 85 773 tons of estimated EOL textiles in Finland in 2019 about 73% was from households and from that amount 64% was discarded through mixed MSW (Dahlbo et al. 2021, 5, 23). The following figure (Figure 1) shows modified description of the

Dahlbo et al. findings of textile flows in 2019 from the household perspective. Part of the estimated figures in textile flow report in 2019 is formed under multiple uncertainties. The estimations were formed from reliable data, but also from statistics, surveys and from literature figures. In some cases, monetary units needed to be converted into mass units in order to describe the flow, and sometimes the estimated weight of the textile waste included products out of the textile definition (like shoes, rugs or handbags). Also, the report could only include the biggest EOL textile handling organizations and relay on their multiple recording styles of material flows. The understanding of differences in meaning of reuse, recycle and material recovery increased the ambiguity of the received figures. (Dahlbo et al. 2021, 18-20). Despite of the estimations and calculated data in the report, the figures show the overall situation of how Finnish people use and discard their textiles and how much potential there is for utilizing the material better.

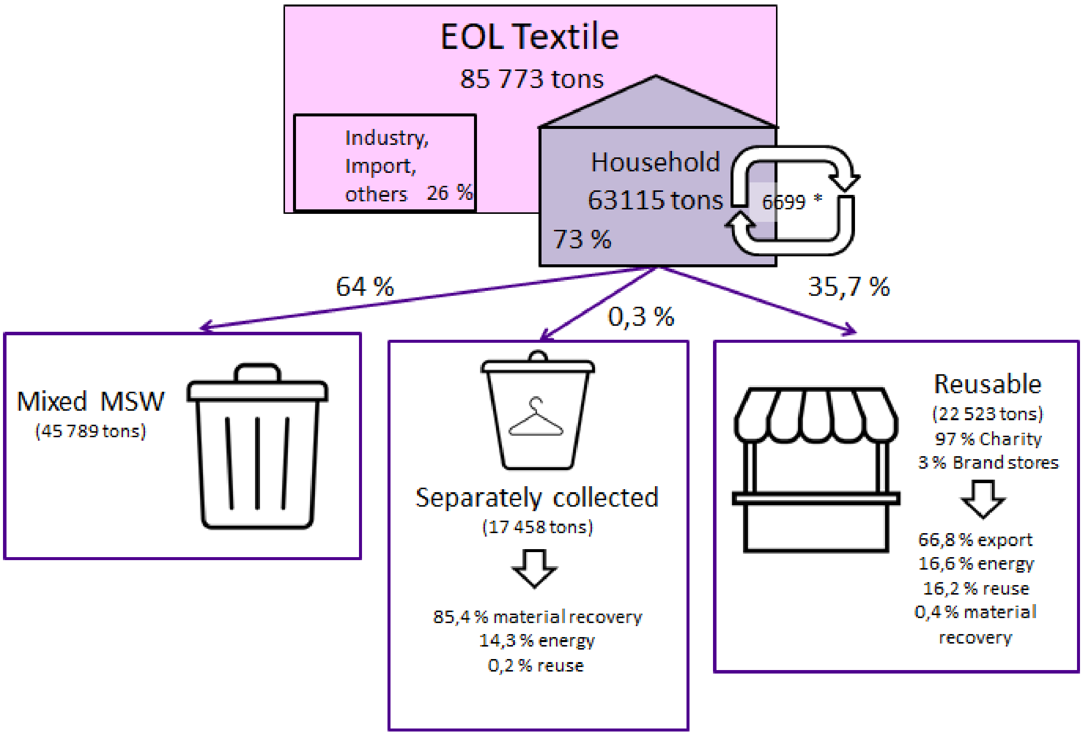


FIGURE 1. Households end-of-life textiles and their utilization in 2019 (Dahlbo et al. 2021, 23-26) (modified)

Out of the two main flows of discarded textiles from households, 64% goes to mixed MSW and further to energy recovery and about 36 % to reuse. Very small amount was collected separately form households and the amount of 17 458 tons was collected from the industry. The post-consumer textile waste collected by regional municipal waste management companies, LSJH and Rauma by their new pilot, has the 0,3% share from households. The reusable section could also be considered as a separately collected textile waste, but is distinguished from the other section by the nature of collection system and the level of sorting the material in different fractions. This separate collection has been done by charity organizations and brand stores. About 6 699 tons of reusable textiles are exchanged between consumers by selling to friends or passing old baby clothes to someone in need. This exchange of reusable textiles has been difficult to estimate but it increases the share of reuse recovery when taking it into consideration in overall figures. This will add up to 1,8 kg/capita of textiles being reused by households in 2019. (Dahlbo et al. 2021, 22, 27, 29). Although the estimated overall amount of EOL textiles are seemingly going to different fractions, inside the fractions some part of the material ends up in the energy recovery and not entirely to reuse or material recovery.

2.3 Separate end-of-life textile collection

Establishing a separate national collection for EOL textiles by 2023 requires all of the Finnish municipal waste management companies to organize and build a collection system and pre-sorting stage in each operating area. The future operating model is being refined during the ongoing step-by-step establishment started by pilot collection in 2016 in western Finland and is now growing under the coordination of LSJH. The collection of EOL textiles done by charity organizations and various companies over the years has always been focused in the reusable textile collection and therefore national separate collection differs from that practise. In order to benefit of the current systems, the new system is created in collaboration with companies that have existing infrastructure and experience on sorting of EOL textiles. (Lounais-Suomen jätehuolto 2020a; Heikkilä et al. 2021, 51).

Sorting starts at household level. EOL textiles that are suited for separate collection are unusable in primary use, dry and clean textiles. This does not include undergarments, shoes or blankets although being textiles and correct quality, not everything is recyclable, and this be made clear to citizens. The collection points should be accessible and located at an easy distance from households. During Telaketju project the functionality of various collection bins, containers and sorting stations was tested to establish the best way of preserving the material. Since textile waste is easily perishable, the organization of collection and transportation presents an additional challenge to maintain material dryness and pest control compared to other separately collected waste materials. Not only the outside conditions affect the preservation, but the collected material might contain damp textiles or non-collected waste, which might reduce the quality of collected material. Because of this, pre-shorting should be located near the collection point and the emptying interval of collection points should be sort. (Heikkilä et al. 2021, 51)

Sorting of EOL textiles is divided into four levels; pre-sorting, further sorting for reuse, further sorting for recycling and material sorting (classification). Municipal waste management company selects the level that suits for them and acts accordingly. (Lounais-Suomen jätehuolto 2020a, 12). Level of sorting increases the value added and affects the composition of recycled products (Kamppuri et al. 2019, 9). In the pre-sorting level, company removes from the collection batch any qualitative and occupational health risk factors. This includes e.g. wet, moldy and very dirty textile items. The second level of sorting distinguishes the reusable textiles separately. This means delegating responsibility to the sorting operators for them to process the reusable items appropriately and to forward them to next phases. Third level, sorting for recycling, adds fraction for the non-reusable textiles sorted in the previous level. From this non-reusable batch, the structurally unsuitable textiles are then removed and forwarded to further to other recovery channels. The last level requires sorting the recycling fractions textiles according to their fibre type. Different fibre type fractions are packed separately and marked before transportation to the recycling facility. A more detailed explanation of the material sorting by fiber type can be found in the next chapter. At least during the pilot stage a delivery contract between LSJH and municipal waste management company includes minimum and maximum delivery volumes (t/a). If the company sorts EOL textile up to fourth level, decreases the delivery quotas that were specified in the delivery contract. This will also lower the processing fee category. (Lounais-Suomen jätehuolto 2020a 8, 12)

2.3.1 Manual Sorting

EOL textile sorting is conducted mainly manually which is effective way of identifying reusable and unsuitable textiles out of the batch. The sorter can, to some extent, identify different fibre types by feel and according to product type. At the moment manual sorting is done in recycling centers, charity organizations and companies using recycled material. (Kamppuri et al. 2019, 9). Manual sorting was studied during Telaketju project (Heikkilä et al. 2021, 58). It was found to be highly employable processing phase. The operators that were focused on collecting reusable textiles had more long-term and paid employees, whereas the operators sorting EOL textile had employees who worked mostly part-time or who were rehabilitators, trainees and subsidized workers (Mäkiö 2021; Heikkilä et al. 2021, 58). This also creates a difference in the work pace. A long-term employee, with practice, can sort 1600 kg of textiles per day, whereas a part-time worker whit possible social, mental or physical problems, can sort around 200-500 kg of textile per day. (Heikkilä et al. 2021, 58). The main phases of manual sorting were identified during the Telaketju project and are described in next figure (Figure 2).

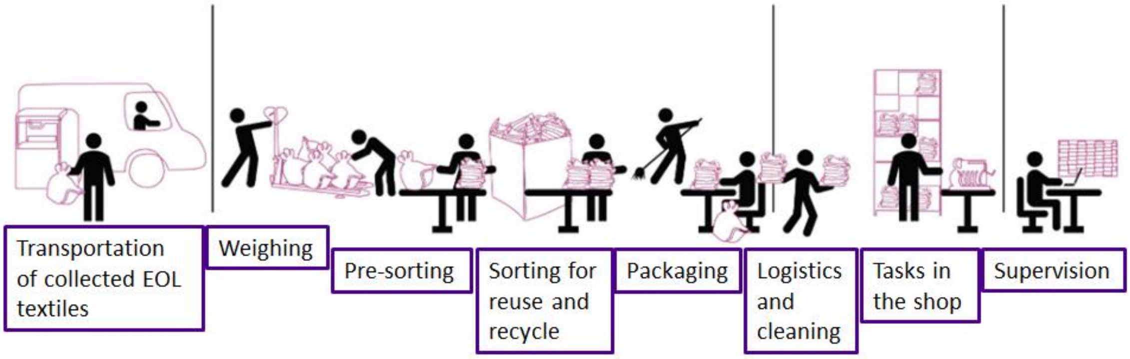


FIGURE 2. Manual Sorting phases of EOL textiles (Heikkilä et al. 2021, 58) (modified)

Some of the work phases are easy, some need knowledge and experience, but all the phases can be organized within one organization and learned by doing. That being said, some level of education on recognition of reusable items and of difference in fibre type is required from the employee.

Sorting the EOL textiles by their fibre type fractions is required in the sorting for recycling. At the moment the sorter identifies fibre types by feel and by product type into cellulose, synthetic, wool and mix or unknown materials. (Lounais-Suomen Jätehuolto 2021). Tags on clothes might help in the identification, but often they are removed or worn out. It is time consuming to find the information from clothes and sometimes it is incorrect. With the help of mechanical identification the sorting of EOL textiles becomes more effective and it will increase capacity. (Kamppuri et al. 2019, 9) Mechanical identification technology in sorting stage is based on NIR (near infrared) which is an infrared spectroscopic method of analysis. This method identifies organic compounds based on IR absorption from the surface, without the need of penetrating the studied material. Sensors equipped with such technology are often so called secondary analysis equipment that needs reference library in order to interpret the result. (Kamppuri et al. 2019a, 6). In manual sorting, a handheld sensor and a cell phone from which the results can be read are used to ensure results. With the help of the above-mentioned identification process, the results can be specified. For example, a cellulose fibre type fraction can be sorted into 100 % cotton, 100 % viscose and cellulose blends or synthetic fraction to 100 % polyester, 100 % polyamide or synthetic blends. (Lounais-Suomen Jätehuolto 2021).

Technology has its limitations. There is a numerus amount of different types of blended materials, the information of which have not yet been transferred to the reference library, resulting in an unknown material classification. Blended material might also have been structured so that the other fibre type is only present in the surface and the other one is on the other side of the fabric, creating false reading. In the future, textile sorting might be eased by automatic textile sorting line where these types of NIR sensors sort the textile batches faster than in manual sorting. (Heikkilä et al. 2021, 52; Kamppuri et al. 2019, 9-11).

2.3.2 Material recovery

Studies have proven that the reuse and recycle of textile waste has environmental benefits compared to energy recovery, but they also state that the reuse of textiles is more beneficial than recycling. (Sandin and Peters, 2018). Material recovery, meaning recycling, is a method where waste is reprocessed to its original or other purpose (Dahlbo et al. 2021, 12). End-of-life textiles recycling methods include also apparel remanufacturing and redesign, in which the apparel is disassembled to form a new product, this is known as fabric recycling or reuse (Sandin and Peters, 2018). In this thesis, the focus is in the fibre recycling process which maintains the original fibres of the textiles. Fibre recycling or textile recycling methods are classified to mechanical, chemical and thermal, but often the method is a mixture of different processes. Recycling often impacts the value and quality of the material compared to the original form. If the material is recycled into lower value uses, it is called downcycling, and if the recycling increases the value, it is called upcycling. (Sandin and Peters, 2018)

Mechanical recycling is the most used method, since chemical recycling is still mostly in its development stage, it is costly and energy consuming, and thermal recycling often seen as melt extrusion of PET flakes; the original form being form PET bottles and not from textiles (Heikkilä et al. 2021, 37; Sandin and Peters, 2018). Material recycling is based on opening textiles back to their fibre form. This method is lowers the fibre length and in terms of fibre quality, the method is considered to be downcycling. Chemical recycling of synthetic fibres, such as polyester is based on depolymerising the polymers. Dissolving is a chemical recycling method for cellulose, like cotton, where the polymer structure is dissolved and further processed into new structure. Before the depolymerisation or dissolution, the material requires purification and mechanical shredding (Sandin and Peters, 2018; Kamppuri et al. 2019, 22). Since the depolymerisation, and re-polymerization, creates almost virgin fibre type of qualities, it is considered upcycling (Sandin and Peters, 2018).

Mechanical recycling is suited for mostly all fibre types, but the best benefits are resulted from textiles that are 100% of the same fibre type (Kamppuri et al. 2019, 7; Auranen 2018, 22). EOL textiles are often made by blending different fibre types, which can go through the process well, but it will affect the new product value. Elastane-rich and coated textiles can cause problems with the machinery. Other benefits of identification and shorting of EOL textiles are identifying the potential application for the new product and discovering which method and driving conditions should be used for each type of textile batch. EOL textile material properties, like colour and weaving or knitting structure, affects the characteristics of the end product. (Auranen 2018, 22). Other quality criteria for textile fractions are cleanliness; contaminated and mouldy textiles are a health risk and the material must not contain flame retardant chemicals (Kamppuri et al. 2019, 33).

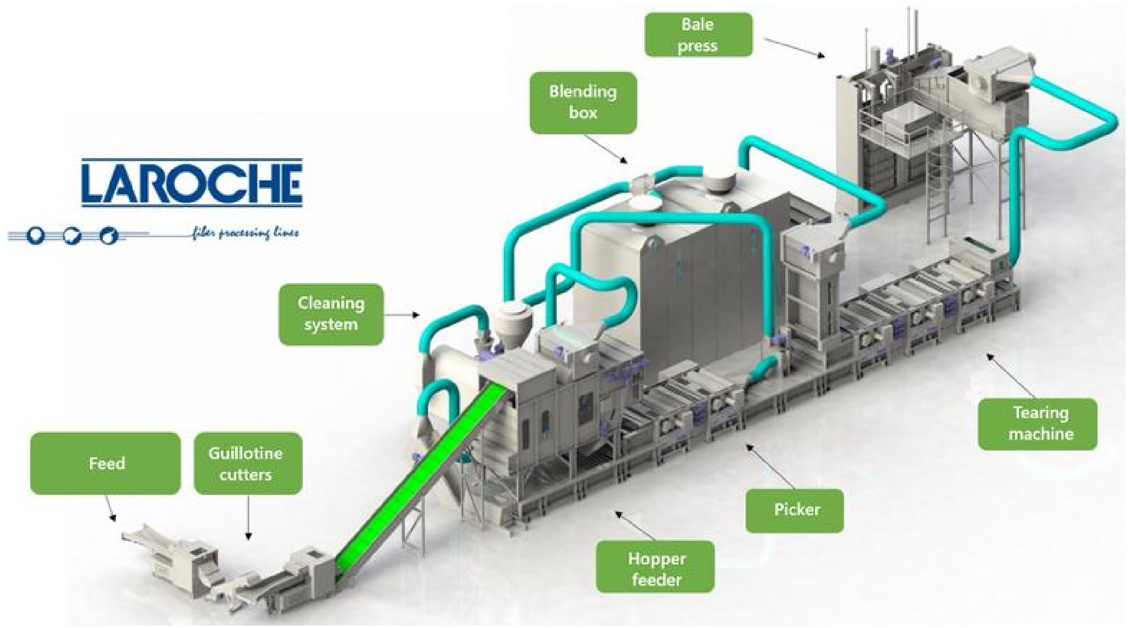
The recycling process starts with cutting and tearing the textile into fibres. Guillotine cutting is the most used method to remove buttons and zippers by cutting them out, at the same time reducing the material size. After cutting process, the material is opened to its fibre level. In this tearing phase, also the debris and unopened pieces are removed. Depending on the quality of the produced fibre material and the properties of the fibre type, it can now be further processed into yarn, nonwoven or use it as it is in composite or in applications. (Auranen 2018, 22-29).

2.3.3 Textile refining pilot plant in Paimio

Paimio is a small city in Southwest of Finland where Rester Oy, owned by workwear supplier Touchpoint, established a textile waste recycling plant, Green Field Hub. The construction of the refinery began in August 2020 and was finished in the spring 2021. LSJH leases a part of the 3000 m^2 large facility and set up own pilot line for EOL textiles collected from consumers, whereas Rester Oy processes industrial textile waste. Both of the refining lines are producing fibres out of the waste through a mechanical recycling method. The estimated production line capacity is 5 000 tonnes in a year (Pokela 2022). Produced fibres can be further processed into yarn, non-woven, fabric or other applications. Based on the experience from the pilot line, LSJH, together with other municipal waste management companies, has started preparing a full-scale refining plant that would handle all Finnish household EOL textiles in the future (Lounais-Suomen Jätehuolto 2020). The full-scale refining plant would have the same processing method, but its capacity would be around 15 000 tonnes per year. It is estimated to be completed during the year 2025 (Pokela 2022).

The EOL textiles coming to pilot plant have been pre-sorted at least by the collector. At the moment the sorting happens in Turku at LSJH’s textile sorting hall, but most of the material gets sorted by sorting partners before coming to Turku. The different fractions travel from Turku to Paimio pilot plant to be recycled. (Pokela 2022)

Laroche’s Mecanical recycling line for post-consumer EOL textiles can be seen in next picture (Picture 1). French Lacroche SA won the tendering for producing LSJH’s pilot line in Paimio. Before entering the processing line, Picture 1, the EOL textiles are qualitatively inspected to ensure that the feed material will be the desired fibre type. (Lounais-Suomen Jätehuolto 2021a). The end product is baled fibrous material.



PICTURE 1. Laroche’s Mechanical recycling line for post-consumer EOL textiles (Lounais-Suomen Jätehuolto 2021b).

The speed of the processing lines depends on the application of the end product. For yarn production, the fibre length has more significance, so the processing speed is 250 – 500 kg per hour and for nonwoven application the speed can reach 800 – 1000 kg per hour. The material flow coming to Paimio has been quite consistent in quantity during this pilot stage, but varies when a new waste management facility starts its separate collection. Sorting stage employs 10 people and the processing line 4 people at the moment. (Pokela 2022).

2.4 Energy recovery

Since a large share of end-of-life textiles end up in incineration, through Mixed MSW and other fractions, the interest would be to know how much energy is recovered by it. If the fibre composition in household textile waste is assumed as being similar to the material sold on the market, the textile waste in Nordic country would contain 57 % of cotton, 34 % of polyester, 4 % of wool and 5 % of unspecified other fibres according to rough estimations done by Schmidt et al. in 2016, the textile (Schmidt et al. 2016, 39).

Cotton consists mostly of cellulose, polyester is a synthetic polymer and wool is formed by one type of protein that gives each of the fibre type different lower heating value, LHV. Calorific value of material describes the amount of heat generated during complete combustion per mass of material. Lower heating value, LHV, signifies the amount of heat generated by combustion of one mass unit of material minus the energy used to evaporate the water which generates during the combustion. (VTT 2016, 13; 18). Due to the lower heating values of different fibres and their estimated share in textile waste (Table 2), one ton of textile waste releases approximately 20,7 GJ of energy (Schmidt et al. 2016, 56). Since Dahlbo et al. (2015) came to roughly same conclusion, 20 GJ/t, using a fibre mix of 50 % cotton and 50 % polyester, the calculations can be considered accurate and that the composition of textile waste fibres effects only modestly to the energy calculations (Dahlbo et al. 2015, 45).

TABLE 2. Lower heating values and fibre share in textile waste (Schmidt et al. 2016, 56)

	LHV (MJ/kg)	Share in textile waste (%)
Cotton	20,2	57
Polyester	21,2	34
Wool	23,2	4
Other	20,2	5

Incineration creates emissions. Incinerated among the MSW, the CO_2 emission factor for textile waste is 36,3 kg of CO_2 per GJ (Dahlbo et al. 2015, 45). Other considerable concerns are bottom and fly ashes and other emissions to air. These alter due to the composition of the mixed solid waste and the textiles among them. (Youhanan 2013; 26).

The energy recovery textile waste does not need to be separately collected, handled or transported to the incineration plant where heat and energy can be collected as by-product. (Youhanan 2013; 26). Overall amount of mixed MSW from households was 1 515 281 tonnes in year 2019 (Suomen virallinen tilasto (SVT) 2020). Compared with the estimated amount of 40 000 tonnes of discarded textiles from households, the share of textiles in energy recovery add up to 2,6 %. (Dahlbo et al. 2021, 29). Therefore, it can be concluded that the possible removal of textile waste from mixed MSW should not greatly affect the energy production in the waste incineration plant.

3 SUSTAINABILITY INDICATORS

3.1 Sustainability

Sustainability is a word often used today. Historically the Brundtland Report described sustainability through sustainable development as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). This famous definition indicates that sustainability is about ensuring that decisions making today enables the same conduct in the same way in the future. Sustainability is seen as the balance of three dimensions; environmental, economic and social, where ideally economic growth can happen at the same time as environmental and social aspects are taking care as well. The term is often associated with the preserving actions done for keeping up Earth's carrying capacity, by alternating human behaviour or creating new technologies to reduce the effects of those behaviours (Portney 2015; 12).

Sustainability can be seen in different ways and to mean different things in different contexts. For a company, making business, sustainability can be growth of "green economy", where for new business it can be found to offer a new type of services, for example relating on energy efficiency or environmental protection. The sustainability of manufacturing company can be changes on their process or in their goods in order to reduce their impacts on environment. The actions done in order to attain sustainability are often advocated to the rest of the world, which creates an opportunity for the organizations to find way to stand out. For some companies, sustainability means economic growth and development, although some may argue that sustainability can't effect positively on economic growth. (Portney 2015; 109–113)

The increase pressure for corporations has created corporate sustainability policies and initiatives to chase sustainability, like zero waste or to use only renewable energy and to affect the companies supply chain as well. This has led companies to advertise their sustainable actions. One forum of that is to incorporate sustainable aspects to company annual reports in various ways, like the “triple bottom line”. The concept in reporting “triple bottom line”, TBL, is to present corporate profits counter to the environmental and social impacts that was formed during the reporting period. (Portney 2015; 117)

Reporting sustainable issues or actions means that effects and changes need to be measured or given a value that can be examined in order to follow the changes during the agreed period. The TBL accounting concept, where all three aspects of sustainability are measured do not seem easy. One difficulty is to Find a common unit for all of the aspects. Solution for this might be creating an index which has widely accepted accounting method, comparing performances of different companies could be achieved. Creating and using this type of index that is divers and meaningful but also built so that companies can find the necessary data for the variables easily and fast, forms its own difficulties. (Slaper and Hall 2011). Although it seems difficult, there are benefits of measuring company sustainability. Calculating sustainability and advertising findings is meeting the need of today’s consumers and other stakeholders. It is used not only to improving image, but also finding long-term profitability in developing processes to more sustainable direction (Slaper and Hall 2011).

3.2 Measuring sustainability

Literature survey done by Ahmad, Wong and Rajoo (2018) to what type of assessments and indicators are used to determinate manufacturing companies their sustainability indicated that all of the sustainability dimensions are not equally measured. Each dimension has different units and measurement methods but also the inconsistent usage of indicators might be reason behind the lack of comprehensive usage of all three dimensions in sustainability measurements. Most used and studied indicators for the environmental sustainability were for energy and material usage and air emissions. For economic assessment the focus was on cost-based indicators and for social aspects the focus was on workers and local community and of society related indicators. (Ahmad et al. 2018).

The production of product or service has negative environmental consequences that affect, for example, quality of air, water and land. They also accelerate climate change, reduce biodiversity, and are energy and material intensive and production of wastes. One starting point for evaluating environmental impacts is life cycle assessment (LCA), where the overall impacts of product or service, beneficial or harmful, are evaluated during cradle to grave life time. After scope and determination of boundaries, the life cycle inventory for all the phases in the life of products or services is described, from raw material to disposal phase. Inventory reveals all inputs and outputs, materials and energy used in production and what is generated during the products manufactory and usage. Found inputs and outputs are then assessed in the life cycle impact analysis on their impact to determinate the magnitude of their effect. The list of different impacts can include calculations of carbon-, ecological-, water-, energy footprints, land use, human toxicity, ozone depletion potential or acidification among others. (Muthu 2014, 2.2)

Carbon footprint or energy footprint can be considered as analytical tools of technical approach to analysis or communicate environmental sustainability, whereas procedural tools are aiding the decision making process with procedures. These tools can be environmental management system (EMS), environmental audit, environmental labelling or environmental impact assessment (EIA). (Muthu 2014, 2.2).

Most of the used and known tools and indicators describe the negative impact that the process or product has to environment. Carbon handprint describes company’s solutions on positive reduction effects for the customer’s carbon footprint (Pajula et al. 2018, 4). This would allow companies to advertise their solutions from more positive angle.

Measuring performance for circular economy, CE, raises need for own indicators. CE, being the old idea but new economic model, needs holistic view on it because one indicator will not show everything. For example following only the total amount of waste does not tell whether the economy has shrunk or whether circulation of materials has increased. Circwaste project, coordinated by SYKE to promote circular economy, suggest using a set of indicators from eight activities of different stages of life cycle, including design, production, consumption and reuse stage (SYKE 2022; Tilastokeskus 2022). Reuse stage would include circular material use rate (CMU), which measures the ratio of recycled material used in product to the total material amount. (Tilastokeskus 2022). Increasing material by reuse, recycle, repair or remanufacturing decreases the need of producing new products and therefor reduces the impact on environment, although they all have impact. From the environmental performance point of view, it would be relevant to measure which of the recovery process has lowest environmental impact compared to value retained.

From the wide range of different performance analysis tools, indicators and assessments the most known and used might be most efficient solution to communicate Netiili ry's environmental benefits. In the following chapters are described those two solutions which seemed to fit to the scope of this thesis and relate for small business environmental communication opportunities. Concentration was on the environmental dimensions of the sustainability since that was the original point of interest. Also the legislation guidelines, like Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) or Emission Trading System (ETS) were not covered in this thesis, although they were also relevant issues.

3.2.1 Carbon footprint

Widely used and know environmental indicator, carbon footprint, expresses the amount of carbon emissions for a specific configurable entity. Carbon emissions, so-called greenhouse gases include carbon dioxide, CO_2 and other gases like methane, nitrous oxide and hydrofluorocarbons. Each of the gases absorb heat and when there are increased amounts of them in the atmosphere it results in rise of temperature, ocean acidification and climate change. (Jha et al. 2021; Muthu 2014). Greenhouse gases have their own lifetime and heating capacity in the atmosphere, the features that can be described as global warming potential (GWP). CO_2 is a reference gas with a GWP of 1 and because it has the biggest effect on climate change, the rest of the gases are compared to it in order to convert their impact on climate comparable for the CO_2 equivalents. (Muthu 2014). In the 100 year time frame, identified by the Kyoto Protocol and calculated by Intergovernmental Panel on Climate Change in its report (2007), the GWP for example methane (CH_4) is 25 and nitrous oxide

(N_2O) 298, indicating that bigger the number, higher the potential of warming the atmosphere (Forster et al. 2007, 212).

Carbon footprint is often formed during life cycle assessment, LCA, where all produced emissions of a product, process or service are estimated during its lifetime, starting from the raw material and ending on the end of life stage, depending on the information wanted; from cradle to gate or cradle to grave. Whit the help of the LCA, calculated carbon footprint can help identify emission hotspots and further on to help to reduce emissions. The publication of the carbon footprint information increases transparency and might help to develop products according to international standards or guidelines. (Jha et al. 2021).

Carbon footprint is sum of greenhouse gas emissions quantified using the GWP indicators over the usual time frame of 100 years. It is represented in units of mass of carbon dioxide equivalent per unit of product or time, resulting as kg CO_2 equivalents (kg CO_2 e). (Muthu 2014)

Product’s carbon footprint calculations start with the identification of the product that is to be studied and carried by further steps seen from the following figure (Figure 3). After the definition of the product, the next step would be mapping the collection of products raw materials, identified by manufacturing flow and charting the supply chain whit the inputs and outputs of resources. Setting boundaries for the any carbon footprint study means defining what will be taken into consideration and what will be left out. This could mean how thoroughly the raw material production is considered or what means of disposal of the product are considered in the end of life stage. (Muthu 2014).

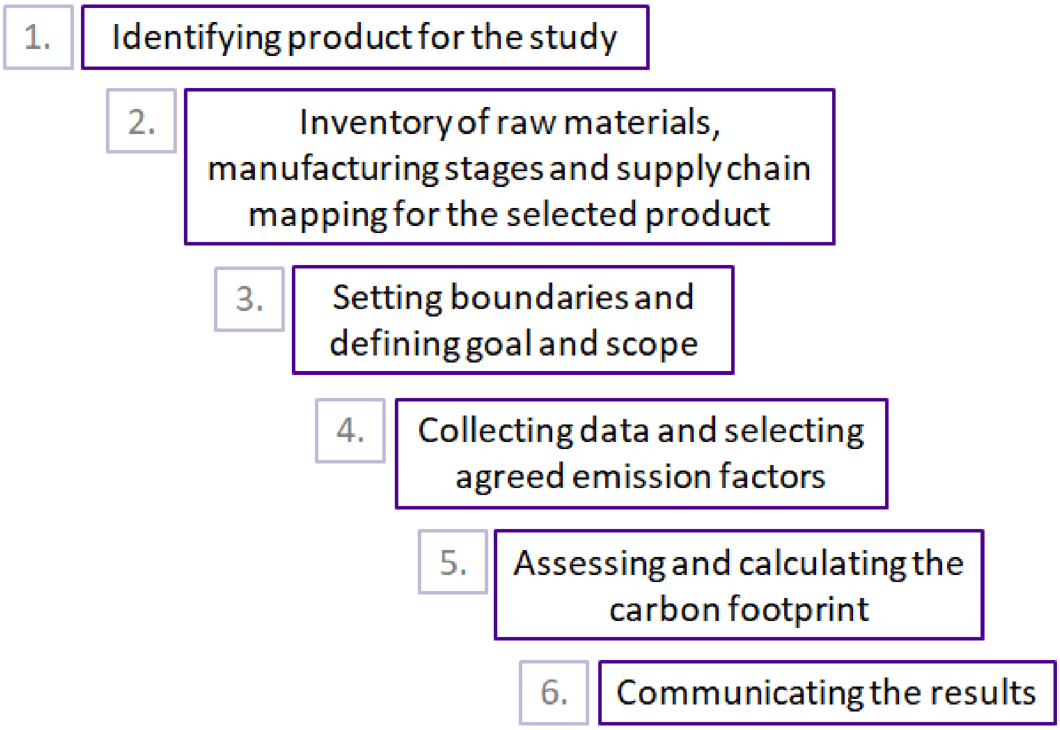


FIGURE 3. The main steps in producing carbon footprint assessment for a product (Muthu 2014)

The forth step would be the collection of data and selection of emission factors. The required data includes amounts of material and energy needed during different stages in the life cycle, waste amounts and discarding methods as well as transportation details from different stage of the supply chain. Information can be collected on the scene, as a primary data source, or utilizing databases and scientific publications as a secondary data sources. Emission factors are representative values where mass of the emission (tonnes, kilograms or grams) is expressed in relation to functional unit (for example amount of product or service used). The final carbon footprint calculations are done within the scope and boundaries by converting all activity data units to match together, multiplying them by relevant emission factor and adding them together. Most important when presenting the assessment in final stages is to define clearly the functional unit used, what elements were taken into the calculations and what life cycle stages were included. (Muthu 2014).

Use of standards in producing a carbon footprint for a product increases uniformity and transparency. The carbon footprint standards are based on ISO 14040/44 standard on full life cycle assessment. Known standards are GHG Protocol; Product Life Cycle Accounting and Reporting Standard, Publicly

Available Standard (PAS) 2050 and product-based ISO 14067: Carbon footprint of products standard (Muthu 2014).

As a well-known indicator, carbon footprint has limitations and problems. Data quality has an important role in achieving reliable carbon footprint and it starts in the LCA stage. The primary data received from manufacturing company can be manipulated in order to gain favourable results and therefore validation from secondary sources, like previous calculations or literature findings, are important. Established boundaries for the LCA should be considered from their versatility since all of them cannot be tested and validated. Not all machineries or articles are standardized and applicable for using conventional energy and renewable applications, let alone every country has its own available energy source, complicating the calculations of global supply chain emissions. The assessment of the impacts of all the life cycle stages require knowledge how a specific action can affect the environment. (Jha et al. 2021) Comparing the results is difficult since each study has its own boundaries, assumptions and scope which mean that it is not possible to generalizing the emissions for a specific industry or a product (Muthu 2014). Emission factors, on which the calculations are based on, for a textile industry, are varying depending on country of origin and time when the factor is created (Gaib et al. 2021, 64). Supply chains for textiles are long and fibre materials are usually mixture of fibres from different origin, often forcing the use of average values.

Carbon footprint is a calculation of generated greenhouse emissions of a product or company operations, but leaves rest of the impacts for environment without processing. Textile industry and especially different textile fibres have different impacts on environment. Water footprint would give different perspective on different fibres, since some of the need more water in cultivation than others. Land use varies a lot depending on fibre as well as chemical demand in different stages of life cycle. Focusing on one impact ignores the other impacts that might be even more significant ones leaving the overall picture of the environmental impacts one-sided. Significance of assessing products or process carbon footprint should be considered as well.

For Nextiili ry calculating carbon footprint of their business would tell how much emissions has been released by heating the building and transportation of textiles to recovery in Paimio, energy recovery and other reusable retailing businesses, depending on the boundaries established. The carbon footprint of different years could be easily compared but its meaning might be lost for customers and other stakeholders. By refraining the calculation of the carbon footprint alone, it did not give an overall picture or exhaustively express the benefits of Nextiili ry processes of sorting EOL textiles to different fractions.

3.2.2 Carbon handprint

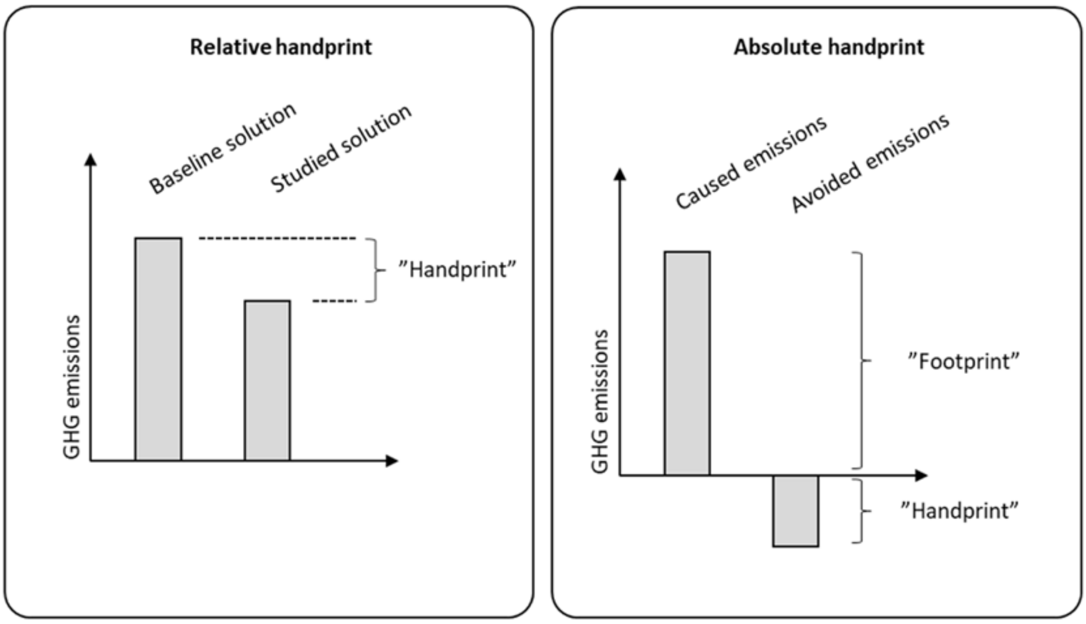
More unknown and rarely used concept of carbon handprint, which most of different sources describes it as positive effects done to the environment. The carbon handprint guide by VTT Technical Research Center of Finland Ltd. and LUT Lappeenranta-Lahti University of Technology defines carbon handprint an indicator of climate change mitigation potential, where greenhouse emission reduction happens when customer switches the basic product with a handprint solution (Pajula et al. 2018). In earlier VTT report by Behm et al. (2016) defines carbon handprint in basic principles: the delivered benefit and the good we do (Behm et al. 2016, 4). Handprint thinking, by Guillaume et al. (2020), arranges the idea on three principles; first to encourage making actions that have positive impacts, second emphasis is in the fact that despite of creating handprint by calculating footprint, it also adds value to them and third in the type of actions needed to be taken. The added value has a more abstract level, since handprint can be seen as doing good and the observation is directed on the actions done rather to the results. Because handprint cannot be used only as descriptive way, assessment on the type of actions considered to be done will require consider ethical implications and reflection for alternative decisions. (Guillaume et al. 2020).

Handprint assessments are based on the carbon footprint and further to the LCA procedure (Pajula et al. 2018, 18). Therefore the benefits of describing products, process or services carbon handprints include the same features; like utilizing it to product development, strategic management or in reporting and marketing. Whit the handprint and positive communication, companies can begin to take more leading roles in bringing solutions to climate change problems and to promote environmentally better solutions. (Behm et al. 2016, 14).

Bigger carbon handprint numbers can be achieved in making changes in material and energy usage, products performance features, reducing waste or creating carbon capture and storage solutions. These changes can be achieved for example by replacing non-renewable materials, increasing energy efficiency, prolonging products lifetime or contributing to reuse and recycling. (Pajula et al. 2018, 10).

The interpretation of carbon handprint may vary. In their article concerning carbon footprint reduction to buildings Kuittinen & Häkkinen (2020) described two viewpoints on how carbon handprint can be seen. The carbon handprint indicates the absolute benefits that are achieved by the actions or changes done by the company or the relative figure to which the new improvement is compared to baseline solution, described in VTT's carbon handprint guide (Kuittinen & Häkkinen 2020; Pajula et al. 2018). Figure 4 displays the separation between forming relative and absolute handprint.

FIGURE 4. The two ways of seeing the carbon handprint; relative and absolute handprint (Kuittinen & Häkkinen 2020) (modified)



Because of the nature of different products and situations, it may become necessary to describe carbon handprint by other means. Absolute handprint, like in the Figure 4, represents avoided emissions during the products lifetime. Kuittinen & Häkkinen justified their use of absolute handprint by the long service lives of buildings. Relative handprint offers positive value received by comparing to reference product during specific timeline and therefore creating handprints that are valid only the time of the calculation. For a building the forming of relative handprint where the comparison between the baseline solution and new building would make the handprint value decline rapidly and it would not describe truly the life-cycle performance received. Whereas forming of absolute handprint the benefits could be described as those that could not be formed without the new building. (Kuittinen & Häkkinen 2020).

Relative handprint consists of either forming a solution which lowers the carbon emissions compared to the baseline solution (alternative or current product, service or process) or the footprint reduction for the customer process with the new solution or both of these are formed. For example food packaging product is produced with lower carbon emission but also the new product will help customers product, the food, be preserved better which lowers the risk of food waste. (Pajula et al. 2018, 11)

The actual assessment of carbon handprint has four stages and ten steps, tightly connected to LCA methods presented in next figure (Figure 5). The first stage requires identifying operational environment conditions so that the baseline solution could be established. The second, third and fourth stages are similar to LCA steps, where other requirements, calculations and communication happens.

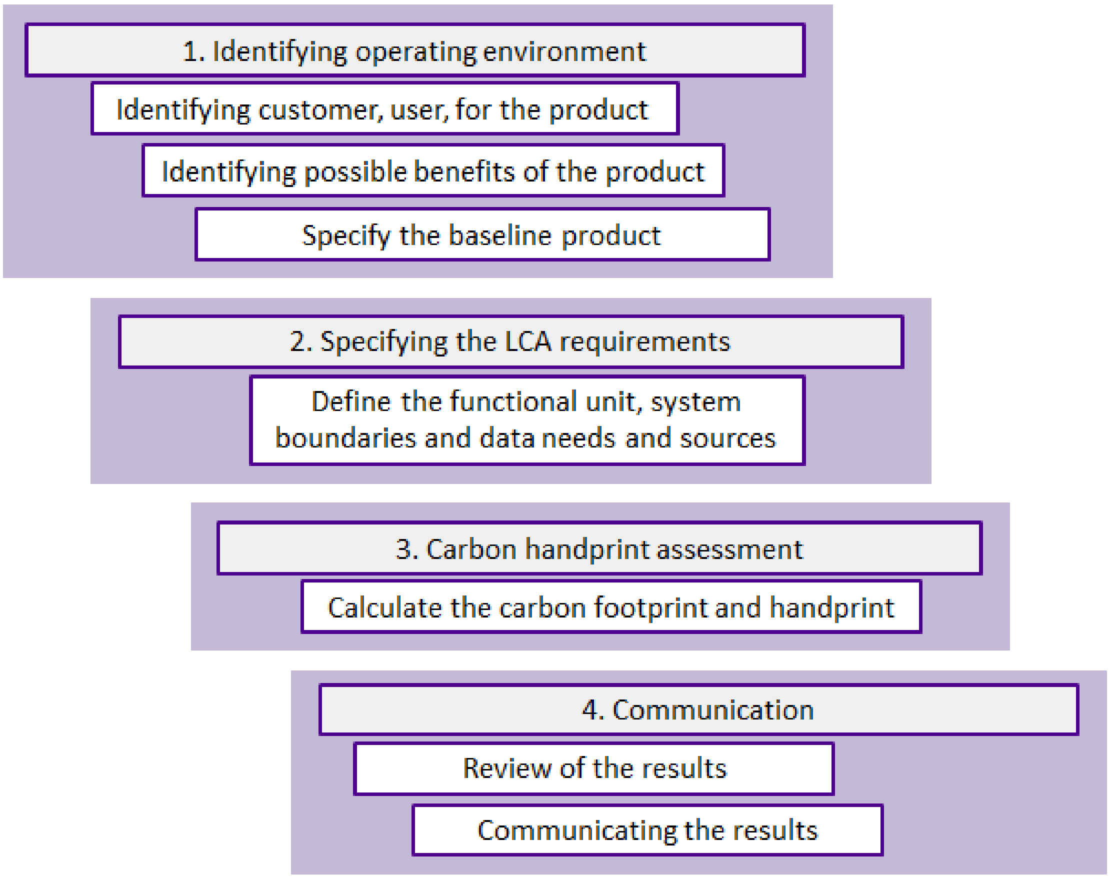


FIGURE 5. The four stages in producing carbon handprint assessment for a product (Pajula et al. 2018, 13)

The first step is to identifying the customer or user for the product which the handprint will be calculated seen in Figure 5. The handprint is formed for a specific situation and user, in order to quantify handprint for one defined product usages situation with its known environmental impacts taking to consideration. The second step is forming an answer for how the new product will reduce customers' footprint. Sometimes factors may change during the assessment affecting the overall estimation and for this preliminary investigation of potential factors and their influence on footprint becomes desirable. There might be several options for the beneficial ways of a new product. By establishing early the most significant reducer of emissions, helps also to decide the baseline product and boundaries specified in the next step. (Pajula et al. 2018, 15 – 16)

Last step in the first operational environmental identification stage is to establish the baseline product in order to make the comparison and receive the reduced emissions. The baseline product can be current or alternative one that has the same functions as the assessed product. If the assessed products, the handprint solution, is new on the market, both of the products should be used for the same purpose, perform the same function, be used in same specified time and geographic region and be available in the market and to be estimated the same consistently manner. When choosing the baseline, transparency and meaningfulness should be considered since there is possibility to select environmentally worst kind of product in order to receive higher handprint result. (Pajula et al. 2018, 16). The next stages and steps follow mostly the same way as in the assessment on the carbon footprint. The actual calculations of carbon handprint, in stage three, is demonstrated in next table (Table 3)

TABLE 3. Carbon handprint calculation formula (Pajula et al. 2018, 20)

$$\boxed{\text{Carbon handprint}_{\text{product}} = \text{Carbon footprint}_{\text{baseline}} - \text{Carbon footprint}_{\text{handprint}}}$$

→

$\text{Carbon handprint}_{\text{product}}$ = Assessment of footprint reduction achieved by product used by the customer
$\text{Carbon footprint}_{\text{baseline}}$ = Footprint of the baseline product used by customer
$\text{Carbon footprint}_{\text{handprint}}$ = Footprint of the new handprint product used by customer

Forming of the carbon handprint relay on the accuracy of footprint calculations and making the LCA, and therefore the problems, on making footprint assessment are the same than in the forming of handprint. The definition also creates its own challenges. As a relatively new concept, the usage of handprint evokes multiple views on the matter. But also the definition of footprint has challenges, since it also covers emissions and removals and so it might raise a question on where handprint would be needed (Häkkinen et al. 2021, 84). Defining the baseline, on which the comparisons are made, requires comprehensive understanding of the purposes of calculations. In the beginning, it is important to define the responsibility of shared impacts, since handprints may overlap in customer chains creating risk for double counting of the same issue. (Behm et al. 2016, 16). As in the calculation process of the carbon footprint, the choices, definitions and establishing boundaries create variability in the results. This also is the case in the handprint assessments and resulting of poorly comparable results. (Guillaume et al. 2020).

Nextiili ry has interest on measuring benefits of their business concept and activities done towards that. Carbon handprint seems to give understandable concept of describing them. However, there are fundamental questions regarding the possibility on creating handprint for Nextiili ry. If the baseline would be a new garment and handprint product would be a used old clothe provided by Nextiili ry, the handprint would be the avoided amount of carbon emission in producing new clothe minus the small amount of company carbon footprint. This would create a handprint for one item. In the case of describing the benefits of Nextiili ry processes, the customer to whom the carbon reduction would be generated, is the society or textile and clothing trade. The footprint reduction would be formed by the amount of sorted textiles that are reducing the amount of new products been produced to the markets or for the society. The sorting of EOL textiles to recycle would have different customer and baseline product and the definition of which seems more difficult. Should the customer be the recovery pilot plant in Paimio to whom Nextiili ry provides sorted textiles? Then the baseline would be the non-sorted EOL textiles that Paimio receives. Or should the customer be the company utilizing recycled textile fibre purchased from Paimio pilot plant? In that case, the baseline would be a new fibre from virgin materials. This scenario would need more information form Paimio recovery plant in order to establish the handprint. Could the calculated benefits of carbon emissions reduction be called as handprint or are they just the estimated amount of reductions on future emissions?

4 NEXTIILI RY

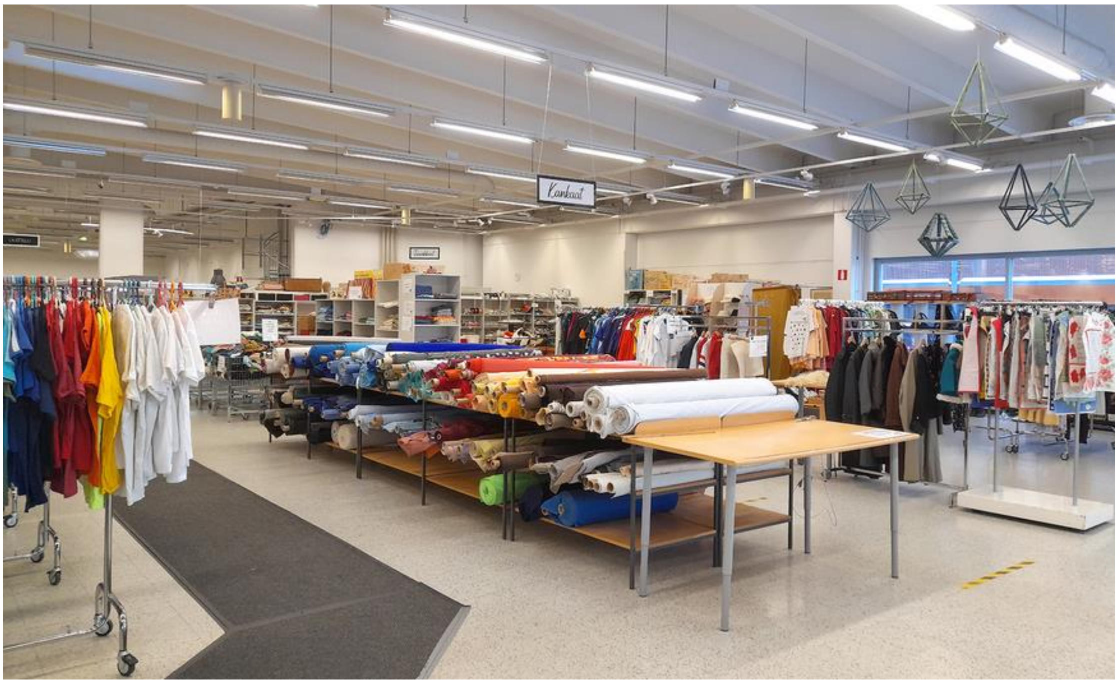
4.1 Company profile

In spring 2011 first recycling center was established in Nekala by the non-profit association, Pirkanmaa kierrätys ja työtoiminta ry, recycling and employment association. It was founded to provide households and communities in Pirkanmaa area an easy and reliable channel for recycling goods, like furniture, electrical appliances and hobby equipment, and other materials. Operations expanded rapidly and new recycling centers were established and new partners joined the operation. In 2015 Ekokumppanit Oy (Ecofellows Ltd) suggested the association to set up separate textile recycling unit, which formed textile workshop Nextiili. (Pirkanmaan kierrätys ja työtoiminta ry 2020).

Starting on October 1 in 2015 as part of the Pirkanmaa kierrätys ja työtoiminta –association, Nextiili workshop’s core activity is to accept donated materials and continue to donate and sell the discarded textiles and other materials. Increased donations and desire to strengthen expertise in circular economy, Nextiili differed from Pirkanmaa kierrätys ja työtoiminta association to its own association in January 2021 and Nextiili ry was founded. Nextiili ry is located in Lielahti. (Nextiili ry 2022).

Together with Pirkanmaan jätehuolto Oy, Nextiili ry started a pilot for a separate collection of end-of-life textiles in Pirkanmaa area with two weeks test batch in November 2020 and from December onwards as a continuous collection. To Nextiili the pilot consist of accepting end-of-life textiles, sorting them according to fibre material; cellulose, synthetic, wool and mixed fibres and packing the sorted items for transportation. Pirkanmaan jätehuolto, PJHOY, transports the material to Paimio, LSJH EOL textile refining pilot plant, to further recycle the textiles. LSJH refining plant takes payment according how the EOL textiles are sorted. More precise sorting of textiles leads to lower gate payments for the collector. PJHOY is responsible for the transportation and for the gate payment. This pilot continues to end of the 2022 and during that time information is collected on how the separate collection is working and what changes might need to be done before the national separate collection of EOL textiles starts in year 2023. At the moment Nextiili ry is the only operator in Finland that sorts the EOL textiles to separate fibre material fractions. (Tuomaala 2021).

Nextiili ry accepts household donations of clothes, textiles, shoes and accessories, handcraft materials and related supplies to the Lielahti store during its opening hours. Orivesi, neighbouring municipality, has one separate end of life collection bin for textiles in pilot phase. Accepted materials can be broken, but dry and free of mold and pests. Most of the donations in 2021 were reusable items for which further use was sought by various channels as donations or sales to finance the operation. Material in the store is changing according to the donations. Clothes, textiles and handcraft materials are sorted according to purpose, fashion decades or otherwise at the store as seen in this picture (Picture 2). (Koskue 2022; Käppi 2021).



PICTURE 2. Nextiili ry store view (Koskue 2022)

Nextiili ry has expanded to online store where vintage items from donations are sold. The sorting of donated textiles and other materials happens at the back of the store, where the primary task is to implement the waste hierarchy and so to find reusable and resalable items. Staff has been educated to identify vintage clothes and accessories that have resale value in the store or online.

Discussions on whether some item has resale value or is vintage, happens often among all of the staff. Other sorting fractions to reusable items are collection to separate destination, like for an art project where a certain type of material is sought. Items for other operators, UFF foundation and Dafecor company, also happens in the sorting stage. (Tuomaala 2021; Käppi 2021).

Nextiili ry employs all together 10 people, only two on the store side, 8 in the sorting stage. Two employees are sorting textiles for the store and six in rest of the reusable sorting. Three staff members are working on sorting the recycling textiles for the pilot and one is responsible for logistics. The store itself requires staff for maintenance tasks, selling and store management. Idea behind the founding of Nextiili was employing at low threshold, which means giving a chance for employment for disabled-, mental health-, partially able to work- and for people requiring rehabilitative work in order to increase opportunities for further employment. Most of the employments are subsidize work. (Tuomaala 2021)

4.1.1 Circular Economy

Where the prevalent linear economy model maintains behaviour of producing products that are, after some period of use, disposed, circular economy, CE, focuses on transforming the need of producing growing number of products by replacing it with provision of service and recycling thus making the products circulating in constant loop (Sitra 2022). McDonough and Braungart simplified all planetary material flows to be divided into either biological or technical nutrients. In these, biological nutrients follow circular model, designed to re-enter the biosphere and build the natural capital. Technical nutrients, like industrial products, on the other hand, are taken from the natural capital and through recycling, remanufacturing, reuse and maintenance, all actions associated with circular economy, are kept in circulation, preventing them ending up as waste in the biosphere. (McDonough and Braungart 2002, 93; Ellen MacArthur Foundation 2013, 22 - 24).

The circular economy diagram, also known as the butterfly diagram, seen in Figure 6, describes the circulation described by McDonough and Braungart in their book Cradle to Cradle and illustrated by Ellen MacArthur Foundation. The diagram describes how materials are kept in the circle. Keeping products in the circle as long as possible would require changes in the entire operating system, starting from the design of a product; products should be designed to be in the circle and not waste, durable and reusable and for the energy used in production to be renewable. Ownerships of products would also require a new perspective. Consumers would need to be considered more like users and the products more like services owned by manufacturer or retailer, and returned to the circle after its use. (Ellen MacArthur Foundation 2013, 7).

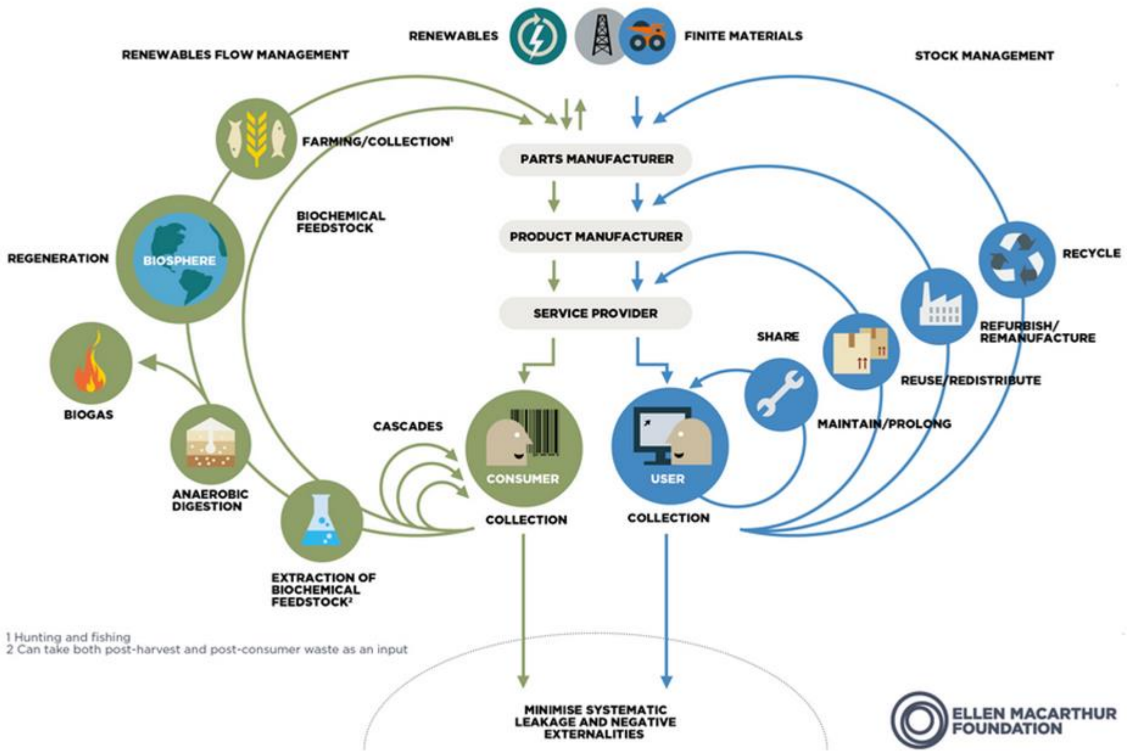


FIGURE 6. The Circular economy diagram of circulation of biological and technical nutrients (Ellen MacArthur Foundation 2022) (modified)

Nextiili ry is a circular economy enterprise working on collecting reusable and recyclable end-of-life textiles and continuing their circle by selling and sorting them for recycling. For Nextiili ry, sustainability is keeping textiles in circulation according to the order of the waste hierarchy, being responsible, ethical and transparent textile recycling operator and thoughtfully sorting and using the donated material. Educating new experts in textile sorting and actively participating in the reform of textile circular economy by taking part in different projects are important ways in ensuring to route the EOL textiles according to the waste hierarchy based on researched information and continuous evaluation. As a member of textile industry, following social sustainability has important role as well. Cooperating with the donators, employees and customers enables successful communication, efficient work and thriving service experience. For Nextiili ry, important community goals are ecology, equality, helping others, fairness and enabling development of work and work community. (Nextiili ry 2022).

4.1.2 Future of Nextiili ry

Nextiili ry receives used textile donations to their own store, from Orivesi separate textile collection bin and soon the textiles will also be collected from Nekala waste station in Pirkanmaa region. This will slightly increase the material flow, but most likely this increase will not make drastic changes in Nextiili operations at the moment.

The contract between Nextiili ry and PJHOY about the separate collection, sorting and transportation of EOL textiles to the textile recovery pilot plant in Paimio expires at the end of 2022 and the plans for 2023 are still open. According to Waste act (646/2011) municipalities have the responsibility of receipting EOL textiles and PJHOY handles the waste management service on behave of the owner municipalities. It has not yet been decided which operator will receive and sort the EOL textiles at the beginning of 2023. Also it is unclear what kind of reginal collection meets the requirements of law and what that would mean for the selected operator. The selection of using subcontractor, like Nextiili ry, to handle the EOL, is possible but plans are also affected by the EU Textile Strategy and the possible Extended Producer Responsibility (EPR) that would affect possible investments and plans made by municipals. (Ojala 2022).

For Nextiili ry the selection of handling EOL textiles in Pirkanmaa region brings not only increase of material flows and increase of responsibility, but it might demand a change from association to a company. Chancing into a company has its own requirements and would affect the employment contracts, making it possible to offer full time contracts to employees. (Tuomaala 2021).

The material flows for 2023 are unknown. The potential amount of EOL textiles for shorting could be the amount that ends up in energy recovery form households. In 2019 the amount from households was about 40 000 tons of EOL textiles in Finland, seen in Figure 1, but that figure also includes the textiles that belong in this category (Dahlbo et al. 2021, 23-26). For Pirkanmaa, the share could be smaller, but drastically still larger that the EOL textiles reused or recycled at the moment. How would the year 2023 and national separate collection of EOL textiles influence citizens in Finland to sort their textiles is also a mystery. For the possible EOL textile separate collection operator it would mean increase in employment, need to invest automation lines, large sorting halls and effective transportation network.

4.1.3 Wieland Textiles B.V.

Founded in 1984 in the Netherlands, Wieland Textiles B.V. operations include purchase of collected textiles, sorting and selling them further. This company in Europe operates partially in same way as Nextiili ry in sorting the textiles, but in larger scale. Wieland Textiles handles about 8 800 tons of discarded textiles yearly purchased from collection companies, such as Salvation Army Reshare and sorts the material in pre- and post-sorting to reusable and reusable raw material fractions. In the pre-sorting stage, materials from the conveyor belt are sorted into waste and reusable items, which are further sorted to numerous different fractions depending on the product, fashion and type of garment. The textiles left on the conveyor belt are sorted by help of optical technology to 45 different fraction categories by fibre type, colours and structure, to be further processed by removing zippers and buttons by cutting and by automated cleaning. The result material can be used for mechanical and chemical recycling. (Wieland Textiles 2022).

Compared to Nextiili ry operations Wieland Textiles removes wet textiles from the material flow in the pre-sorting stage and partly dries them and returns them to the usable textiles to then be sorted again, enabling some of the unusable textiles to be utilized and reducing the waste amount. Wieland Textile estimates that 15 % of material coming to the company belongs to waste fraction. Nextiili ry energy recovery fraction was in 2021 about 20 %, which compared to

Wieland was higher, but Nextiili also discards wet textiles due to hygienic reasons. Wieland Textiles main markets for reusable textiles are in Africa, Asia and Eastern Europe. (Wieland Textiles 2022).

Wieland Textiles describes their sustainability performance by explaining some of its advantages in offering reusable textiles over new textiles which realized as reduced environmental impacts. In addition to this Wieland gives estimation on positive environmental impact by referring to the amount of upcycled second hand garments in 2017, 3 978 tons of material which was roughly 15,9 million pieces of clothes. Assuming that prevention of selling three new clothes equals about 57 kg CO_2 emissions per year and assuming that new clothes can be replaced by reused one, makes the Wieland's operation involved in reduction of 302 kiloton of CO_2. This amount was estimated to be 35 % of Zeenstad municipality's total CO_2 emissions. (Wieland Textiles 2022). Wieland describes their sustainability activities understandably but very shortly and with few assumptions to explain the situation. For the reader pictures and charts can make the description more interesting than just writing the situation with few sentences. Like in any published information, the use of source entries creates credibility and transparency. The description of sustainability performance of Wieland's operations has been a practical solution for a small enterprise to get attention to the good sides of the business idea by using only a few numbers.

4.2 Processing method

Nextiili ry receives end-of-life textile donations from customers during the opening hours. Smaller portion of donations come from other companies, associations or industry. Orivesi has one separate end-of-life textile waste collection bin, which is being emptied once a week achieving 3 cage trolleys of material (Käppi 2021). This pilot collection place is located under roof but outside, which increases the risk of possible condensation damaging the quality of the material. Customer donations are usually packed in plastic bags which are then carried from front to the back of the shop. The bags are opened and textiles are taken one by one for review on the table, seen in the picture (Picture 2). There is no weighing of incoming material.

PICTURE 2. Pre-sorting table for donated textiles in Nextiili ry

The sorting of textiles starts at pre-sorting stage which is followed by the first order of precedence. Two sorters from the store side (recycling center) are sorting reusable textile items from the material. Reusable items are those that have potential of being sold, vintage and retro clothes, brand items like Marimekko and Nanso, even if they are not in perfect condition and Muumi-textiles, all of which are in high demand. Separately asked textiles are also taken side from the material. These types of separately collected items are for artists, animal shelter, congregation or other individuals that have raised interest on specific textile items. For this, long-term collections projects are recommended for the smoothness of the process. Pre-sorting stages includes also visual and odour-based inspection, where only dry, mould free and items included in the collection continue further in the sorting as dirty and wet items are discarded to energy recovery fraction.

In the pre-sorting stage the further sorting for reuse and recycling happens simultaneously. Two other employees start the sorting of textiles in order to identify material to reusable, recyclable and energy fractions. Sorting is partly team work, since there are no specific standards on what is considered as vintage, what has potential to be sold and what is better to be put in the energy fraction. The sorting to reuse and recycling is the line determining if the material is going to the last stage, material sorting. Items that are sorted to be reused are clothes that have working zipper, but maybe one button missing. These items are further sent to UFF. Items that are sorted to go in recycling are clean, but can be damaged. No high hygiene risk products like underwear are going to the recycling fraction. One employee has the responsibility for the logistics. This includes transporting filled plastic bags of different fractions to their designed places. These blue plastic bags are seen in the picture 2.

The textile material that was identified as EOL textile in pre-sorting stage are those that are further sorted according to different fibre types at different table, seen in next picture (Picture 3). Classification to material compositions happens visually, by touch and sometimes by means of a combustion test. This stage needs more educated sorters and in this stage there are two employees classifying recyclable textiles into their own plastic bags.

PICTURE 3. Sorting of EOL textiles according to fibre type in separate table

Classification for the EOL textiles forms cellulose, synthetic, wool and mixed/or other fractions. The cellulose fraction includes textiles and clothes manufactured from cotton, linen and viscos fibres with pure composition or textiles with small impurity of other fibre like elastane or textiles mixed with synthetic fibre up to 75 % of cotton mix ratio. T-shirts, tablecloth or jeans are good example of textiles in cellulose fraction. Synthetic fraction consists of “man-made” fibres like polyester and polyamide. These materials are usually used in technical textiles or in sportswear. Wool faction contains wool mostly from sheep, since other animal fibres, like cashmere or angora are rare. Mixed or other fraction has more heterogeneous content. It includes textiles with obvious mix ratio, like 65 % of polyester and 35 % of cotton and textiles that cannot be clearly identified belonging in previous fractions. Separate fractions in their designed bags were collected and transported by PJHOY to textile recovery pilot plant in Paimio 4-5 times a month in year 2021. (Käppi 2021; Nextiili ry 2021)

The sorted fractions for recycling are first transported to LSJH textile sorting hall in Turku, where EOL textiles from other sources are handled as well. From the textile sorting hall, the desired material fraction goes to the pilot plant in Paimio to be transformed to fibre form. The sorting in Turku is also done to the main four fractions, but small batches of specific fibre, like pure cotton, can be identified from the lot and processed separately in the pilot line to form cotton fibre for client. For this hand held NIR sensors are used for assistance. In year 2021 Nextiili ry’s sorted EOL textile material accounted for less than 14 % of the at least pre-sorted EOL textiles delivered to LSJH and ending up in the pilot plant. Most of the material sent to textile recovery gets to be processed to fibre form. Some quality inspections are done to ensure dirty, damp or mistakes in sorting phase to not ending up in the process. In the process line 5 to 10 % of material gets removed by taking out zippers, buttons or other harder parts from the textile. The material from Nextiili ry is processed in Paimio and further utilized in chemical recycling, yarn manufacturing, making rags and as material in composites. The markets in Finland are still quite small for recycled fibres so the material form Nextiili ry would most likely end up in foreign markets. (Pokela 2022).

5 RESULTS

5.1 Literature review

Efforts to find a suitable way to express the environmental benefits of Nextiili ry's processes in sorting textiles into reusable and recyclable fractions resulted in the expression of avoided impact. This expression seemed to describe the benefits understandably and utilize well known indicator; carbon footprint. The results could also be described as carbon handprint if it would be desirable to modify its definition to suit the Nextiili ry case. To form avoided impact assessment figures of emission factors and carbon footprints of the most used fibres and textile products were needed in order to establish a reference product. Since there was no possibility of obtaining primary data of different fibres or clothes life cycle emissions, or accessing emission factor database, literature review was conducted. The findings on fibre emission factors and textile products sources and figures are described under following titles. Gained values are summarized in Figures 8 and 9 and explained in more detail in Appendix 1. Calculations of the avoided impact are in chapter 5.3, to which Nextiili ry's data from in Table 7 and values of literature review in Figures 8 and 9 where fitted to form estimation on the avoided impacts of that year.

Textile industry has multiple environmental impact sources and following greenhouse gas, GHG, emissions gives one sided, but indicative image of the situation. Typically the carbon footprint estimations starts with the determination of products life cycle in order to calculate the overall emissions created in different stages. LCA being the most used method; it usually starts from raw material cultivation or extraction and ends up in the end of life stage. Variations in the estimations are caused by the raw material, fibre type, methods used and the end product manufactured from the fibre. All of these variabilities affect the carbon footprint calculations and complicates possible comparison between different fibres or textile products. Next figure (Figure 7) has a short introduction to the main steps in the manufacturing of a textile product, which are usually included in the emission calculations.

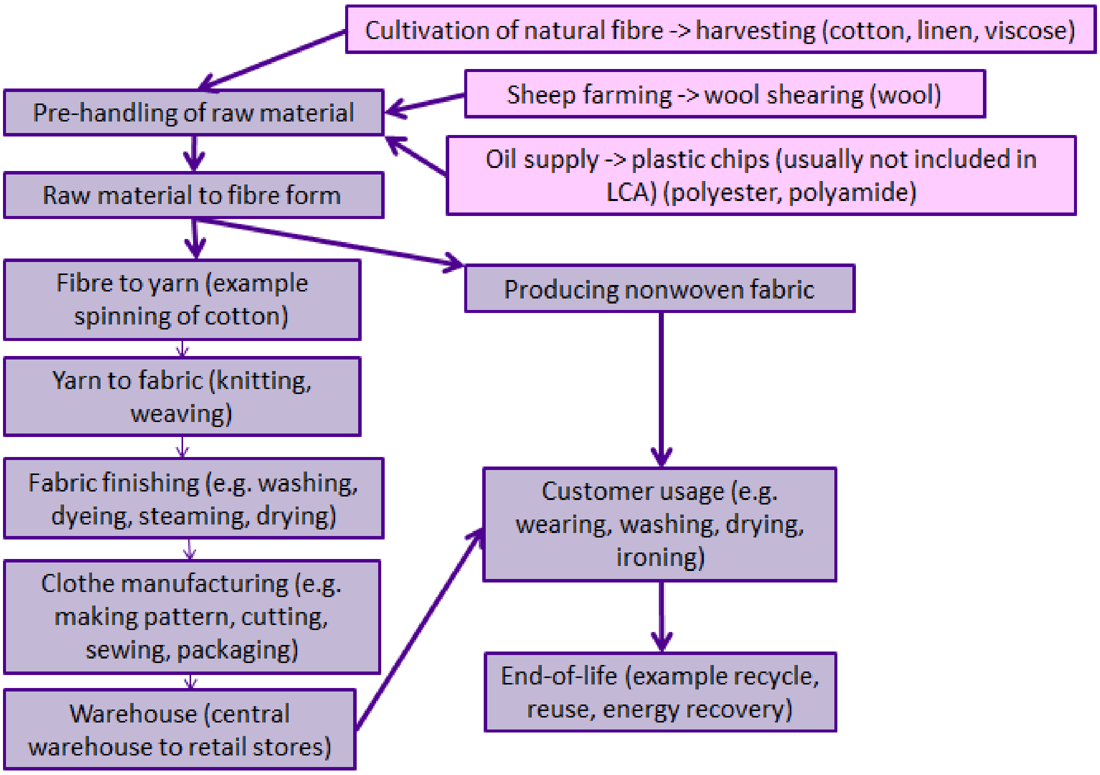


FIGURE 7. The main stages on forming textile product out of most common fibre types. (Muthu 2014)

Natural fibres such as cotton or wool require land to be cultivated or farmed. This stage usually requires water, fertilizers and pesticides. They also require pre-treatments to remove debris and dirt before fibres can be further processed into yarn. Synthetic fibres like polyester come from non-renewable resource, fossil fuel, needing processing first into plastic chips before fibre formation. The process requires more energy in production stage than natural fibres. The machinery used in fibre to apparel production requires energy. Emissions formed by this process are depended on the country's energy mix and on provided sources of energy and on machinery efficiency. The transportation of product to different factories, warehouses and retail stores, possibly in different counties, bring their own addition to the amount of emissions. Most of the studies used as reference in this thesis conclude that from the carbon footprint point of view, the most significant emission impact is generated during the use phase of the textile product (Muthu 2014). This means washing, drying and ironing of textile product after usage and this varies according to the user behaviour and the fibre type in the product. Also depending on consumer behaviour is the end of life stage. There are few options for a product at the end of its life cycle all of which has their own environmental impacts.

Diversity of chosen functional units, boundaries, assumptions, reporting result format and different standards or methods used affect the comparison between products or fibres' carbon footprint results. Studies that lack explanation on used methods, boundaries or stages included in the calculations reduce their reliability. Lack of reliable data or complete absence of data makes it difficult to form carbon footprint. (Muthu 2014). Regardless of the variabilities and difficulties, some of the carbon footprint studies have been reviewed for this thesis and inaccuracy has been accepted in order to determine the calculations for Nextiili ry.

5.1.1 Used sources

In order to increase the reliability of the figures, used in the calculations, efforts were made to find carbon footprints and emission factors from several sources and to form an interpretation out of them. The sources were found by internet search and by using library search program. The sources had been published in scientific books or in professional journals. Most of the studies and their findings were from secondary sources, from collections of findings from several origins or from older studies in which the original source was not found. The next table (Table 5) has a short description of the used sources. Some sources had more descriptions of the methods, boundaries, and of the product used in their research, but some had narrower description of the study conducted.

TABLE 5. Short description of the sources where the carbon footprints or emission factors were found

Source	Short description
(Benton et al 2014, 75)	JRC Scientific and Technical Report conducted in 2006, published 2014, for European Union contain emission estimations for produced fabrics. ReCiPe – hierarchy perspective was informed to been used in the LCIA methodology. Data was collected from Ecoinvent 2.0, Wisard 4.2 and PlasticsEurope databases. Because of the object of this study was in identifying the market shares of textile products in EU-27 and in comparing potential impacts of textile products consumed in EU-27, the emphasis was not in the accurate determination of differences in fibre origin or in fibres processes. Estimations were kg CO2 per 1 kg of fabric.
(Bevilacqua et al. 2012)	In this case study, merino wool sweater was studied by using Simaprò software, the Ecoinvent database, and primary data from production phases. ISO 14041 was the used standard and calculations were made according to IPCC 2007. The study also compared the impacts of different transportation option on emissions. Uncertainty in the results; was the figures only CO2 or CO2e?

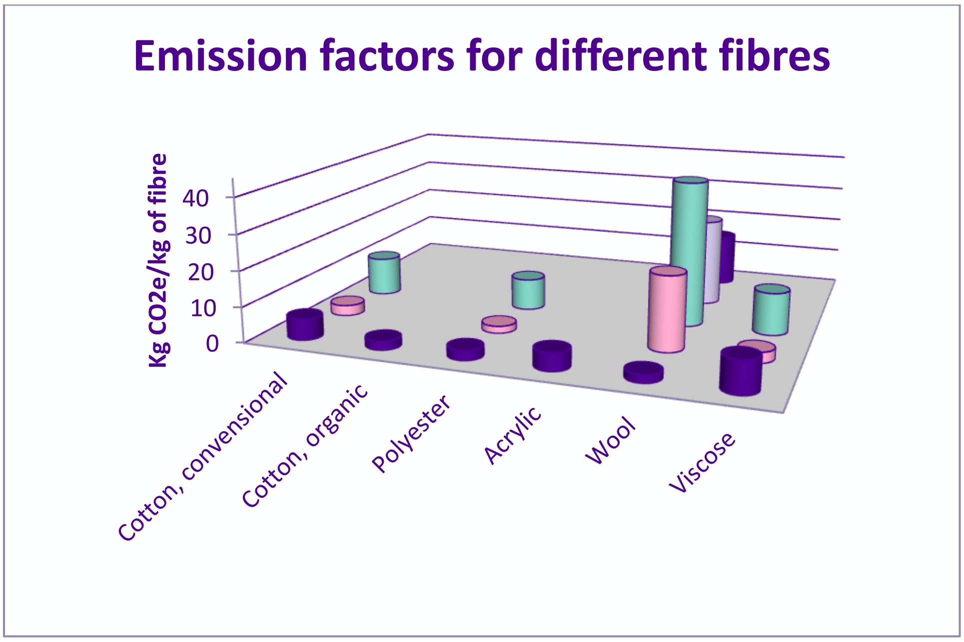
(Cherrett et al. 2005)	In 2005, on behalf of the Bio Regional Development Group, the Stockholm Environment Institute studied the emissions emitted by cultivation and fibre production stages of different fibre types. The result was that the synthetic fibre emits more CO2 emissions than natural fibres. Only CO2 emissions were calculated by following the energy consumptions.
(Gaib, A. 2021, 35)	Study of Finnish textile and fashion industry's climate impacts in relation to global value chains. The emission factors for different fibre types were taken from emission database OpenCO2.net and Ecoinvent which both include various sources. The findings were represented as circles whose magnitude reflected the variability and uncertainty of the values
(Gracey & Moon 2012, 59)	A research report studying the estimations of carbon, water and waste footprints of clothing during its yearlong life-cycle in UK. The purpose of the research was on finding reduction opportunities on the clothing value chain. The study does not include the emission estimations included in the LCA concerning the study boundaries and how the footprint calculations were made. The estimations include emissions during the usage stage. The washing and drying was conducted by standard way and does not take into account the different washing instructions for various fibres. Estimations expressed as tonnes of CO2e per tonne of fibre in clothing indicating that the variable attribute is the fibre in readymade clothing
(Henry et al. 2015, 223)	This is a study of emission estimates for wool fibre production emissions in Australia. Study concluded that if the estimation was economic allocation between wool and meat the emissions for wool fibre are higher than if the farming focuses on the meat production. Estimations are done to cradle-to-farm gate.
(Moazzem et al. 2018)	Study of polyester t-shirt manufactured in China and used in Australia. Emission estimation are done on all stages of its life cycle. Conclusion made in the study was that the highest contributing factor was the usages stages (30,3 %) and the second highest the polyester fibre production. LCA was conducted using ISO 14040:2006, the functional unit was a knitted polyester t-shirt used 50 days over one year of its life time. Literature research was used as activity and emission data sources. Same time comparison between energy was conducted to different LC stages.
Muthu 2014 (1.3.1)	Secondary source, no mention of methods. Several studies, several sources.
(Muthu 2014 (3.5.2))	Secondary source. GHG emissions of fibres in their cradle to gate life cycle from various studies. The author had previously made a model determining the GHG emissions from cradle to gate stages to quantify the impacts and used those figures since in following studies.
(Muthu 2014 (9.2.1))	Secondary source. Continental Clothing made a study in 2009 of T-shirt supply chain using PAS 2050:2008 with the aim of finding hot-spots of GHG emissions in the products entire life cycle. The t-shirt was certified as organic and produced in low-carbon environment. Highest impacts were found to be in the user phase (48 %)
(Muthu 2014 (9.2.3))	Secondary source. Study was conducted in 2010 by University of Pretoria on 100 % organic cotton T-shirt manufactured in India and sold in South Africa. The study found that the manufacturing stage had most of the contribution to carbon footprint (88 %). The results were informed as per tonne of t-shirts but converted to one t-shirt as well.

(Periyasamy & Duraisamy 2018, 15)	Study the carbon footprint of denim jeans, manufactured in 2015. LCA was made with ISO 14040 standards in 2016, which included raw material extraction, fabric manufacturing, coloration, garment manufacturing, transportation, retailing and distribution. Also estimations included the user phase impacts which included washing and end of life. The product was men's bottom blue jeans with 98 % and 2 % EL weighing 570 g. Origin of the cotton and usage of the product were in India.
(Rana et. Al. 2015, 153)	Secondary source. A 2010 study by German Systain Consulting on the estimation of carbon footprint of long cotton shirts. Study concluded that the biggest emissions were made by user phase and the manufacturing of shirt. The standards used in the study are not mentioned.
(Zhao et al. 2021)	Study of virtual carbon and water flows of denim products to fill research gaps. Based on literature review of combination of emission factors. LCI of different denim products around the world were conducted by utilizing peer reviews and Ecoinvent (v3.5) database. Suggestions on sustainable future on production and consumption.

The figures found from these studies are under the next title. The source information was recorded as follows; after author and year of publication the page number was informed. Source Muthu 2014 has number sequence indicating title numbering, since the source did not contained page numbers.

5.1.2 Emission factors

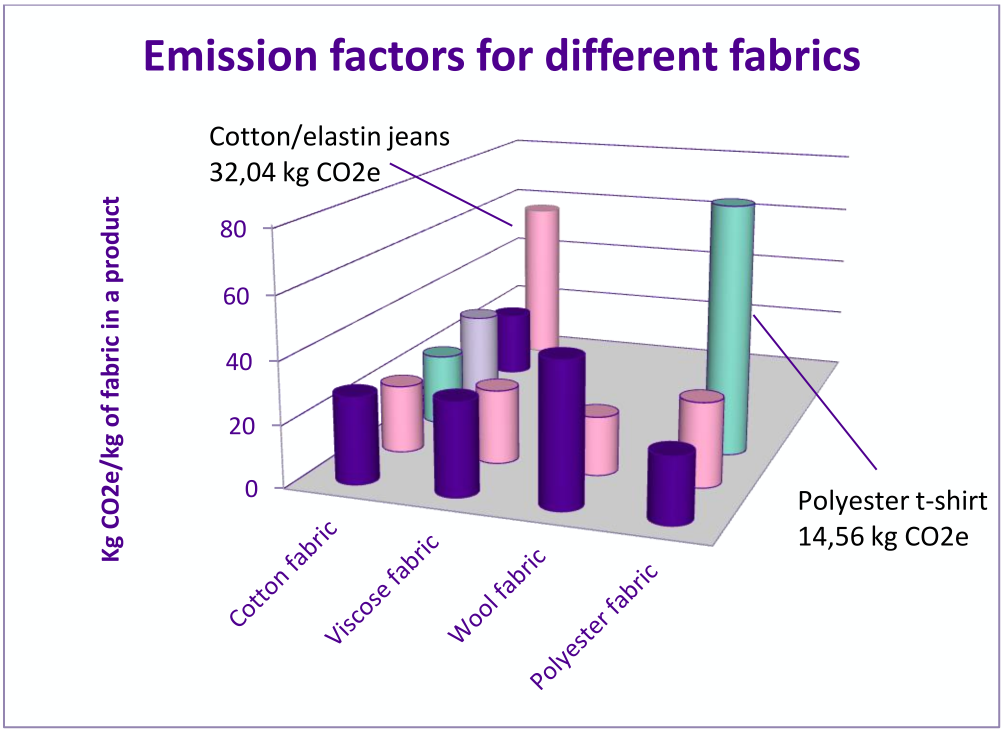
The found carbon footprints and emission factors for textile fibres are presented in the next figure, Figure 8. The figure contains estimations from various sources described visually in one glance. The found values are recorded in Appendix 1 and can be found in the end of this thesis. Since Nextiili ry provides carbon footprint reduction by replacement of virgin fibre material usage and manufacturing a new garment, the life cycle stages of user and end of life phases were not required and were reduced from the whole life cycle carbon footprint, if that was possible for the found values. References for each value used in Figure 8 are found from the table in Appendix 1.



FIGÙRE 8. Carbon footprints and emission factors for different textile fibres. (Various sources)

The main reason for choosing the studies and values used in Figure 8 was the ease of finding the studies. At first glance, studies conducted on cotton products and fibres were more common than studies conducted on other fibre types. Other reason was that cotton, polyester and wool textile fibres were thought to represent the average material flow in Nextiili ry and the emphasis was to find reliable values for them. The usage of other fibre types, like acrylic, in Figure 8 was to give comparison value for the common fibres. As seen in the Figure 8, wool fibres estimations vary lot from small to large emission values. The carbon footprint of wool fibre depends greatly on the calculation method and on the farms primary objective on the fibre or meat production. Because the first value in Figure 8 differs from the rest of the findings strikingly it was not taken into account in the following calculations of avoided impact.

Figure 9 contains emission factors and carbon footprints of fabrics and textile products visually presented. The values used in this are found in the Appendix 1 table where the original sources are also mentioned. Some of the textile products where converted to match 1 kg of textile in a product in order to use them in the following calculations.



FIGÙRE 9. Carbon footprints and emission factors for different textile fabrics. (Various sources)

The estimations taken to this Figure 9 of carbon footprints of textile fabrics and products were varying according to calculation methods. Literature review findings revealed that cotton textiles, products and applications were studied the most since there were lot of figures of them. The deviations, Cotton and elastin jeans, 570 g in the cotton fabric section and polyester t-shirt in polyester fabric where taken into calculations although the figures differed from other findings. The studies behind the values seemed reliable and therefore were considered correct. One reason behind the bigger values might be the cutting waste that was taken into consideration in the carbon footprint calculations for final textile product. Drastic deviations of organic cotton t-shirt, carbon footprint only 1,13 kg CO_2e pre t-shirt and merino wool sweater, carbon footprint of 1,667 kg CO_2e pre sweater, were not taken into calculations since the difference was seen too large and these study values were not included in the Figure 9, but can be found from Appendix 1.

Some studies focused only on counting CO_2 emissions and no other GWP were taken into consideration, making the emission factor smaller than CO_2e of other studies. This made it more difficult to verify the carbon footprint of wool product, for example, as the literature review did not provide any other research examples on the subject with the same functional unit.

5.2 Data from Nextiili ry

During review period of January 2021 to the end of December 2021, Nextiili ry handled about 291 000 kg of textiles. (Nextiili ry 2021) This figure includes only the textiles and clothes donated to Nextiili ry, excluding accessories and other handcraft items. In 2021 Nextiili ry shorted the textiles being sold in their own store, collected textiles to be sent to UFF, to separate collection, to Pirkanmaa kierrätys ja työtoiminta ry, to textile recycling pilot plant in Paimio and to energy recovery. The next table (Table 5) has a short description of the fractions according to which Nextiili ry was sorting the textiles in 2021 and what assumptions there might be in order to create the calculations.

TABLE 5. Fractions of sorted textiles by Nextiili ry and the assumptions made for the calculations

Fraction	Description	Assumption
Own store	Reusable and resalable textile items, mostly vintage and brand clothes	This fraction was considered to be reused 100 %
UFF (U-landshjälp från Folk till Folk i Finland sr)	UFF is a foundation maintaining a clothing collection service in Finland. In 2020, donated textiles were 95,9 % reused or utilized as material. About 80 % of the textiles were directed to wholesale and rest of the textiles were utilized as material, sold in the store, directed to energy recovery or donated. The wholesale customers are in Finland, Baltic countries, Russia and Asia. (UFF 2020). Clothes collected to UFF are reusable, but not the best quality. Items can have missing buttons, but working zipper (Käppi 2021).	Although the information on the share of reuse in the wholesale cannot be verified, it was assumed in this thesis that material guided to UFF to be reused 100 %
Separate collection of textile	Separately collected textiles are previously requested materials to be collected by Nextiili ry for example art or hobby projects	This fraction was considered to be reused 100 %
Pirkanmaa kierrätys ja työtoiminta ry (Recycling center)	Reusable and resalable textile items	This fraction was considered to be reused 100 %

EOL textile recovery pilot plant in Paimio	EOL textiles are sorted to four different fractions; Cellulose fibres (cotton, linen and viscos), Synthetic fibres (polyester, polyamide), wool fibres and mixed and other fibres. 5-10 % of material was waste that was removed in the pilot line. Removed items are buttons, zippers and so on. (Pokela 2022)	This fraction was considered to be recycled 100 %
Energy recovery	Depending on the pre-sorting done by households and proper storage of the textiles, some of the material was not suitable for reuse or recycling and therefore was sorted as mixed waste for energy recovery	This fraction was considered to be utilized as energy 100 %

The data of sorted textiles amounts were received from Nextiili ry. Nextiili ry tracks monthly the amounts of textiles and their allocation. The figures represent distribution of textiles and not sales, so at this stage they do not replace the production of new material. Figure 10 describes the distribution of textiles in different shares in 2021. EOL textile recovery share was further subdivided into different fibre volumes during the year. Table 6 has the same distribution in numeric values.

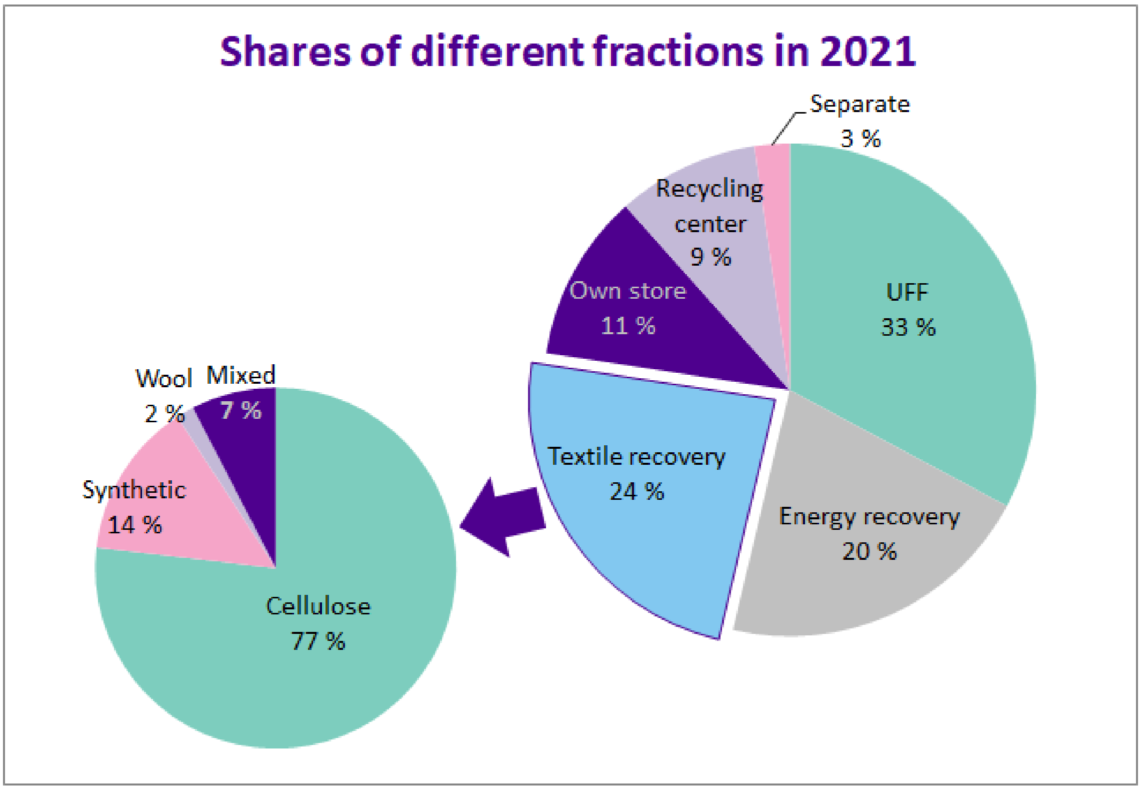


FIGURE 10. Textile material distribution to different shares in 2021 (Nextiili ry 2021)

TABLE 6. Textile material distribution in different shares in 2021 by kilograms (Nextiili ry 2021)

January - December 2021	kg
UFF	95677,1
Textile recovery	69033
Energy	61062,8
Own store	32231,45
Recycling center	26995,1
Separate destinatio	6768,5
In total:	291767,95

Textile recovery	kg
Cellulose	53059
Synthetic	9670
Wool	1072
Mixed	5232

The overall share of reuse consist of donations to UFF, selling items in own store, donations to Recycle centre and the separate textile collection to customers. This will add up to about 55,4 % of sorted textiles which was 161 672 kg of textiles in 2021. The large share of energy indicates that the pre-sorting by households or the elements in separate collection bin in Orivesi have not been successful and the textiles that are considered as waste have been consuming resources in Nextiili ry. The new process of shorting EOL textiles to the recycling pilot plant in Paimio was 24 %. That share would have been previously considered as waste, but now this share had a chance to be utilized as material and not as energy.

5.3 Avoided impacts

Several studies and sources indicate that directing used textile products to reuse have multiple environmental benefits compared only utilizing discarded textiles in energy recovery. Lower benefits will be received from directing EOL textiles for recycling. (Sandin and Peters 2018). To express this, avoided impact estimation for year 2021 was conducted of Nextiili ry operation. According to some understanding the avoided impacts can be considered as carbon handprint since it describes the difference of carbon footprints and the benefits of operations form carbon footprints point of view. But for a handprint to be used as a term requires the calculation of carbon footprint on reused and recycled products according to the carbon handprint guide by Pajula et al. (2018). According to the guide the evaluation requires baseline product and customer to whom the benefit was created. These seemed difficult to form to both of the fractions and therefore calculations for carbon handprint were not conducted.

On the other hand avoided impact result could be viewed as handprint since the idea and unit match the handprint result.

Transportations of material flows are mainly conducted by donors, customers and by PJHOY from the Orivesi collection. PJHOY is also responsible for transporting recyclable fraction to textile recovery pilot plant in Paimio. The large share of energy recovery means that significant amount of waste was transported to incineration plant creating emissions. This could be viewed separately from the calculations of avoided impacts and not taken into consideration at this point. Maintenance of the building; heating, electricity and cleaning, are constant source of impacts and not included to the calculations.

For the calculations of the avoided impacts or benefit of reuse and recycle, an example study was used for advantage. Evaluation of Cooperative Mani Tese -case conducted by Castellani et al. (Castellani et al. 2015) had the same type of situation than Nextiili ry in their desire to express the benefits of second-hand shops in offering reused items instead of new products. In the Mani Tese – case the benefits of different items like furniture and clothes were expressed as avoided impacts of several indicators. The study methodology was formed from WRAP guidelines and according to ISO guideline 14040 and 14044. (Castellani et al. 2015). The case study was used partly as guideline in estimating the avoided impact of Nextiili ry. The terminology and the calculation order were seen as a good guide in building systematic and clear calculations. Nextiili ry avoided impact was the refined carbon footprint whereas the Mani Tese – case study calculated several environmental indicators. Focusing only on the avoided impact of carbon footprint could be seen usable and understandable way of describing Nextiili ry’s benefits. Estimation of the benefits was conducted separately to the reuse and recycle fractions found in the following chapters.

5.3.1 Benefits of reuse

The carbon footprint emissions and the estimation its amount were the avoided impact of Nextiili ry. Estimation was conducted in two phases; first by calculating the average avoided impact of 1 unit of average reused textile product and second by calculating the cumulative avoided impact formed during year 2021 by shorting textiles to reuse fraction. The cumulative avoided impact were formed by multiplying avoided impact of average reused textile with the quantity of years 2021 reuse fractions amount.

Nextiili ry shorts all type of textile products, from light kids t-shirts to heavy men’s leather jackets. The average reused textile product should represent as accurately as possible the year 2021 by weight and fibre composition. As previously descripted in Table 2 of the fibre share in textile waste by Schmidt et al. (2016); and by Dahlbo et al. (2015) estimations on textile waste, an average product can be constructed. According to those estimations one average product would contain 56 % of cotton, 40 % polyester and 4 % of wool with average weight of 250 g.

Inventory data for the forming of average product was descripted in previous chapter 5.1.2 Emission factors and in the Figure 9. The system boundaries include fibre production, fabric production, apparel production and transportation to resale destination which are considered to be the avoided impact phases. Additional impacts are formed by the transportations of textile material by the donators to Nextiili ry and the separate collection bin in Orivesi, which collection share in 2021 was about 3089 kg of textile. The impacts caused by these transportations were considered outside of the study boundaries.

Most of the data collected from literature included the user as well as the end of life phases in their carbon footprint calculations. These were not included into the average products footprint for they are not yet occurred in the products second life cycle. The carbon footprint of Nextiili ry has been estimated to be insignificant to greatly affect the estimated benefits, since operations consist mostly of manual shorting, no changes are done to the products, and the impacts of heating and electricity can be consider being standard. The average product and its carbon footprint can be seen in next table (Table 7).

TABLE 7. The average textile products carbon footprint

	Share of AP	Average carbon footprints	Average products carbon footprint	
Cotton	56 %	30,01 kg CO2e / kg of textile in a product	16,805	
Polyester	40 %	43,03 kg CO2e / kg of textile in a product	17,212	
Wool	4 %	32,5 kg CO2e / kg of textile in a product	1,3	
		1 kg of AP	35,31	CO2e
		250 g of AP	8,82	CO2e

Average products, AP, CO2e was converted to represent 1 kg of product and further to average product; 250 g

Before concluding the average avoided impact of carbon footprint, the discussion of substitution or replacement factor needs to be made. Substitution factor expresses the quantity of material that can be replaced with reused or recycled material. In textile reuse situation the factor express the received value from reused textile compared to similar new textile. Whereas recycle, the factor also accounts the quality of product generated by recycled material compared it to a product made out of virgin material. (Schmidt et al. 2016, 39). Substitution factor of 100 % or 1:1, indicates that the reused textile replaces the purchase of new equivalent textile and is often used as assumption in study cases. With 100 % substitution factor the avoided impacts are the largest possible but in reality the factor might be 50 – or even 10 %. (Sandin and Peters, 2018). High substitution factor indicates that the reused textile meets the specific need or the customer follows specific lifestyle or is environmentally aware. Some purchasing decisions are made spontaneously or are attraction of cheap prices resulting in meeting the customer's purchasing desires and it cannot be concluded that the reused item would replace the production of a new one. (Schmidt et al. 2016, 39). But since the customer's motives of purchasing decisions are uncertain and there are no agreed factor, the calculations were made using 100 % substitution factor in scenario 1 (S1) and to establish theoretical value and 50 % substitution factor in scenario 2 (S2), to seek more realistic value. In the replacement of virgin with recycled fibres, customer behaviour is not affect. In some products the substitution factor can be realistically 100 %, but in some cases recycling lowers the quality of fibres and therefore replacement is not complete. (Sandin and Peters, 2018; Schmidt et al. 2016, 39). In this thesis recycling's substitution factor was 100 % and can be considered realistic.

The calculated average avoided carbon footprint for average product of 250 g in scenario 1 was 8,82 kg CO_2e and in scenario 2 it was 4,41 kg CO_2e. These figures need to be converted to 1 kg to be used to calculate the cumulative avoided impact. Nextiili ry sorted reusable textiles 161 672 kg in year 2021, approximately 646 688 pieces of clothing, described in Table 6 more specifically. The data did not contain information on the type of textiles being sorted or what fibre type the textiles were. For this the average product was created to represent overall textile flow in Nextiili ry. The cumulative avoided impact in year 2021 was calculated by multiplying the average products carbon footprint with the yearly quantity of sorted reusable textiles in both scenarios following the next formula.

$$\text{Avoided carbon footprint} = \text{Average product (100 \% substitute factor)} \times \text{Quantity of reused textiles sorted by Nextiili ry in 2021}$$

For the scenario 1, the calculations were as follows;

$$\begin{aligned}\text{(S1) Avoided carbon footprint} &= 35.31\ \text{kg CO}_2\text{e}/\ 1\ \text{kg}\ \times 161\ 672{,}15\ \text{kg}\\ &= 5\ 709\ 872{,}3\ \text{kg CO}_2\ \text{e} \approx 5\ 700\ \text{ton CO}_2\text{e}\end{aligned}$$

For the scenario 2, where the substitute factor was considered to be 50 %, the calculations were as follows;

$$\begin{aligned}\text{(S2) Avoided carbon footprint} &= (35.31\ \text{kg CO}_2\text{e}/\ 1\ \text{kg}\ \times 0{,}5) \times 161\ 672{,}15\ \text{kg}\\ &= 2\ 854\ 936{,}1\ \text{kg CO}_2\ \text{e} \approx 2\ 850\ \text{ton CO}_2\text{e}\end{aligned}$$

The substitute factor has significant influence on the estimations of avoided impact, but more importantly the replacement of new about 646 688 pieces of clothing has positive environmental impact. According to the carbon handprint method (Pajula et al. 2018) the effect of Nextiili ry in 2021 was at the most 5 700 ton CO_2e reductions in the carbon footprint of Pirkanmaa residents.

5.3.2 Benefits of recycle

Estimating the amount of avoided impact by sorting textiles for recycling fraction was made same way as the reusable evaluation. In the year 2021 the fraction sorted in Nextiili ry for the textile recovery pilot plant in Paimio was about 69 033 kg, divided into 4 sub-fractions: cellulose, synthetic, wool and mixed. The estimations on avoided impact was evaluated separately to each of the fibre types after which the cumulative avoided impact was calculated. Finally the overall benefit of recycling was estimated by calculating the figures together.

Nextiili ry sorts the end-of-life textiles to cellulose fraction containing 100 % cotton, 100 % linen and 100 % viscose textile products, to synthetic fractions containing 100 % polyester, 100 % polyamide and 100 % acrylic, to wool fraction containing pure wool, and to mixed fraction containing other fibre types or polyester/cotton textiles with diverting mixture rate. Impurities in the fibres are accepted, like few percent of elastane mixed in with reported 100 % pure cotton and some amount of mixing different fibre types. In the calculations purity was default. In this thesis the mixed fraction contains polyester/cotton textiles with ratio of 65/35 % (Pokela 2022).

Formation of the emission factors for the different fibre types used in the collection of inventory data was previously presented in Figure 8 in chapter 5.1.2 Emission factors. System boundaries include the fibre cultivation or extraction and fibre treatment in production facility. These phases were considered to form the avoided impact of carbon footprint phases. Additional impacts are formed by the transportation of EOL textiles from donators and from the separate collection bin in Orivesi, which collected about 3000 kg of material sorted to recycling fraction in 2021. Transportations are considered to be outside of the boundaries. The collected emission factors for different fibres vary greatly due to a different measurements methods and boundary settings. As a result, an average footprint was determined for each fibre type based on the collected data. Table 8 consist of the average footprint estimations. Nextiili ry's carbon footprint has been assessed as insignificant as it does not significantly affect the estimated benefits, since operations consist mostly of manual sorting, no changes are being done to the products, and the impacts of heating and electricity can be considered standard. Cellulose fraction was assumed to consist mainly of cotton and small portion of some other cellulose fibre, in this viscose fibre was the representative. Synthetic fraction could contain other fibres, but in this thesis it was assumed to be purely polyester. Table 8 also includes the quantities of different fractions in 2021.

TABLE 8. The average carbon footprints for each fraction based on the estimated fibre composition and the quantity in year 2021

	Composition in the fraction	Average carbon footprint	Average footprint of fraction	Quantity in 2021
Cellulose	95 % CO 5 % CV	5,63 kg CO2e / kg 8 kg CO2e / kg	5,74 kg CO2e / kg of fibre	53059 kg
Synthetic	100 % PES	4,6 kg CO2e / kg of fibre	4,6 kg CO2e / kg of fibre	9670 kg
Wool	100 % WO	20,78 kg CO2e / kg of fibre	20,78 kg CO2e / kg of fibre	1072 kg
Mixed	65 % PES 35 % CO	4,6 kg CO2e / kg 5,63 kg CO2e / kg	4,95 kg CO2e / kg of fibre	5232 kg

The substitution factor of 100 % was considered to represent well the situation of replacing virgin fibres with recycled ones regardless of the intended use of the fibres. Since Nextiili ry pre-sorts and sorts further the EOL textiles into their own fractions well (Pokela 2022), it can be assumed that the whole amount could be utilized in Paimio textile recovery plant. At the Paimio process line, 5 – 10 % of the material is removed. The amount consists of removed zippers, buttons and other hard pieces needed to take out form the line, and this needs to be taken into account. (Pokela 2022).

The calculated average carbon footprints for 1 kg of each fraction, seen in Table 8, was used to calculate the cumulative avoided impact in year 2021 by multiplying the average footprint with its year’s quantity by reducing 10 % from the amounts to compensate the removed quantity in Paimio processing line. The calculations are in next table (Table 9).

TABLE 9. The calculations of cumulative avoided carbon footprints for each fraction based on the estimated fibre composition and the quantity in year 2021 and the overall avoided impact in year 2021 by recycle

Avoided carbon footprint = (Average carbon footprint x 100 % substitute factor) x (Quantity of fraction sorted by Nextiili ry in 2021 x 0,9 reduction of 10 % discarded amount in Paimio)	
Cellulose	5,74 kg CO2e / kg of fibre x (53059 kg x 0,9) = 274102,79 ≈ 274 000 kg CO_2e
Synthetic	4,6 kg CO2e / kg of fibre x (9670 kg x 0,9) = 40033,8 ≈ 40 000 kg CO_2e
Wool	20,78 kg CO2e / kg of fibre x (1072 kg x 0,9) = 20048,5 ≈ 20 000 kg CO_2e
Mixed	4,95 kg CO2e / kg of fibre x (5232 kg x 0,9) = 23308,5 ≈ 23 000 kg CO_2e

Overall cumulative avoided carbon footprint by recycle = Cellulose fraction + Synthetic fraction + Wool fraction + Mixed fraction
= 357 493,65
≈ 357 000 kg CO_2e

By sorting the EOL textiles to be recycled, Nextiili ry avoided creation of approximately 357 000 CO_2e of greenhouse gas emissions. If the same amount of EOL textiles would have been sent to energy recovery from Nextiili ry, it would have resulted in the creation of 33 556,24 kg CO_2e according to Finnish Environment Institutes (SYKE) Y-Hiilari carbon footprint tool, where the emission factor was 400 CO_2e (kg/t), emptying interval in once a week and distance to the energy recovery facility 20 km (SYKE 2020). If taking aside the benefit of energy production and the emissions created by the recycling process, the recycle of textile was 10 times more beneficial than energy recovery.

When looking more closely at the calculated avoided carbon footprint or the benefits, it should be considered what the actual avoided phases were in the fibres emission factors. The factor most likely contains the cultivation and treatment into fibre form, where the textile recovery has also phases of turning textiles into fibre form. Therefore there are risks in taking into account the same production step twice and overestimating the benefits. This risk can be bypassed by calculating the carbon footprint of turning textiles into fibre form and by reducing that from the avoided impact calculation. This would require more information from the textile recovery pilot plant in Paimio. Emissions from the transportation from Nextiili ry to the Paimio recycling pilot plant can be estimated, and considered as indirect emissions from Nextiili ry operations, but affecting the benefits. According to SYKE's Y-Hiilari carbon footprint tool, the footprint of transportation between Nextiili ry and Paimio was 5 923,3 kg CO_2e in the year 2021. This consisted of 49 round trips of 165 km one way, driven by delivery truck (6 t/3,5 t), using traditional diesel and consisting of emissions from producing and using diesel. (SYKE 2020).

By reducing the transportation from the avoided impact, the benefits of recycling would be 351 570,3 kg CO_2e, approximately 350 tons CO_2e. Compared to the benefits of reuse, the same amount would have gained about 1 219 tons CO_2e with substitution factor 50 % and with 100 % factor 2 438 tons CO_2e, making the reuse 3,46 to 6,93 times more beneficial than recycling depending on the substitution factor. If transportation was reduced from the benefits, recycling would be 9 times more beneficial than energy recovery.

5.3.3 Presentation of results

The purpose of this thesis was to find a way to communicate the environmental benefits of Nextiili ry's operations regarding the provision of new chance to be useful for the discarded textiles in society. The communication should be understandable and informative for several stakeholders. Short descriptions and the use of charts were seen as sufficient ways to make the situation clear. The next paragraph has an example of the presentation form.

In the year 2021 Nextiili ry enabled new life for 230 705,1 kg of discarded textiles, consisting of approximately 0,92 million pieces of garment. To manufacture 0,92 million pieces of garments would have required lot of raw materials, energy, water and chemicals, which would have created emissions to air, water and land during different manufacturing stages. These stages were avoided by providing reused and recycled items instead of producing new clothes. New life as reused clothing or recycled textile fibre potentially made possible to avoid 6 061 tons of CO_2e emissions in year 2021. For this amount of carbon footprint to be successfully avoided assumption of one reused clothe replaces the purchase of new one and average material composition follows 56 % of cotton, 40 % polyester and 4 % wool.

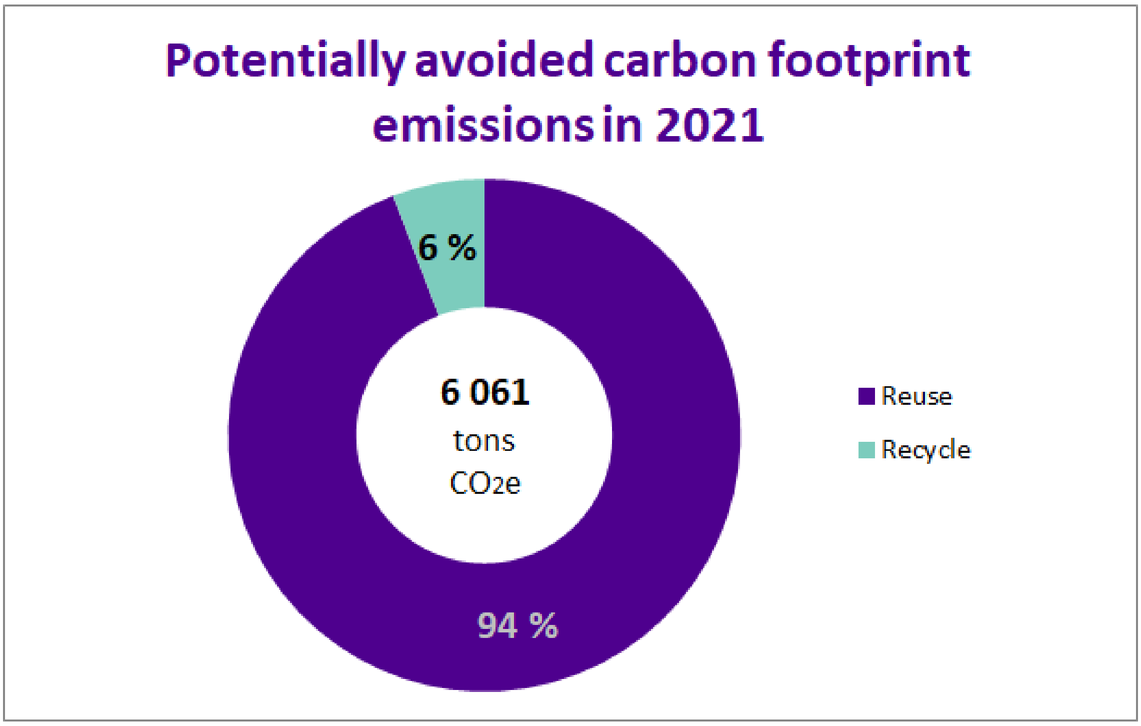


FIGURE 11. The potentially avoided carbon footprint by shares

In 2021 Nextiili ry participated in separate collection of end-of-life textile pilot project together with Pirkanmaan Jätehuolto Oy. As a result, suitable material was sorted to be recycled as fibre material in EOL textile processing pilot plant in Paimio and its share for the overall avoided carbon footprint amount can be seen in the Figure 11. The figure shows that the share of recycling was smaller than reuse in 2021, but the reason for smaller share was that with the reuse larger amount of carbon footprint can be avoided due to clothe production having more production phases than fibre production. Potentially avoided carbon footprint of 6 061 tons CO_2e equals 0,63 % from the carbon footprint of the city of Tampere in year 2018 and was same size as the agricultural emissions of 6,5 kt CO_2e at the same time in Tampere (Benviroc Oy 2020). The emission amounts of 6 061 tons CO2e are equivalent also to about 43 million km of driving (OpenCO2.net 2022).

6 DISCUSSION

Textile industry and environmental issues have long been a topic of conversation. As one of the most pollutant industry improvements for each life cycle phase are needed. Development in cultivation, manufacturing and retail phase can give a certain amount of reductions on the impacts, but the actions done in households during use and end of life phase has potential of having even greater influence. Since affecting on decisions made in households on textile care requires long-term work, end of life stage comes more and more important.

In Finland the work on the treatment of textile waste has been started. Interesting projects and reports, like Telaketju and Global climate impacts of the Finnish textile and fashion industry (Gaib et al. 2021) and others are actuations for the national separate collection of textile waste in 2023. There are still a lot to do before Finland is ready to utilizing the possible 40 000 tons of discarded textiles from households in 2023 that ended up in the energy recovery in 2019 (Dahlbo et al. 2021). The amount of separately collected textile waste would most likely to be smaller. Heikkilä et al. (2021) estimated that 4 kg per person of textiles would be collected, making the estimated overall amount in separate collection in 2023 about 20 000 tons. (Heikkilä et al. 2021, 59).

Potential challenges are the choice of sorting operator, collection containers, the utilization possibilities and knowledge of terminology. As Dahlbo et al. (2021) justified the difficulty of forming the textile flows in Finland 2019 from the perceptions of various stakeholders on the terms of reuse and recycle the confusion may also be reflected in the possible understanding of the results in this thesis by some of the stakeholders. Bigger problem in the separate collection would form if the population do not have a clear understanding of the pre-sorting of textile waste into reuse, recycling or energy fraction, taking place in households. Unrelated material in the collection creates unnecessary burden to the sorters in different sorting stages impairing efficiency, meaningfulness of handling the material and potentially affecting the quality of material. With good education and clear instructions for household, the risk of wrong type of material ending up in the collection can be reduced, thus increasing the environmental benefits.

Nextiili ry has gained experience and understanding of the composition and sorting of EOL textiles that would be useful as a potential designated textile waste operator in 2023. Gained experience and description of environmental benefits of the operation would reinforce the importance of the work, maintain transparency and promote environmental actions that might influence the selection of operator. The challenge for small companies and associations has been in the how and with what to describe environmental benefits of their business. The solution for describing the benefits of operations as avoided impact was seen as understandable and easily reproducible by Nextiili ry in coming years. The avoided impacts may not be a very scientific interpretation of the benefits and more of estimation on the potential amount of escaped impacts than absolute value. The aim was to get the most accurate calculation possible in order to avoid an overly positive image of the situation or falling into green washing, but at the same time achieve something relevant. It was necessary to end in assessment of the benefits because most of the data was estimations, emission factors were not accurate and studies used lot of assumptions.

Nextiili ry operations in 2021 enabled avoiding of possible 6 061 tons of CO_2e emissions by sorting discarded textiles to reuse and recycle. Reuse was 3,5 to 7 times beneficial than recycle, attention to which several previous studies have also received. Reviewing reuse, the net environmental benefit should take into account the calculations on transportation, collection, sorting and reselling impacts, but as Dahlbo et al. (2016) studied the benefits obtained by replacing the virgin material usage, transportation was found to have small contribution to the overall impacts. (Muthu 2014; Dahlbo et al. 2016). Affecting the obtained results would be the selection of emission factors, fibre composition distribution in selection of average product in reuse and fibre compositions in fractions in the recycle and the substitution factor. Changes in those figures would change the final value. For example with the substitution factor of 50 % the results of 3,2 kiloton CO_2e avoided carbon footprint the benefits would still show. Other uncertainties for the results can be detected in the question of whether clothes actually end up in reuse. Some reuse clothes are exported from Finland, through other operators and it cannot be said for certain that they are utilized by reuse, which was assumed in this thesis (Dahlbo et al. 2015). The carbon footprint of recycling also raises questions. Separating textile fibres form each other requires energy; a phase that was not possible to calculate during this thesis, but when calculated gives more accurate estimation in the future. Also the utilizing possibilities of for example mixed textile items; are the gained benefits truly bigger if the gained material has no demand.

For Nextiili ry opportunities to influence the results in coming years are small. If it would be possible, handling wool textile would be the most beneficial, since the emissions generated in its production are highest and therefore sorting wool has biggest avoided impact possibility. Viscose has bigger emission factor than cotton, but there are more recycling solutions for cotton developed in Finland over the years (Gaib et al. 2021). Decreasing the share for energy recovery would also increase the avoided impact value. For changing the share of energy recovery would mean changes in household pre-sorting behavior and condition improvements in outside collection stations for maintaining high quality of material. Adding washing and drying for partially damaged EOL textiles, would decrease the waste amount. This would increase environmental impacts of Nextiili ry operations and increase need for employees and facilities and therefore additional benefits might not occur. If the future holds the designated operator title, the material flow will increase and create possibility to increase the environmental benefit by increase of quantity. Because of this the consideration of investing on automatic sorting line with NIR sensors would help with the increased quantity. Automation might not help to identify the damp or moldy items from the lot or to sort possible reusable items from the EOL textiles indicating the need for human labor in the future as well.

Wieland Textiles estimated their avoided impact in 2017 being 302 kiloton of CO_2 emissions when assuming that selling 3 new clothes makes about 57 kg of CO_2 (Wieland Textiles 2022). If the calculation method would be used for Nextiili ry, the result of reuse for 646 688 pieces of clothing would equal about 12 kiloton of CO_2 emissions. Comparing to the avoided 5,7 kiloton of CO_2e formed only by reuse by the methods used in this thesis, Wieland Textiles estimations seems optimistic, even with the calculations of CO_2 emissions alone. Therefore the gained results in this thesis can be seen realistic.

The gained result gives starting point for following studies. How would the national separate collection influence the amount of energy recovery fraction or how the carbon footprint of operation affects the benefit? The aim of this thesis in finding suitable way of describing environmental benefits of Nextiili ry operations can be said to be succeeded. Finding a way of verifying own operations positive actions has influence, if nothing else, on Nextiili ry's work atmosphere. At least the results of this thesis can be seen as verification for the previous studies on the benefits of sorting textile waste to reuse and recycle.

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APPENDICES

Appendix 1. Carbon footprints and emission factors for different textile applications.

The overall carbon footprints are also shown in the table, in some cases, inside parentheses.

Material	Value includes	Emission factor / Carbon footprint	Source
Cotton, conventional (USA)	Crop cultivation and fibre production	5,9 kg of CO2 /per ton of fibre	(Cherrett et al. 2005)
Cotton, organic (India)	Crop cultivation and fibre production	3,8 kg of CO2 /per ton of fibre	(Cherrett et al. 2005)
Polyester (USA)	Crop cultivation and fibre production	9,52 kg of CO2 /per ton of fibre	(Cherrett et al. 2005)
Cotton, conventional	Fibre production form cradle to gate	6 kg CO2e / kg of fibre	(Muthu 2014 (3.5.2))
Cotton, organic	Fibre production form cradle to gate	2,5 kg CO2e / kg of fibre	(Muthu 2014 (3.5.2))
Polyester	Fibre production form cradle to gate	2,8 kg CO2e / kg of fibre	(Muthu 2014 (3.5.2))
Acrylic	Fibre production form cradle to gate	5 kg CO2e / kg of fibre	(Muthu 2014 (3.5.2))
Wool	Fibre production form cradle to gate	2,2 kg CO2e / kg of fibre	(Muthu 2014 (3.5.2))
Viscose	Fibre production form cradle to gate. -3,5 kg CO2e for biomass credit	9 kg CO2e / kg of fibre	(Muthu 2014 (3.5.2))
Cotton	e.g. market for fibre, GLO - fibre, cotton, market for fibre, cotton, organic…	3-11 kg CO2e / kg of fibre	(Gaib, A. 2021, 35)
Polyester	e.g. Market for fibre, GLO - Fibre, nonwoven polyester…	2-9 kg CO2e / kg of fibre	(Gaib, A. 2021, 35)
Wool	e.g. sheep production, fow wool, RoW - sheep fleece in the grease…	21-41 kg CO2e / kg of fibre	(Gaib, A. 2021, 35)
Viscose	market for fibre -GLO - fibre, viscose	3-12 kg CO2e / kg of fibre	(Gaib, A. 2021, 35)
Wool fiber	Raw material production (to the farm gate) Australia	24,9 kg CO2e / kg of greasy wool (14,8 kg CO2e / kg grasy wool if the meat had dominance)	(Henry et al. 2015, 223)

Textile products			
Cotton fabric	Clothe produced and used (washing included)	28 t CO2e / tonne of fibre in clothing	(Gracey & Moon 2012, 59)
Polyester fabric	Clothe produced and used (washing included)	21 t CO2e / tonne of fibre in clothing	(Gracey & Moon 2012, 59)
Wool fabric	Clothe produced and used (washing included)	46 t CO2e / tonne of fibre in clothing	(Gracey & Moon 2012, 59)
Viscose fabric	Clothe produced and used (washing included)	30 t CO2e / tonne of fibre in clothing	(Gracey & Moon 2012, 59)
Cotton fabric (woven)	Raw fibre production to the fabric production. Transportation, consumer use and end of life stages not included	22 kg CO2e / 1 kg of fabric	(Beton et al 2014, 75)
Polyester fabric (woven)	Raw fibre production to the fabric production. Transportation, consumer use and end of life stages not included	27,2 kg CO2e / 1 kg of fabric	(Beton et al 2014, 75)
Wool fabric (woven)	Raw fibre production to the fabric production. Transportation, consumer use and end of life stages not included	19 kg CO2e / 1 kg of fabric	(Beton et al 2014, 75)
Viscose fabric (woven)	Raw fibre production to the fabric production. Transportation, consumer use and end of life stages not included	24 kg CO2e / 1 kg of fabric	(Beton et al 2014, 75)
Cotton denim fabric (Global average)	Fibre to fabric production and transportation	23,2 t CO2e / tonne of fabric	(Zhao et al. 2021)
Cotton/polyester denim blend fabric (90 % CO & 10 % PES)	Fibre to fabric production and transportation	24,4 t CO2e / tonne of fabric	(Zhao et al. 2021)
Cotton, White long shirt	Cultivation in USA, manufacturing in Bangladesh and sold in Germany.	7,2 kg CO2e /shirt (10.75 kg CO2e / shirt for whole LC)	(Rana et. Al. 2015, 153)
Cotton, organic, T-shirt, small short sleeve, one colour	Manufactured in India, silk printed in UK and sold in UK.	1,13 kg CO2e/ T-shirt (2,34 kg CO2e / T-shirt for whole LC)	Muthu 2014 (9.2.1)
Cotton, organic, T-shirt (India)	Cotton and manufactory in India, sold in South Africa. No usage phase included. (250 g T-shirt)	5,455 kg CO2e /per t-shirt (1922,8 kg / tonne of t-shirts)	Muthu 2014 (9.2.3)

Cotton 98%, Elastane 2% blue men's jeans (570 g) India	Fibre form India, fabric, manufacturing, packing, transportation and retail in India.	32,04 kg CO2e / pair of jeans (53,48 kg CO2e / pair of jeans whole LC)	(Periyasamy & Duraisamy 2018, 15)
Merino wool sweater 264,8 g coloured	Wool from South Africa, manufacturing yarn Italy, Knitted in Romania, Distribution in Germany.	1,667 kg CO2 / per sweater 264 g (1,947 kg CO2 / sweater for whole LC)	(Bevilacqua et al. 2012)
Polyester, T-shirt (180 g)	From PET production (China) manufacturing t-shirt to transport (Australia) (Study was conducted to full LCA, to disposal)	14,56 kg CO2e / T-shirt (20,56 kg CO2e / T-shirt for whole LC)	(Moazzem et al. 2018)