Final report

AI for resource-efficient circular fashion

Project period:
2021-10-15 - 2024-04-30

Project manager:
Wargön Innovation

Project partners:
RISE (AI, UX, LCA),
Björkå Frihet,
Röda Korset,
Myrorna,
ShareTex,
Inimini
TexAid

Preface*

The background of the project is the increasing environmental impact of production and consumption of textiles. In early 2000s, the global consumption of textiles was about 55 million tonnes per year. By 2019, it had increased to 111 million and is forecasted to increase to 146 million tonnes in 2030.
Textiles is the fourth highest pressure category in the EU in terms of use of primary raw materials and water (after food, housing, and transport), and fifth for GHG emissions (EEA). Europeans consume about 11 million tonnes of textiles per year and as of today, only 2,8 million tonnes are collected for reuse or recycling. The same is true on a global scale where only 20% of the yearly textile consumption is collected whereas 80% is incinerated or ends up in landfills. Swedish textile consumption corresponds to about 3,5% of the global 1,2 billion tonnes of GHG emissions per year as CO2 equivalents.
LCA studies on Swedish textile consumption has shown that 80% of a garment's climate impact and 92% of the toxicity occurs in the early stages of production.
In addition, it has been shown that if the textile life span (appr 2 years today) is increased by a factor three, the total environmental impact is reduced by 70%. Hence, as the use phase of a garment is prolonged, a substantial decrease in GHG emissions can be achieved when the corresponding new production is offset.
To address this a new European Waste Directive states that by January 1, 2025, EU member states are obliged to have systems in place for separate collection of textiles, which will drastically increase the collected textile volumes and the need for textile sorting for both reuse, repurpose(remake, refresh, reapir etc.) and recycling.
In Sweden, 75 000 tonnes of textiles per year is discarded and becomes residual waste and input material for central heat power plants; hence, the Swedish EPA has set the following suggestions for national goals regarding collecting and sorting of used textiles:
The amount of textiles in the residual waste shall be decreased by 60% compared to year 2015 (corresponding to +45 000 tonnes in collected volume). 90% of the collected textile volume shall be prepared for reuse or recycling according to the waste hierarchy, and recycling into new textiles shall be prioritised over downcycling.

This increase in collected volumes would exceed the sorting capacity of Sweden. Textile sorting and valuation need to increase to a larger scale and also be more efficient, including more accurate, to meet requirements from a larger variety of customers.
The aim of the project was to explore and pilot AI-based concepts to facilitate larger volumes and more complexity in textile sorting. To achieve this, a large amount of data was needed, and therefore the project aimed to build a dataset of 30 000 postconsumer garments.

* Note: References for all numbers in the Preface can be found in appendix 2.

Abstract*

Large scale textile sorting facilities will be crucial as collected textile volumes increase Europe due to new regulations coming in 2025. Currently, only a few European countries host large-scale reuse sorting facilities, and these facilities rely on manual labour-intensive sorting by skilled textile sorters or second-hand retail staff.

The introduction of AI/ML-based systems, particularly computer vision, and associated datasets for second-hand garments, can greatly enhance efficiency in textile sorting by increasing the speed and managing the growing complexity of requirements when circular business models are more commonly used. This has a potential to significantly decrease national and global GHG emissions. If only 5 percent of Europe's textile consumption is substituted by circulated alternatives, the climate impact reduction would be 4 percent, meaning a reduction of 19 million tonnes CO2, yearly.

In this project, AI for resource-efficient circular fashion, the challenge of introducing AI to the second-hand sorting was addressed. Preparatory work revealed that no open dataset for second-hand garments existed. Therefore of the main goals of the project was to establish a dataset of 30 000 post-consumer garments which should be open for use for anyone interested do further research or to develop their own AI-model.
The goal was reached, and the final published dataset contains photos and information (annotations) for 31997 garments. Three photos of each garment were taken (front, back and brand-tag) and several attributes were annotated such as: garment type, gender, colour, condition, material, and estimated price. The attributes were identified by Wargön Innovation in co-operation with the project partners. Following the definition of attributes to include in the dataset RISE was responsible for establishing technical requirements for an AI-annotationstation including both software and hardware such as cameras.
All stages in the creation of the dataset, including setting up the AI-annotation-stations and testing the annotation process, took longer than anticipated. Consequently, the project reached its goal of 30 000 garments late, beginning of 2024. This delay impacted the project's ability to build and train AI-models with good accuracy.

Another objective of the project was to test AI/ML assisted sorting with focus on automation of the reuse sorting processes. A user-driven design process was applied integrating competencies in AI, UX, reuse models for textiles and climate impact knowledge with problem owners and users. The RISE UX-team mapped the needs and wishes of the project partners and developed design solutions for the functionality of an AI-tool accordingly. These solutions were tested iteratively refined based on the feedback. Due to diverse needs expressed by the project partners it was decided that the final solution from the UX-team would focus on functionality of assessing "best use" (such as reuse, repair, recycle).

In parallel with the UX work the AI-team at RISE began building and training AI-models to assess the accuracy achievable for the different annotated attributes. As mentioned earlier, there were delays related the dataset creation, which resulted in insufficient amount of data available for the AI-model preparation. When sufficient data was available, there wasn't enough time left within the project to adequately train the AI-models to achieve higher results. This limitation particularly affected the assessment of garment condition.

A proof-of-concept (POC)-test was conducted at the end of the project where AI-models, for a few of the annotated attributes, were tested by the project partners. One AI-model also generated a short description of the garments. As expected, due to time and data limitations caused by delays in dataset creation, the AI-models results did not reach their full potential. However, despite lack of training and not reaching full potential yet, the AI-models proved faster than humans when tested.

A LCA was made with focus on the benefits of using AI instead of manual labour in the sorting process.
The results demonstrates that the implementation of an AI-assisted sorting process most likely will result in environmental benefits downstream. The environmental impacts would be offset by achieving as little as 1% of increased reliability in sorting for all impact categories. Given the low rate of recycling and reuse achieved currently in Europe, the potential to improve is significantly high.

* Note: References for all numbers in the Abstract can be found in appendix 2.

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1. Workpackage 1 – Project management

1.1. Activities

Core Team Meetings
Since RISE had a large role in the project “core team meetings” were set up early in the projects including Wargön Innovation and RISE to keep close track of progress. The core team meetings were held on a bi-weekly basis.

Project meetings
Two times a year the whole project group with all partners was gathered for a project meeting to inform about status and progress in the project. Usually, the meetings were connected to some other project activity such as testing for the UX-team.

Reference group meetings
Reference group meetings were also held two times a year usually in connection with the project meetings. AI Sweden and Sellpy came to be the most active partners in the reference group, and they were really interested and gave good feedback.

1.2. Project changes

During 2022, one of the project partners, Hack Your Closet, went bankrupt. They were the only project partner having the services-perspective (rental) so it was an unfortunate loss for the project. A new project partner was found in Inimini who sells second-hand kids clothes online, with a good experience of testing automation and AI-solutions in small scale.

1.3. Result

All project objectives have been reached.

The work with the dataset of 30 000 garments was more complicated and took a longer time than expected. Every step of the work process was a little more time-consuming than expected, from the start of defining what attributes to annotate, to define requirements for the AI-annotationstation, getting hardware and software at the station to work together properly, training the annotators and getting up to speed and so on.That gave the AI-team at RISE less time to train AI-models with sufficiently large amounts of data which affected the end-result. The project did reach the goal of having done POC (proof of concept) tests on a prototype AI-model, but with more time it could have had higher accuracy and could have been integrated in a more user friendly interface.

2. Workpackage 2 – Communication

There has been a high interest about the project since it was one of the first (if not the first) project about AI for textile sorting. The unique dataset has also brought a lot of attention. Some communication about the project is presented below but it has also been mentioned in a lot of social media and other contexts.

2.1. Press releases

27th of September 2022

Framtiden är här – nu sorterar AI dina gamla kläder | Innovatum Science Park (mynewsdesk.com)

Resulted in these two publications and some more smaller ones on social media:

Här ska 30 000 plagg scannas av AI | SVT Nyheter

Nu blir dina gamla kläder sorterad av AI | IT-Retail.se

2nd of October 2023

Världsunik öppen AI-databas för second hand | Innovatum Science Park (mynewsdesk.com)

Resulted in fifty-five (55) publications in different media, both locally and national, such as: TTela, Svenska Dagbladet and Aftonbladet.

The same press releasewas published in English a week later but did not give any visible result: Groundbreaking AI Database Revolutionizes Second Hand Sorting | Innovatum Science Park (mynewsdesk.com)

26th of June 2024

Innovativ AI-satsning för second handtextilier tar kliv framåt | Innovatum Science Park (mynewsdesk.com)

This was released when the full dataset was released, which was a short time after the project end date. When this report was written we had not seen the effect of this made.

2.2. Other project communication

The project has been presented at (at least) these events/opportunities:

- Vinnova Impact Day – September 2022 (presentation)
- Short article in TTela – May 2023 (short article)
- Framtidsdagen på Wargön Innovation – May 2023 (presentation) Facebook post
- EU event on sustainabile AI and AI for sustainability – May 2023 (demo) LinkedIn
- Automation day – November 2023 (presentation)
- Breakfast event about AI together with IUC Väst - 2023 (presentation)
- Program conferens for Vinnova ”AI I klimatets tjänst” – February 2024 (representation) Linkedin post
- Avfall och Miljö – February2024 (article) Article
- Webinar about the project results – February 2024
- Habit – Mars 2024 (article) Article
- Red Cross event about upcycling – Mars 2024 Facebook post

3. Workpackage 3 – UX-design

3.1. Background/Purpose/Objectives

This part of the project had the purpose of understanding and identifying the user needs and pain points, create design proposals of a user interface and evaluate the proposals. The aim has been to support the AI development with a better understanding of how this dataset can be used and how it could help the users (project partners) and where in the sorting process.

3.2. Work process

To reach the goals of this part of the project the team has used an iterative design process based on Design thinking and the Double diamond model. Design Council (n.d.), *The Double Diamond*, Design Council. Available at: https://www.designcouncil.org.uk/our-resources/the-double-diamond/ (Visited: [14th June 2024]).

The process has been divided into three parts; Need analysis, Concept development and Evaluation. Within these parts different methods has been used to interact with users, create design proposals of user interfaces and evaluate them through user testing. As the process has been iterative the testing of a design then looped the team back to new insights on user needs and gave input to further development.

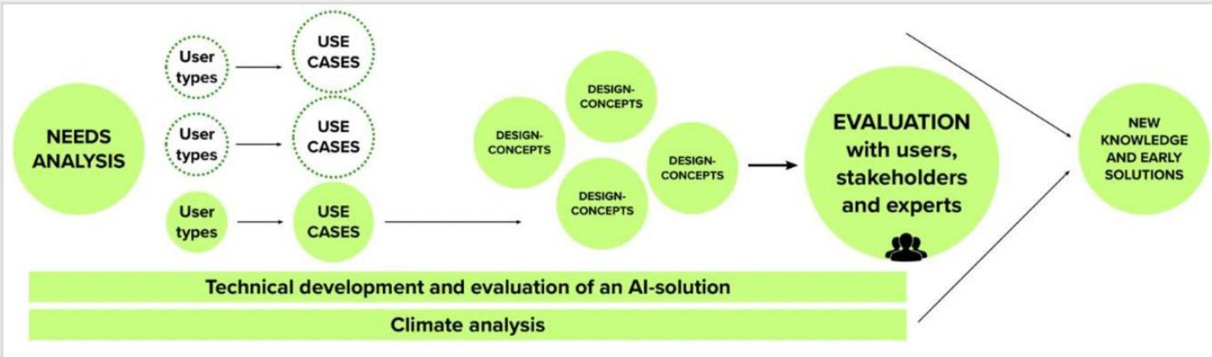


Figure 1. Visualization of the design process

Needs Analysis

During this phase, the first half of the project, a vigorous data collection took place through the use of different methods. One key aspect was to understand the need of and potential usage of the AI during the sorting process and therefore focus was to involve the users (the project partners) to get insights into their current state of work and what aspects could be helped by implementing the AI. The objective was to understand their context, motivations, and approaches to using the potential product.

Data Collection Techniques

To conduct a comprehensive needs analysis, the UX-team employed a combination of qualitative methods, including 13 interviews, 6 observations, workshops, user type identification, use case development, and envisioning exercises. This multifaceted approach enabled the possibility to gather diverse perspectives and insights from key stakeholders across various sectors involved in the textile and fashion industry.

As a result, from interviews and observations with the stakeholders *User types* and *AI Use cases* were developed. Both to understand more about the secondhand sorting in Sweden and to lay a foundation for conceptual development of how to implement AI in user friendly and useful way.

User Types

This section presents the user types involved in various processes, detailing their pain points, needs, opportunities, and use cases where AI could improve these processes. User types enable us to empathize with and prioritize our users' needs, helping us Identified User Types and Associated Insights.

Sorting Facilities

- **Textile Sorter (Educated/Experienced)**
  - **Profile**: Typically educated in textiles with a fashion interest, working on the sorting line and pricing items.
  - **Pain Points**: The first sorting stage often demands long hours, quick decisions, and monotonous work. Pricing requires time and knowledge of trends, brands, and quality
  - **Value:** Reduces the risk of poor decision-making due to human error, saves time, and decreases monotonous tasks for humans.

- **Textile Sorter (Not Educated/Beginner)**
  - **Profile**: Potential user; currently, non-educated or new personnel cannot work at stations demanding fashion interest and textile knowledge.
  - **Pain Points**: Lack of knowledge, dependence on certain staff members.
  - **Value:** Don’t need staff with ceratin knowledge

Rental & Online

- **Stylist**
  - **Profile**: Takes photos of items and uploads them to Tradera or a dataset, writes descriptions/check boxes, and is trained by the company without specific formal education.
  - **Pain Points**: Manually writing descriptions is time-consuming.
  - **Value**: Time-saving.

In-Store

- **Volunteers**
  - **Profile**: Only a few staff members have the knowledge to set the right price.
  - **Pain Points**: Dependence on specific staff members.
  - **Value**: Reduced vulnerability, Time-saving.

Recycling Facilities (Sharetex)

- **Engineer**
  - **Profile**: Lacks information from the sorting process, conducts fiber tests on items to determine material composition.
  - **Pain Points**: Performing fiber tests is time-consuming.
  - **Value**: Time and resource-saving.

Retail

- **Consumer**
  - **Profile**: Consumers comparing second-hand clothes with newly produced ones, aiming to make second-hand shopping easier with AI assistance.
  - **Pain Points**: Finding items they like second-hand is time-consuming.
  - **Value**: Time-saving.

AI Use Cases

The users (project partners) assessed the potential effects of various AI-driven use cases on their processes, providing valuable insights into how AI could address identified pain points and enhance efficiency across different stages of the value chain. To be able to proceed with process on how to implement AI there was a vote on which use case to work with and create design proposal for; "*Recommend Best use*" got the most votes.

Table 1. Showing the different potential use cases for AI

Identify Characteristics	A tool that can recognize the characteristics of an item and generate the text for it. Possible to sort on different characteristics, find red blouses for example.

Price	A tool that can support the staff on setting the "right" price for the specific store. Take photo of item and add information what the sorter can see and feel.
Recommend "Best use"	Is this item best suited for Reuse, sold in stores in Sweden, recycling, remake or export? Is it better that an item goes on export or is recycled here? Can AI give a recommendation based on calculations ?
Matchmaking (consumer)	Use AI to recognize items online that consumers are looking for. Send notifications to consumers when the items are available, and they can pick up items in store.
Regularly updated dataset on trends	Instead of educating the staff each month on trends, a tool can support in identify items that are trendy the coming season that you are sorting for.
Identify Materials/Fibers	A tool that can identify fibers/materials and generate the text for it. Make it easier to send items to recycle companies and share information about the items.

Concept development

The development of a user-friendly interface for interacting with the AI was driven by the specific use case requirements, *see the table above*. During this phase of the design process, various activities were conducted in collaboration with project partners to iterate and generate different concepts. After prioritizing the options, one concept was chosen for further development, leading to the creation of a prototype for testing and refinement.

Methods

- 2 Brainstorming Sessions: These sessions were utilized to evaluate findings and generate new concepts.
- 4 Workshops: These workshops were conducted to gain insights and obtain feedback from various stakeholders on the generated concepts.
- 2 Pugh's Elimination Matrix: This matrix was employed to evaluate and prioritize the concepts generated during the brainstorming sessions.

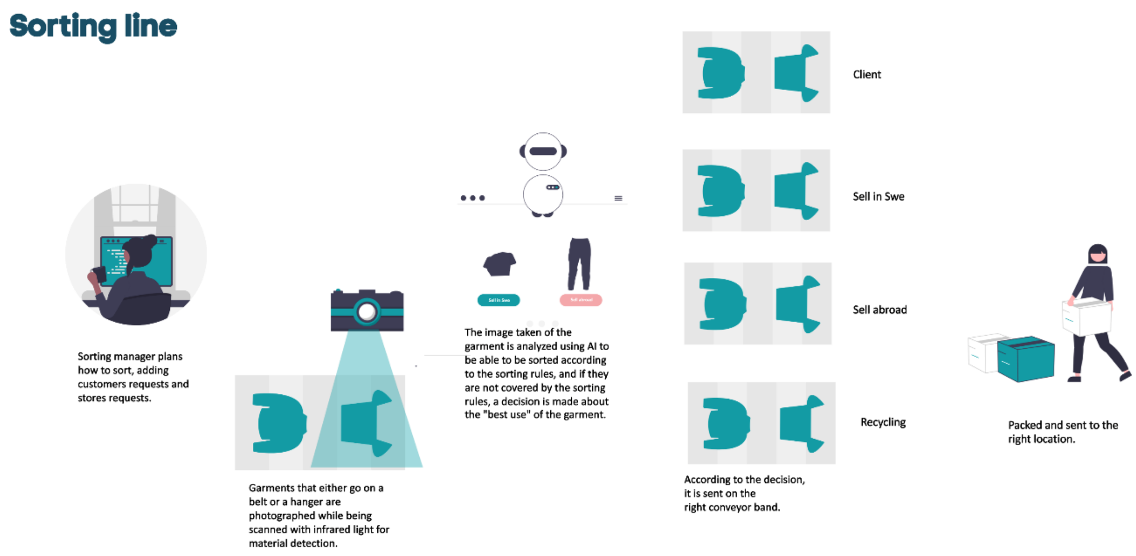


Figure 2. Image showing how the sorting line would work and where AI/image recognition would be placed.

The sorting facilities have both similar and distinct interests and methodologies for determining the best use of items. To accommodate these differences, a software tool prototype (interface for AI-algoritm) has been developed in the project, aiming to cater to individual facility needs in deciding how AI should sort garments.

However, the rules governing this process are complex, with certain attributes such as condition and trend relying on a multitude of other factors for determination. In the following sections, we seek to visualize, define, and describe how these challenges can be addressed in two different scenarios: *Visionary prototype* an idealistic scenario where advanced technology is available, and the current scenario, *Functional prototype*, based on existing technology.

Visionary prototype

The Visionary prototype developed for this project serves as the control hub for an AI-assisted sorting system designed to streamline the garment sorting process on the production line. It works together with a camera station positioned strategically along the sorting line, capturing images of garments as they pass by for analysis. The software facilitates the AI's decision-making process by providing a user-friendly interface for setting rules and parameters for the sorting managers.

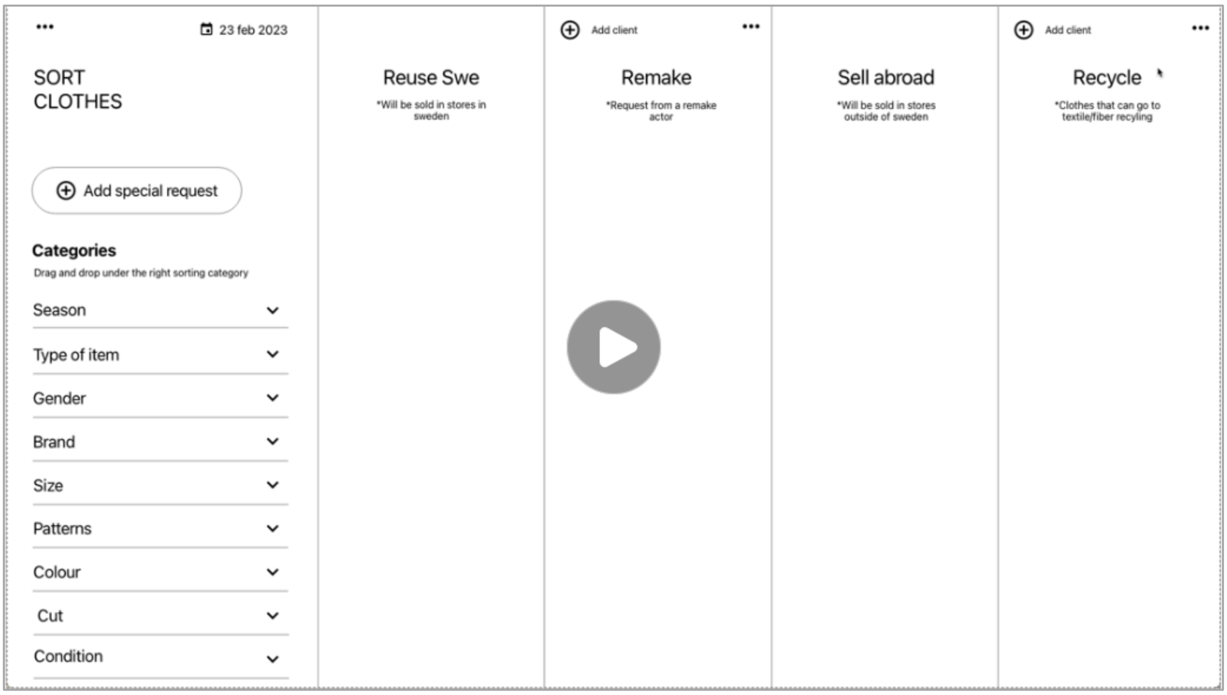


Figure 3. Image showing the user interface for deciding how the AI should sort in a specific facility.

Key Features:

Rule Setting Interface: The software provides an intuitive interface for users to define rules and criteria for sorting garments. Users can specify parameters such as color, size, brand, and type of item to guide the AI's sorting decisions.
Image Analysis: Upon receiving images from the camera station, the software utilizes advanced image processing algorithms to analyze garment attributes. This analysis enables the AI to categorize garments based on predefined rules set by the user.
Decision Making: Based on the analysis of garment attributes, the AI within the software makes real-time decisions on sorting, determining the appropriate destination for each garment within the production line. This could include categories such as staying in Sweden, export, or further quality assessment.

Streamlined Workflow: By automating the initial sorting process, the software aims to streamline workflow efficiency on the sorting line. It reduces the manual effort required for basic garment classification, allowing personnel to focus on assessing garment quality and suitability for specific markets.

User-Friendly Interface: The software features a user-friendly interface. It provides feedback on sorting decisions and allows users to easily adjust rules and parameters as needed.

Overall, the software could serve as a powerful tool for optimizing garment sorting operations, enhancing productivity, and ensuring that only garments meeting specified criteria proceed along the production line for further processing.

User-test of the visionary prototype

The purpose was to gain insights into the usability of the created prototype and to understand if the direction adds value to the project and its potential future.

The user test employed scripted tasks and guidelines to ensure each participant had an equal opportunity to complete the tasks. It commenced with an introduction to the project, the planned AI station set-up, and the prototype itself. Subsequently, each participant engaged in seven different tasks to evaluate usability. The session concluded with an interview where follow-up questions regarding the prototype and the concept in general were asked. A total of 10 users participated.

General Insights

- Users quickly grasped the system's logic and how to use it.
- Setting rules with drag and drop was easy for most users.
- Changing set rules was straightforward for all users.
- All users could easily navigate and find categories.
- The ability to search for items by brand was appreciated.
- Adding requests with an image or manually choosing categories was equally simple for users.

Room for Improvements

- Difficulty finding the "Add client" button.
- Expectations regarding the functionality of "Add special request."
- Clarity on when scrolling is necessary and what is visible.
- Improved sorting within categories and the ability to search within or across all categories.
- Instructions on how to change a request and suggested categories from an image.

- Clarification on the title of the "Remake" column.

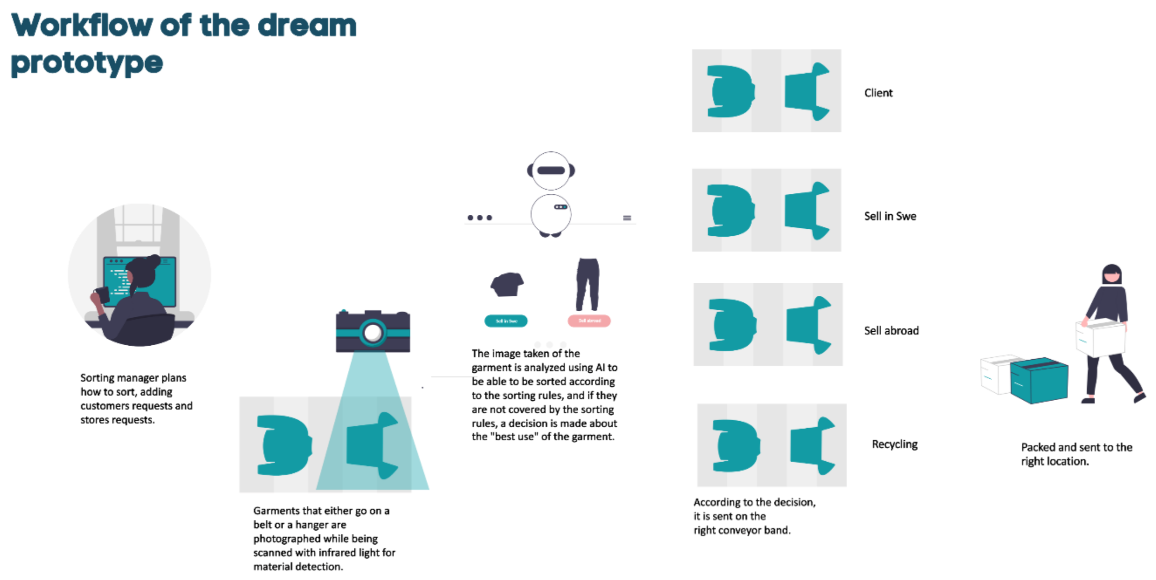


Figure 4. Image showing the sorting line with the AI incorporated.

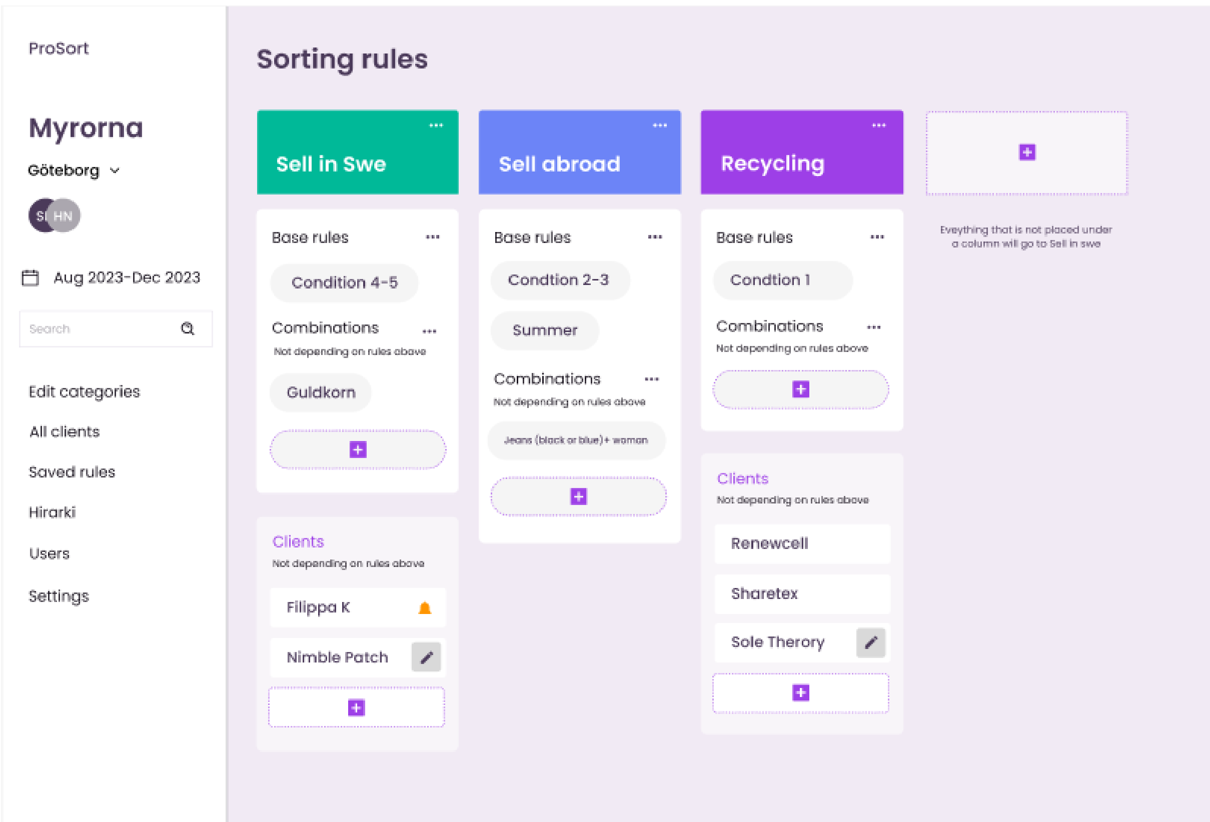


Figure 5. Image showing the revised Visionary prototype after the feedback.

Functional prototype

Based on the AI-model and the data collected from the algorithm, a user interface was developed for testing the AI-model in its current state of development. There was a need for a simplified version of the *Visionary prototype* to conduct a user test of the interface and to primarily observe user reactions to the state of the AI-models in October 2023. At that time, the AI was still working with the initial release of the dataset, which included only approximately 3,000 images of various clothing items, so the accuracy was low due to insufficient amount of data.
The aim of this prototype was to serve as an interface for user testing the concept of an AI-assisted sorting tool in a physical sorting environment. There were some limitations in terms of interaction and the results provided by the AI-model due to the limited amount of data it had to work with at the time.

Development of the Functional prototype

A simplified version of the Visionary prototype was created, implementing only the most basic features. In this prototype, the user can choose from a limited number of parameters and set rules for the sorting facility. It also includes an interface that allows connection to a photo station or the option to upload an image from another connected source. The AI-model then reads the image and provides its output. The prototype was built using a platform called Hugging Face for developing interfaces with integrated AI functionality.

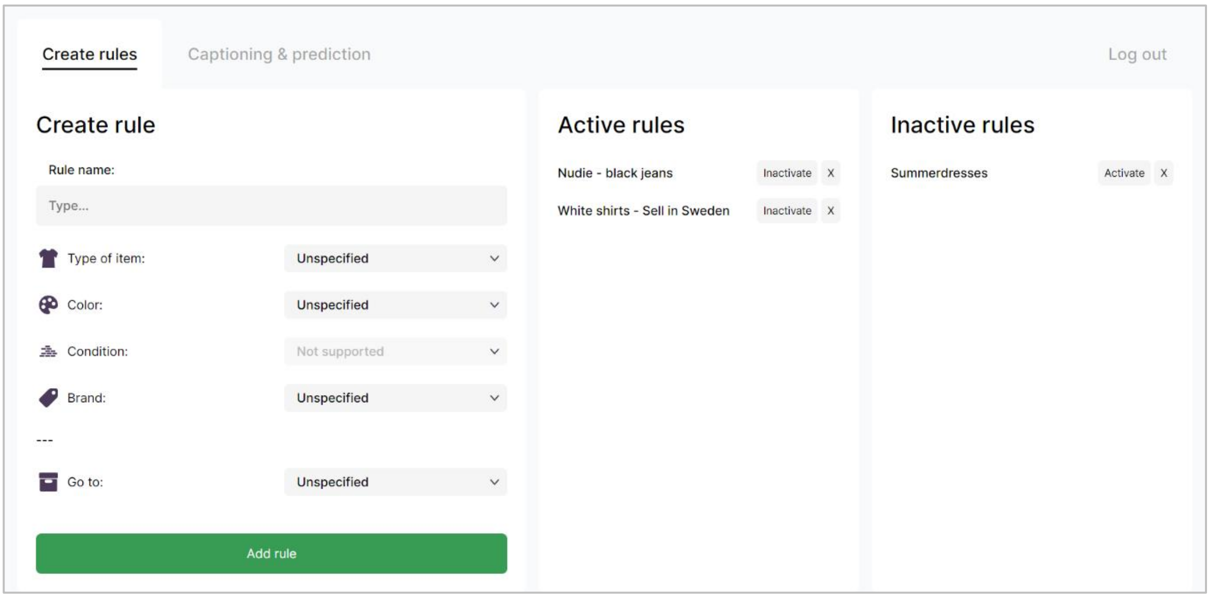


Figure 6. Image showing the first page of the functional prototype, from where the sorting rules are set.

The image above shows the page where a sorter sets the rules, by choosing from the categories to the left. The user can see which rules are active and not and use this function to change the state of the rules. The second page of the prototype *Captioning and Prediction* is where the user can interact with the camera station, upload images and receive results from the AI model.

User test of the functional prototype

The functional prototype was developed for user testing at Wargön Innovation facilities. The goal was to test the AI-model together with a sorting tool (interface) to gain insights into how the AI model would perform in an actual sorting facility, even though it is not fully implemented yet.
The test was conducted at the Wargön Innovation site with the aim of simulating a real-world use case for the test participants. The test was divided into two parts:

1. Setting the sorting rules. Which could be done from a laptop in the sorting facility, from an office desk, or from home.
2. Conducting the second part at a sorting station equipped with an installed photostation and a computer running the prototype.

Figure 7. Setup of the camera station in the sorting facility that was used in the second stage of the test.

There was a total of 5 test participants from Wargön Innovation, Röda Korset, Myrorna, Sharetex och Björkåfrihet.

Test results

The participants generally found it challenging to envision how this service/product could integrate into their sorting process, primarily because their current sorting is done entirely manually. The limited amount of data affected the decisions and information given by the AI-model and affected the second step of the test.
Several participants expressed a desire for more feedback from the program regarding their actions and how these would impact production on a larger scale. There was feedback concerning the names of the different attributes, and one conclusion is that the system needs to accommodate the varying needs of different users. Each user has their own way of labeling categories, such as "Best Use," and preferences for sorting based on different types of requests.

General Insights

- Difficulties envisioning the value of implementation in the sorting process (due to the fact that this is a future vision of an automated sorting process).
- The prototype was overall easy to use and understood by the participants.

Room for Improvements

- More feedback when interacting with the sorting tool is needed.
- Functionality that allows different users to set their own names on recommendations for best use; *Sell in Swe*, *Abroad* and how to work with *client requests* etc.
- The participants didn't agree with the AI model's decision on Best use. Which needs to be tested again with an upgraded dataset for more accurate results.

3.3. Result

The result from this work package is divided into several parts. The need analysis is one big part of the result, which lead to the result of the concept of a sorting tool and where in the sorting process this could be implemented. The future sorting tool was then envisioned through two prototypes; one visionary and one functional that are described in sections *Visionary prototype* and *Functional prototype*.

The key insights from the need analysis

- The stakeholders believed that the biggest impact could be created if the focus of the AI was on recommending the best use of a garment.
- Since other technologies would be needed to focus on pre-sorting, it was decided to concentrate on the main sorting.
- Personas of all potential roles that could interact with and benefit from the AI dataset.
- Similarities and differences of sorting facilities in Sweden and their different needs.
- Ideas on how the future sorting station could look. How could the sorting, and specifically the camera station, be automated (conveyer belt, hangers etc.).
- Identiyfing a wish-list of supporting solutions such as:
    - multiple cameras capable of capturing front and back views, brand labels, and size labels.
    - High-quality photo capabilities to detect imperfections such as pilling, tears, and defective prints, and to distinguish between knitted and woven materials.
    - A moving sorting line to efficiently present items to cameras while ensuring data accuracy.
    - Infrared light for material detection. Sensors for detecting odours, moisture, and other characteristics.
    - A software tool capable of integrating input from multiple technologies simultaneously.
    - An updatable AI system that continues to learn over time.

Key insights derived from the prototypes and testing

- The results shows that there is potential in using the dataset to assist the sorting process, by reducing the time it takes to make a decision of where the clothing items should go.
- The way of interacting with the sorting rules that was implemented in the prototypes enables a user-friendly way of digitalizing the sorting and enable future automation of the decision making of Best use.
- There is a great potential in what the dataset together with a sorting tool (interface) could help the sorting facilities with.

3.4. Conclusions

We have followed a design process and completed all planned activities in the work package.

It was challenging to reach consensus on the meaning of a 1-5 condition scale in a joint definition among stakeholders. We made one attempt but would recommend trying again to achieve a shared agreement. This would benefit consumers as well.
The market is taking a general approach to this problem and a new standard was released, by Svensk Handel, for second hand items in general in the end of the project: https://www.svenskhandel.se/api/documents/dokument/hallbar-ehandel/hallbar-e-handels-skickgradering.pdf

One of the challenges was getting stakeholders to envision how this technology could benefit their facilities. Each facility is unique, making it difficult to design a solution that satisfies everyone.

Prototyping a sorting tool interface is challenging when the AI model has not yet reached its full potential. Users had to imagine how future sorting facilities could utilize the AI, along with a camera station and other technical tools, to improve accuracy and save time and money. The functional prototype can currently be used with the existing AI-model. It can be iterated and expanded as the dataset grows larger and the AI-model becomes more accurate.

Future development should focus on investigating how this system can be integrated into existing solutions, such as their business systems. Additionally, exploring how facilities might need to be redesigned to accommodate the necessary technology is crucial.

4. Workpackage 4 – Open dataset

4.1. Background

The sorting process for second-hand clothes poses serious challenges to the reuse and recycling of clothes. Full automation requires combining robotics, AI, fusion of multiple sensors such as RGB and multi-spectral cameras including near infrared cameras for material detection as well as smell sensors. In this work package, we are focusing on building AI solutions using cameras by taking images of used clothes and annotating them.

The objective is to build a dataset of 30 000 garments that will be open for anyone who wants to continue research or build their own AI-model.

4.2. AI-annotationstation and data collection

The first milestone in this work package was to build a AI-annotationstation at Wargön Innovation (WI). The first step was to understand the needs for that, both hardware and software wise. The sorting staff at WI made a suggestion for attributes to annotate and that list was communicated to the project partners to give feedback about their needs. It was decided that photos would be taken of the front, the back and the brand tag. RISE then built an app for the annotators to use at the station.
RISE also contributed with information about what camera to use and what resolution of the photos that was reasonable to make the AI-models work well (too high resolution would make the models to slow). Two cameras were included, one for the front and back photo and one for the close up of the brand tag.
A handheld NIR scanner was used to determine fibercomposition.
An extra large table top were ordered to be able to include large/long garments and it was painted in a grey colour that would serve as a good background for the photos.
During the project the AI-annotation-station got continuous touch ups to make it better, such as more user friendly app and grid on the table top.
Later in the project an AI-annotation-station was also set up at Myrorna.
It should be noted that during the project timeline camera technology and processor speed has been developed a lot and different choices of hardware might have be done based on the conditions of today.

RISE made efforts to try to collect data from other sources, both online and through partners. That turned out to be difficult either because it was not right type for the project or that it was under some kind of license. Therefore, no other data than the dataset from the project has been used to train the AI-models.

4.3. Data

In the dataset each item is represented by three distinct images, one showcasing the front, one the back, and one image dedicated to the brand. To enrich this dataset, sorting experts annotated each item with attributes unique to second-hand fashion that are not found in first-hand fashion such as condition, pilling, holes, stains, smell, and optimal use.

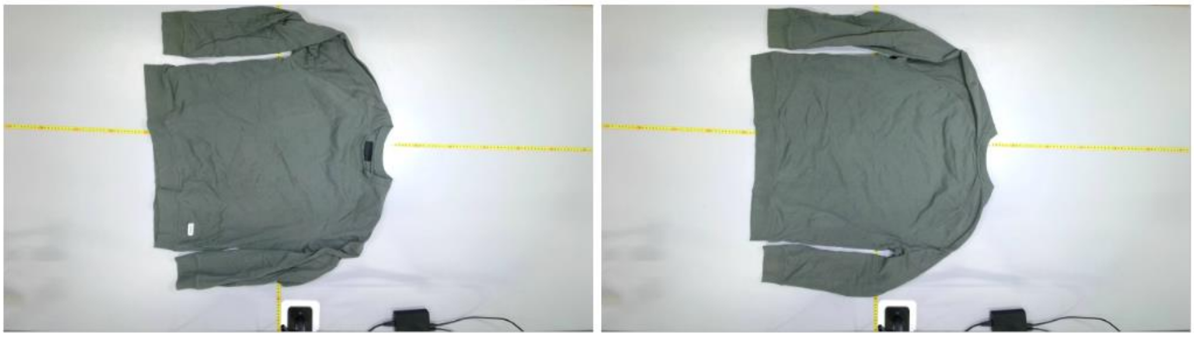
The dataset for this project focuses on the sorting of used clothes within a sorting facility. The primary objective is to classify each garment into one of several categories to determine its ultimate destination: reuse, reuse outside Sweden (export), recycling, repair, remake, or thermal waste.

Each data point in the dataset represents a single garment and includes a variety of annotations, some of which require nuanced interpretation:

- **usage:** Arguably the most critical label, usage indicates the garment's intended pathway. Options include 'Reuse,' 'Repair,' 'Remake,' 'Recycle,' 'Export' (reuse outside Sweden), and 'Energy recovery' (thermal waste). About 99% of the garments fall into the 'Reuse,' 'Export,' or 'Recycle' categories.
  Note: The attribute Repair did not have distinct definitions in the beginning and that might affect the result. Same for Remake that is hard to define due to that different stakeholders have very different and specific requirements.
- **price:** The price field should be viewed as suggestive rather than definitive. Pricing models in the second-hand industry vary widely, including pricing by weight, brand, demand, or fixed value.
- **trend:** This field refers to the general style of the garment, not a time-dependent trend as in some other datasets (e.g., Visuelle 2.0). It might be more accurately labeled as 'style.'
- **material:** This is determined either from the garment's brand label or using a Near Infrared (NIR) scanner.
- **damage labels:**
  - condition (1-5 scale, 5 being the best)
  - pilling (1-5 scale, 5 meaning no pilling)
  - stains, holes, smell (each with options 'None,' 'Minor,' 'Major'). Note: 'holes' and 'smell' were introduced after November 17th, 2022, and stains previously only had 'Yes'/'No' options.
  - damage (free text; usually left empty by annotators)

Note:
Label standardization remains a challenge in the fashion domain. For example, different systems may use varying scales to assess condition (e.g., 2, 3, or 5-point scales) or different terminology for categories (e.g., 'Ladies' vs. 'Women's' or 'Female').

Data samples



Lager 157, Ladies, Sweater, XXL, Green, Price: 50-100 SEK, Use: Export,
Trend: None, Cut: C-collar, Plain, Material: 100% cotton
Holes: None, Stains: Yes, Pilling: 4, Condition: 3

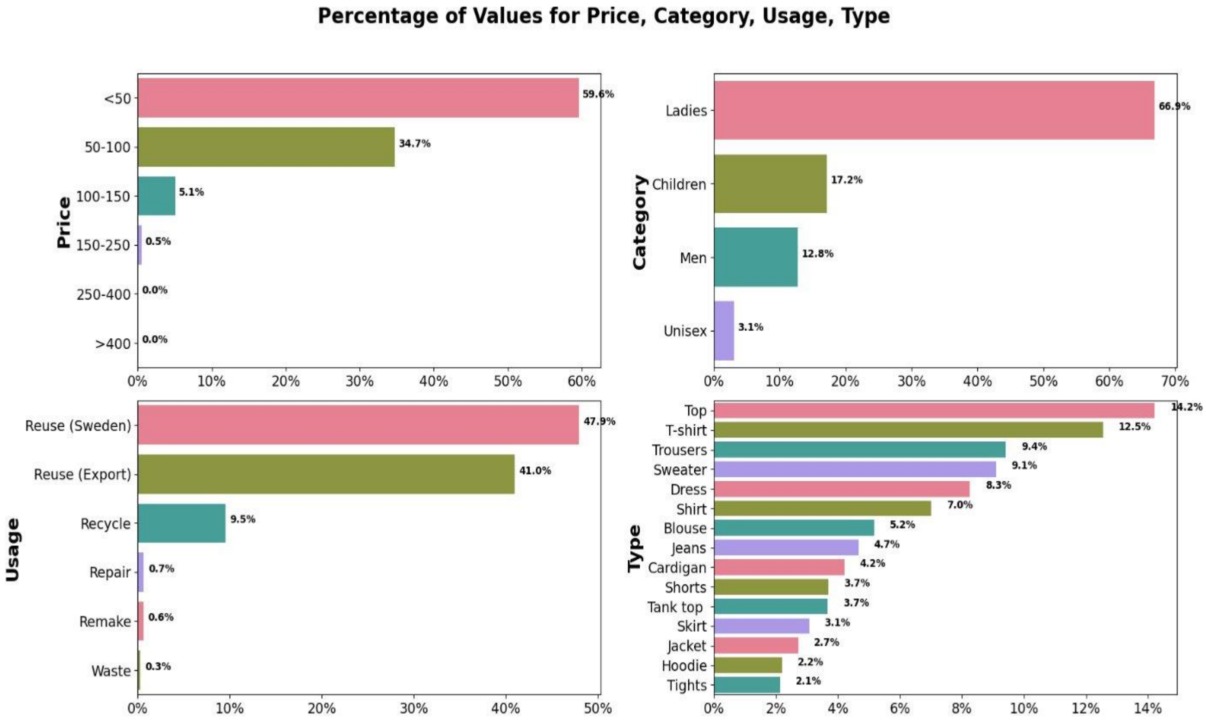
The example item from our dataset shows a front and back image on a white table background and a measuring tape. These images are taken from roughly one meter distance using a webcam. The measuring tape was added to give size information about the garments, but it was realized that the image resolution was not enough to read the size clearly. This prompted WI to suggest a new table design where each square grid is 10cm by 10cm marked with black lines. The labels highlighted in red are generally the most relevant for second-hand fashion and the material composition that plays a role in assessing the garment's recycling.

A sample with the new table is given below:

Mywear (Ica), Ladies, Cardigan, XL, Beige, Price: 50-100 SEK, Use: Reuse,
Trend: None, Material: 77% viscose, 23% polyester
Holes: None, Stains: No, Pilling: 4, Condition: 4

One can observe that the images do not always simply contain the garment and the table background, but end up also including wires and auxiliary camera (placed for a close-up shot of the brand image – not shown here). Additionally, strong reflection due to lighting lamps placed on top of the garment compromises the overall image quality. This is a limitation of our dataset that future work should address.

Dataset statistics



For the most important target variables, it was found that the data shows strong imbalance. For instance, nearly 99% of the data usage is annotated as reuse, reuse outside Sweden and recycling with almost no data for repair, remake and waste. This strong imbalance is both a reflection of what kind of garments end up at a sorting facility and potentially some selection bias where a small fraction of obviously unusable garments might have been discarded rather than annotated as “waste”. One possible explanation of having only low priced items in the data is that most consumers like to sell higher priced garments themselves through customer to customer platforms like Pliq, Tradera, Blocket, etc. instead of placing them in used garments collection boxes.
Similarly, the sorting facility receives less than 6% of garments in the >100 SEK category implying a strong preference towards low priced clothing items. It should also be highlighted that WI accounts for nearly 80% of the annotated data and WI does not set prices in practice. WI is a demo facility for development of textile sorting. In contrast, Myrorna does sell clothes and are used to setting the price.

Selection of database solution:

For this project, it was opted to use a file-based storage system rather than a traditional database solution. This choice was made due to the nature of our data, which consists primarily of image files and associated JSON metadata files. Each clothing item is represented by three images (front view, back view, and brand label) and a JSON file containing detailed annotations. This structure lends itself well to a hierarchical file system, organized by stations and timestamped folders. While a database could have been used to store the metadata, the simplicity and portability of the file-based approach aligned well with our project needs and facilitated easier sharing and distribution of the dataset.

Selection of data sharing solution:

After careful consideration, we selected Zenodo as our primary data sharing platform. Zenodo was chosen for several key reasons:

- It is a widely recognized and respected platform for sharing scientific datasets, ensuring visibility within the research community.
- Zenodo assigns a Digital Object Identifier (DOI) to each dataset, which enhances discoverability and enables proper citation of our work.
- The platform supports version control, allowing us to update the dataset while maintaining records of previous versions.
- Zenodo's robust infrastructure ensures long-term preservation and accessibility of the data.
- It offers flexible licensing options, which was crucial for our decision to release the data under the CC-BY 4.0 license.

This solution not only meets our current needs for data dissemination but also aligns with best practices in open science and data sharing.

Ownership model investigation and selection:

Given the collaborative nature of this project, involving multiple organizations (RISE Research Institutes of Sweden AB, Wargön Innovation AB, and Myrorna AB), it was crucial to establish a clear ownership model for the dataset. After thorough investigation and discussion among partners, a shared ownership model was implemented with the following key features:

- All partners agreed to release the data under the CC-BY 4.0 license, promoting open access and reuse of the dataset.
- A basic data ownership agreement was signed by all involved parties, establishing shared rights and responsibilities.

- The agreement stipulates that if any partner wishes to release the data under a different license in the future, they must first consult with all other partners involved in the agreement.

This model was selected to balance the interests of all contributing organizations while maximizing the dataset's potential impact on research and innovation in the field of second-hand fashion. It ensures that all partners have a say in future decisions regarding the dataset's use and distribution, while still maintaining the open-access principles that guided the project from its inception.

Challenges during data collection and recommendations for future projects

Most large scale data creation processes are cumbersome and result in a dataset that can suffer from a range of issues. Despite the best efforts to ensure the creation of a high quality dataset, some lessons have been learned on how to improve the data quality in the future:

- **Higher resolution images:** When the project was initially started in 2021, our goal was to simply classify garments into reuse, reuse outside Sweden (export) and so on. Predicting a single label from the image is called single label image classification and does not necessarily require higher resolution images. Indeed, most models resize all images to 224x224 regardless of their initial resolution. Most of our images are of 1024x1920 size and this selection were satisfying in the beginning. However, as the project went on and with the simultaneous exponential increase in the capabilities of AI-models in general, higher resolution images (for instance, 4K or higher) would have served us better since the key property that distinguishes second-hand fashion from first-hand fashion is the "condition" that is a function of properties such as damage (holes, stains, pilling) and some unobservable (to cameras) properties such as smell. For correctly identifying damage, one requires detailed close-up images of the garment, otherwise AI models cannot correctly identify damage. Our ***recommendations*** for future projects creating similar datasets would be to use higher resolution cameras to enable detection of tiny damages on garments.
- **Lighting and colors: W**ebcams like Logitech C920 was used to take the images, but later it was realized that these cameras do not capture garment colors consistently. Additionally, the addition of two lighting lamps mounted next to the camera about one meter above the garment led to strong reflections off the surface of the table and compromised image quality. For future projects, it is ***recommended*** using a camera and lighting setup that can capture garment colors accurately without compromising the visibility of the garment.
- **Annotator training:** The annotation app was not always properly used and mistakes like collecting duplicate images or assigning the wrong annotations to a set of images were made. Furthermore, the frequent use of human hands, faces, etc. required excessive post-collection cleaning that went on for weeks and required going through every single one of nearly 100,000 images to ensure no private data is leaked. Our

recommendations are to ensure that annotation staff is adequately trained to avoid these issues.

- **On-site support:** The data was collected at sorting facilities without adequate technical support. In general, while the data collection process was smooth, often cameras were incorrectly displaced from their original position. Furthermore, the data was by default only saved locally and during the transfer to the cloud, some data was lost. We **recommend** having on-site technical support to ensure that image quality is regularly checked and data is not mistakenly deleted.

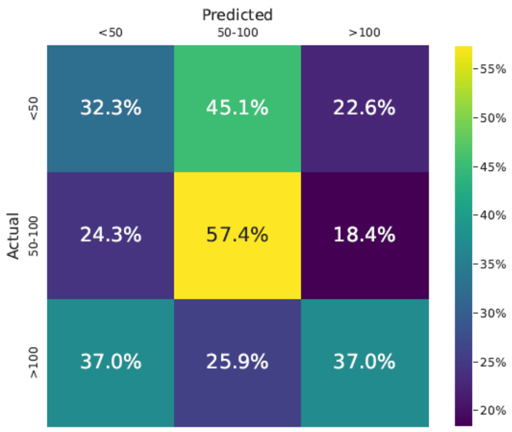
4.4. AI Models

The most critical attributes for effective sorting are:

Usage: Determining whether a garment is destined for reuse, reuse outside Sweden, recycling, repair, remake, or waste is paramount.
Price: While annotations offer "suggested" prices, accurate price prediction remains a valuable goal.
Category: Identifying the garment's target demographic (men's, ladies', children's, unisex) is essential.
Trend: Classifying garment type (top, jeans, etc.) is also informative, despite the long-tailed distribution of types.

These attributes present a series of classification tasks, some of which may be multi-label (e.g., a garment could be both a "top" and a "tank top"). Notably, each data sample includes three images: front, back, and close-up of the brand label. However, most models primarily utilize the front image, omitting brand information in some cases.

Price classification



The current performance of price prediction is not great as witnessed by the above figure that compares the predicted price vs the actual. The probable reason is that only a fraction of the data of our eventual goal of 30,000 clothing items was collected at the time. A larger dataset will improve the robustness and generalizability of the AI models.

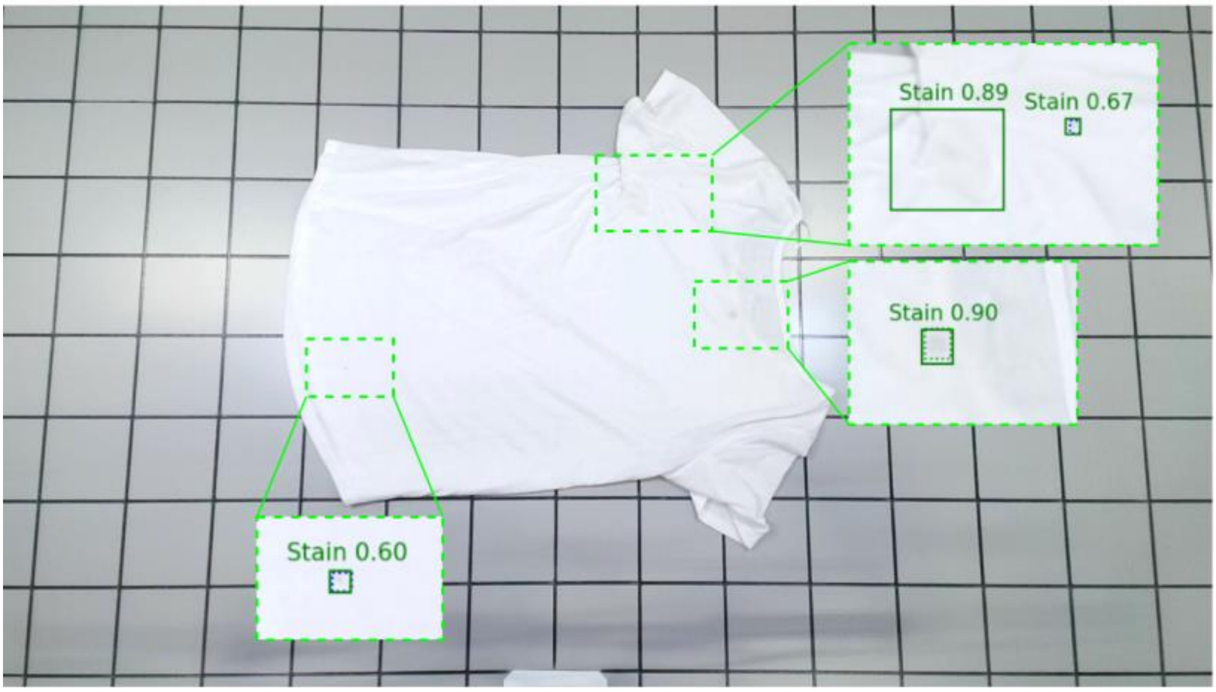
Image embeddings/Similarity search

Existing search engines using pre-existing knowledge graphs to quickly search through items when a text query is entered. However, deep learning allows to construct image based searches, something Google Lens for example, has been using for a while. Simon Hermansson (Master's thesis, LiU, Jan. 2023-Jun. 2024) conducted a comprehensive study on building image embeddings using the dataset developed in this project. He primarily focused on two models: Masked AutoEncoders where part of the image is masked and the model is forced to learn how to fill in the mask, and Contrastive Language Image Pretraining (CLIP) that matches text captions and image embeddings in latent space. CLIP has been successfully used as a back bone of many modern LLMs with vision capabilities.

Example of image retrieval based on the query image in the left most column. Results are shown from the CLIP model.

Damage detection

Size	mAP@[.50; .05; .95] ↑	mAP@.50 ↑	**mAP@.25 ↑**
Small ($< 32^2$ pixels)	1.29	5.03	25.56
Medium ($32^2 - 96^2$ pixels)	12.39	26.29	41.2
Large ($> 96^2$ pixels)	3.3	5.71	6.07



While originally not planned, through a Master's thesis done by Leonard Norblad at Linköping University (Jan. - Jun. 2024), it was studied whether the AI can detect damages on garments using computer vision algorithms such as Faster RCNN. The sample detection is shown in the image above. The table shows mean Average Precision (mAP) metric for each size (row) and each metric (column). For instance, mAP@0.25 means that even if the predicted bounding box has only a 25% overlap with the ground truth bounding box, then it is considered a correct result. As one can observe from the table, the best performance is for the medium sized objects while detecting small damages remains incredibly challenging.

4.5. Result

A unique dataset consisting of 31 997 garments have been created and released openly here: https://zenodo.org/records/12518734

4.6. Conclusion

The project managed to build the dataset but it was completed late in the project, much later than originally planned. Building the AI-annotationstation and creating a dataset was a tougher task than imagined when applying for the project.

Getting everything to work in a good way with the AI-annotationstation, both considering the data collection and a smooth working flow for the annotators, was a process that needed upgrading several times during the project.
The data collection was time consuming, but after all the data was collected, data-cleaning was needed too, which also took quite a while considering the amount of photos.

5. Workpackage 5 – Prototype of AI solution

5.1. Background

The primary objective of this work package is to try to build AI-models (prototypes) for the attributes annotated in the dataset. All categories will be used in different models to see what kind of performance is possible to deliver.

A prototype of a sorting tool should be verified with the needs owners (project partners) in a POC (proof of concept) test.

The future goal is that the models can be developed to a full decision support tool in a textile sorting facility and potentially drive fully automated sorting of second-hand garments.

5.2. Overview of AI models used for demonstration

During the course of the project, multiple AI models were developed and demoed at various internal and external events. Here we briefly describe a few models that were developed during the project and the models that were eventually used for the final testing:

- **June, 2023:**
  Models trained on 3000 clothing items were built to predict:
  Caption using a front image only
  Brand using a brand image
  Price and usage prediction using a front image only
  Image retrieval based on similarity to the images in the vector dataset
  Text based retrieval on searching through images based on a text prompt

  These models are based on the multi-modal text and image encoder model called CLIP by Open AI and can be accessed here:
  https://huggingface.co/spaces/fashion-demo-organization/fashion_demo/tree/main

- **April 15th, 2024:**
  The initial plan for the final demo and testing was to train the earlier models on newer data, but because of delays in both data collection and model development, the project was forced to instead try models either trained on 3000 items as before or accessing foundation models through an API that support vision inputs.
  RISE trained a one vision model finetuned on the dataset developed in this project and used GPT4-Vision as the second model to predict a range of attributes. The advantage of powerful LLMs with vision capabilities is that it have been pretrained on much larger datasets compared to open source pretrained vision models. The results reported in the next section are based on feeding the GPT4-Vision model (gpt-4-turbo-2024-09-04) that was prompted for structured outputs using the *instructor* library.

5.3. Tests

Sorting with increased amount of requirements

One realization made during the project was that all users have different requirements for the fractions they sort for and the fractions are not necessary the same either. In the future, when the volumes of collected textile increases and more companies have circular business models with certain requirements on the input material, the amount of requirements and fractions to keep track of in the sorting will be very complex.
A small test was conducted to show how more complex sorting affects the quality of sorting.
The test was conducted at Wargön Innovation and had three sorting levels. Every level had a duration of 1 hour.
Level 1: 9 categories. The normal base categories in the sorting line.
Level 2: 19 categories. 14 of those are known in the line and 5 new unknown categories.
Level 3: 34 categories. 14 of those are known in the line and 20 new unknown categories.

The result showed an increase in number of garments that was placed in the wrong category. Just this small addition of categories gave a summarized increase of mistakes by 4-5 %.

AI vs Human

This test had the purpose of comparing the time it takes for a human to assess a garment vs when the AI-model does it. Considering the AI-model was not trained on a large amount of data at the time we knew that it would make some mistakes in the result. Therefore, we choose to compare the results only for time not for accurate assessment.

The human assessment was made by three different skilled sorters at Wargön innovation. Everybody assessed eight garments for best use and also giving a short description of it. For example "Red shirt for a woman, oversize fit, probably cotton, a little worn but good enough for reuse".
A total of eight garment were assessed by the humans and AI.

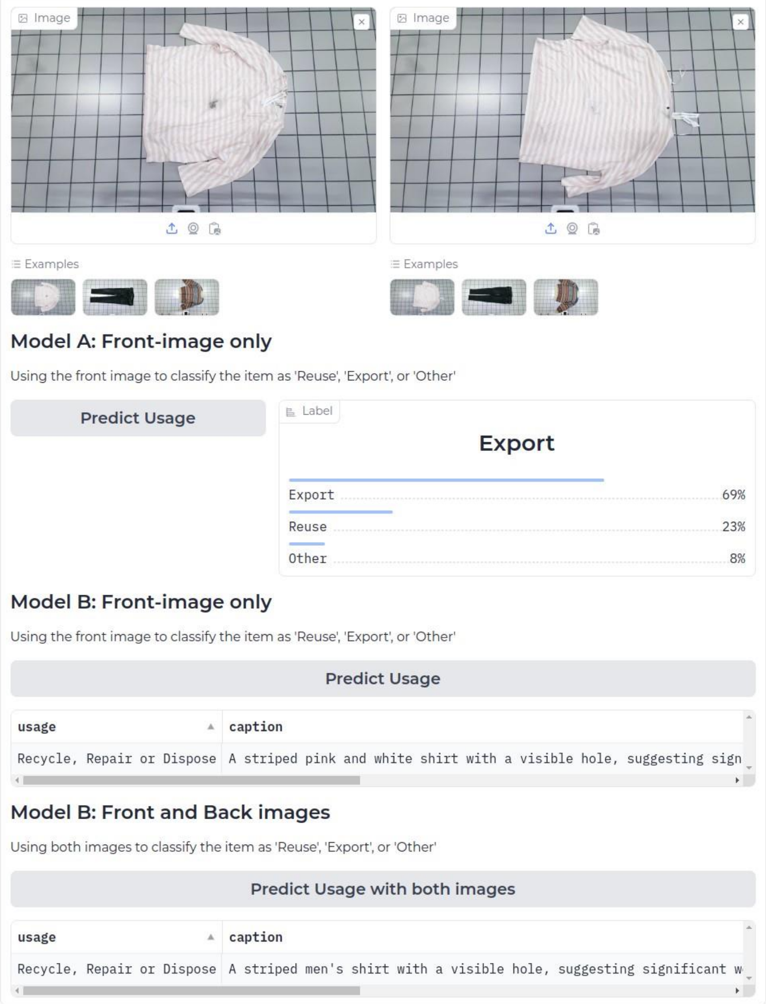
The table below show the results in percent how much faster AI was.

Garment	1	2	3	4	5	6	7	8
How much faster was AI	54%	37%	56%	19%	34%	35%	44%	7%

The conclusion is that the AI-model is faster than the human, even though it was not perfectly trained.

POC

In April 2024 the last project meeting was held at Wargön Innovation and all results was presented. A part of this meeting was that the present project partners could try to use the AI-model. An interface had been put together especially for the trial to make it possible to use the AI-models, it was not a fully developed AI-tool and as mentioned before the AI-models had not, at the time, been trained on the full amount of data in dataset due to the delay of that. The picture below show how the “tool” looked at the POC testing.



The Proof of Concept trial gave the project’s needs owners a chance to try AI assisted sorting and give feedback on how it worked. There were a lot of good discussions and ideas. It gave proof that there is a definite future for AI in textile sorting, however, the models need more training and connection to the more advanced interface in the Visionary prototype developed by the UX-team.

5.4. Result

The objectives of having user tested prototypes analyzed and evaluated was fulfilled.

Modeling second-hand fashion presents unique challenges compared to first-hand fashion.

Key difficulties include:
Importance of subtle details: Minor damages, not always visible in images, can be the deciding factor between reuse and disposal.
Class imbalance: Some usage categories are significantly more frequent than others.
Limited information: Many models rely solely on the front image, neglecting brand and other potentially informative data.

Despite these challenges, the results demonstrate promising potential for AI models to support and potentially automate the complex task of sorting second-hand garments. Continued research and development, including incorporating more comprehensive data sources, may further enhance model performance and drive sustainable practices in the second-hand fashion industry.

5.5. Conclusions

It should be noted that when this project started, AI was not on top of everybody's mind as it is now. The development in the field during the project time has been huge and now "everybody" is using Chat GPT. It has been a bit of a struggle for the project to make interested people understand the complexity of the task since AI in general is communicated as "the simple solution for everything".
However, when discussing solutions with interested stakeholders it is clear that the work done in this project is ground breaking and a great stepping stone for further development within the field of using AI in textile sorting.

A learning from the project is that a sorting tool needs to be easy to adopt after each user. Every user has different workflows and customers and need to be able to establish their own different categories and connected requirements and to be able to change that due to the daily demands.

6. Workpackage 6 – Life cycle assessment

6.1. Background/Purpose/Objectives

The fashion industry has well-known environmental impacts that have been studied for several years, with increasing consumption of textile products leading to a steady increase in such environmental impacts[1]. This has led to multiple calls for action towards impact mitigation and improvements of circularity practices in the sector. As a response, a plethora of solutions in the form of innovative technologies, practises and processes have been developed aiming to accelerate a transition to circular business models, but some of these solutions have their own environmental challenges to solve[2].

Life cycle assessment (LCA) is a systems analysis tool that has been widely applied to assess the environmental impact of textile reuse and recycling technologies. Typically, LCA studies of textile waste management exclude the environmental impact from sorting because it is considered to be negligible, which may lead to underestimating these impacts[3]. Even if enhanced sorting via Near Infrared (NIR) technologies has been found to have positive environmental effects in all impact categories[4], the environmental effects from implementation of AI technologies in sorting has not been studied.

The purpose of this work package is to study the environmental effects from implementing AI technologies in sorting using LCA and provide stakeholders with recommendations for upscaling based on these results.

6.2. Work process

The work in this task consists of two parts; the life cycle assessment and a gap analysis of current policies and business models from an environmental perspective. This section describes the methodology used for these.

Life cycle assessment methodology

The goal of the LCA carried out in this work package is to explore the environmental effects of applying AI tools for sorting of post-consumer textile waste. The LCA will focus on the impacts of AI training, the potential downstream benefits of enhanced reliability and speed of sorting, and an estimation of a break-even point for AI implementation based on error rate reductions. The target audience of the LCA are the stakeholders involved in the project, and the intended use is to communicate internally the potential of AI for sorting. The functional unit applied is Tonnes of sorted and treated post-consumer textile waste. An additional functional unit was analysed to capture the

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[1] Munasinghe, P., Druckman, A., & Dissanayake, D. G. K. (2021). A systematic review of the life cycle inventory of clothing. In Journal of Cleaner Production (Vol. 320). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2021.128852

[2] Ribul, M., Lanot, A., Tommencioni Pisapia, C., Purnell, P., McQueen-Mason, S. J., & Baurley, S. (2021). Mechanical, chemical, biological: Moving towards closed-loop bio-based recycling in a circular economy of sustainable textiles. Journal of Cleaner Production, 326. https://doi.org/10.1016/j.jclepro.2021.129325

[3] Sandin, G., & Peters, G. M. (2018). Environmental impact of textile re-use and recycling – A review. In Journal of Cleaner Production (Vol. 184, pp. 353–365). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2018.02.266

[4] Dahlbo, H., Aalto, K., Eskelinen, H., & Salmenperä, H. (2017). Increasing textile circulation—Consequences and requirements. Sustainable Production and Consumption, 9, 44–57. https://doi.org/10.1016/j.spc.2016.06.005

difference in time efficiency of the sorting; kilogram-second of sorted and treated post-consumer textile waste.

The system boundaries of the LCA are illustrated in Figure 8. The studied system begins at the gate of the sorting facility, excluding collection since it will not be influenced by the implementation of AI. The sorting process includes the operation of the facility where pre-sorting and sorting is carried out, including energy and water use as well as waste generation. Another module of the system is the AI training and operation, with focus on energy use and hardware requirements. Finally, the downstream effects of enhanced sorting are studied in a separate module where three streams are modelled for the fate of the textile waste following the sorting; re-use in Sweden, re-use for export and what is commonly referred to as special request, assumed to be only for recycling.

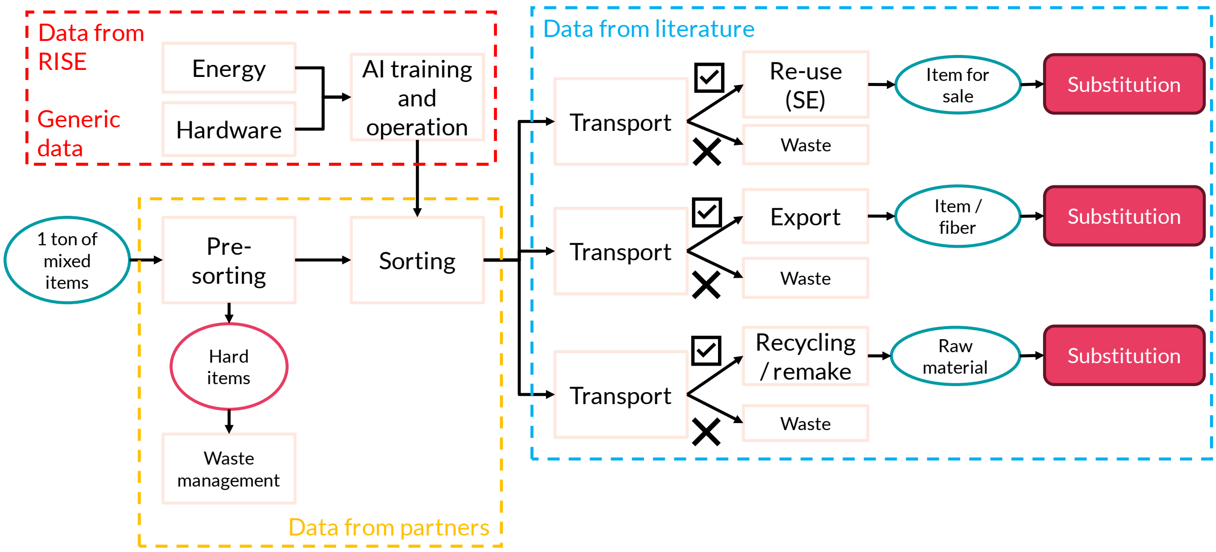

Figure 8 System boundaries of the LCA

For the downstream module, different scenarios were assessed for different levels of reliability of the AI tool applied. Enhanced reliability means that with more reliable sorting, less textile would end up in the wrong stream, meaning that more textiles would end up being reused or recycled. A base case scenario was applied with fully manual sorting, and business as usual downstream fates. The base case corresponds to an 85% level of reliability, while two additional scenarios of enhanced sorting of 90% and 95% were also analysed.

All the data used for the LCA, including assumptions and scenarios, can be found in the Appendix (LCA data). Inventory data for the assessment was obtained from different sources. For the sorting facility module, site-specific data from two of the project partners was used while generic databases were used for upstream processes. For the AI module, the data was provided by the researchers in work package 4 who worked on the development of the AI tool, also with generic datasets for energy supply and hardware manufacturing. Finally, the downstream module was modelled based on literature data, as follows:

- The fate of exported waste from a recent EEA report[5].
- The share of mechanical and chemical recycling from Dahlbo et al. (2017) and the JRC report by Huygens et al. (2023)[6].
- The waste composition (fibers) also from the Huygens et al. (2023) report.
- The transport distances for exports from the Norion – EURiC report by Treszpacz et al. (2023)[7]
- To model the recycling processes and substituted outputs, different sources were used; the Siptex report by Lidfelt et al. (2022)[8], the EC report by Duhoux et al. (2021)[9] and the Mistra Future Fashion[10] database owned by RISE (not publicly available), with generic databases for upstream processes.
- The substitution rates were assumed based on a literature review.
- The error rates for manual and AI-enhanced sorting as well as the time per sorted garment were obtained from the tests carried out in work package 5.

Finally, for life cycle impact assessment the latest environmental footprint method was used; EF 3.1 as available in SimaPro. All the impact categories included were assessed, but only climate change and water scarcity are presented in this report.

Gap analysis

For the gap analysis, a qualitative review of the current and upcoming regulations at the EU level was carried out. The goal of the review is to identify gaps in current legislation to address the use of AI in textile waste management, and to use this gap analysis together with the LCA to provide policy recommendations towards more circular business models.

[5] Deckers, Duhoux, Due (2024) Textile waste management in Europe's circular economy. Available at: https://www.eionet.europa.eu/etcs/etc-ce/products/etc-ce-report-2024-5-textile-waste-management-in-europes-circular-economy

[6] Huygens, D., Foschi, J., Caro, D., Patinha Caldeira, C., Faraca, G., Foster, G., Solis, M., Marschinski, R., Napolano, L., Fruergaard Astrup, T. and Tonini, D., Techno-scientific assessment of the management options for used and waste textiles in the European Union, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/6292, JRC134586.

[7] Trzepacz, S., Dina Bekkevold Lingås, N., Lise Asscherickx, N., Karolien Peeters, V., Hilde van Duijn, V., & Marieke Akerboom, E. (2023). LCA-based assessment of the management of European used textiles. Available at: https://circulareconomy.europa.eu/platform/en/knowledge/lca-based-assessment-management-european-used-textiles

[8] Lidfeldt, M., Nellström, M., Albertsson, G. S., & Hallberg, L. (2022). Siptex WP5 report:
Life cycle assessment of textile recycling products. Available at:
http://urn.kb.se/resolve?urn=urn:nbn:se:ivl:diva-4098

[9] Duhoux, T., Maes, E., Hirschnitz-Garbers, M., Peeters, K., Asscherickx, L., Christis, M., Stubbe, B., Colignon, P., Hinzmann, M., & Sachdeva, A. (2021). Study on the technical, regulatory, economic and environmental effectiveness of textile fibres recycling – Final report. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. Publications Office, 2021, https://data.europa.eu/doi/10.2873/828412

[10] More information: http://mistrafuturefashion.com/sv/hem/

6.3. Result

LCA results

The results from the LCA are presented in two parts; one focusing on the sorting stage with and without AI support and another on the whole system, including the downstream impacts.

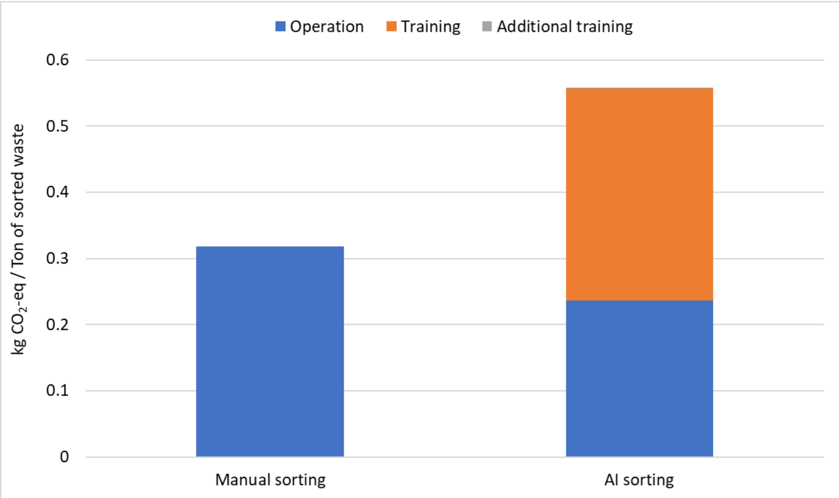

Figure 9 Results from the LCA at the sorting level, for climate change

The results for the impact category climate change at the sorting level are presented in Figure 9. The potential climate impact for the AI sorting, including the training, additional training and operation of the AI tool is about 43% higher compared to manual sorting. The climate impact for the AI sorting stems mainly from the hardware for the training and operation of the AI tool. Additional training time refers to extra time used for unsuccessful training attempts. These attempts are assumed to be made on the same AI training hardware and tools so it is only impacts from the running time that are given.

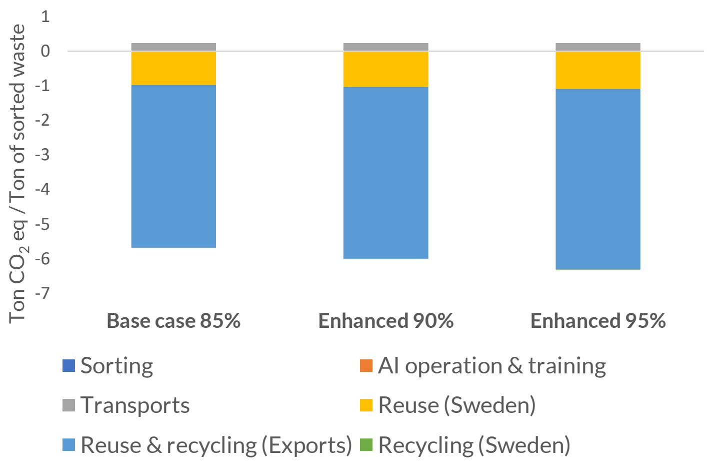

Figure 10 Results of the LCA including the downstream effects for climate change, per tonne of sorted waste

The climate impact effects of implementing AI-enhanced sorting are outlined in Figure 10, while the effects in the water deprivation category can be found in Figure 11. The results show that the potential benefits from improved reliability in sorting can very easily offset the additional environmental impacts from developing an AI tool and implementing an AI sorting station in both impact categories. It only takes an 1% increase in reliability to overcome the impacts caused by the AI tool.

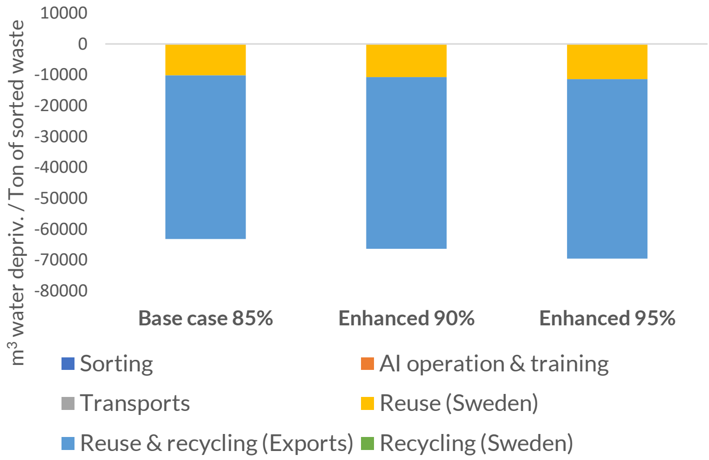

Figure 11 Results of the LCA including the downstream effects for water deprivation, per tonne of sorted waste

The magnitude of this difference can be explained by different factors. First, the relative impact of sorting activities is very low in comparison to other life cycle stages of circular textile models. Second, the high environmental impacts from the production of new garments and primary fibers means that any improvement in reuse and recycling would result in significant benefits downstream. Finally, the share of textile waste that ends up being successfully reused or recycled is low at the moment. This is specially the case of exports, where a significant share of the textiles ends up in dumpsters. By increasing reliability of sorting, any reduction achieved for this waste stream results in significant environmental impacts.

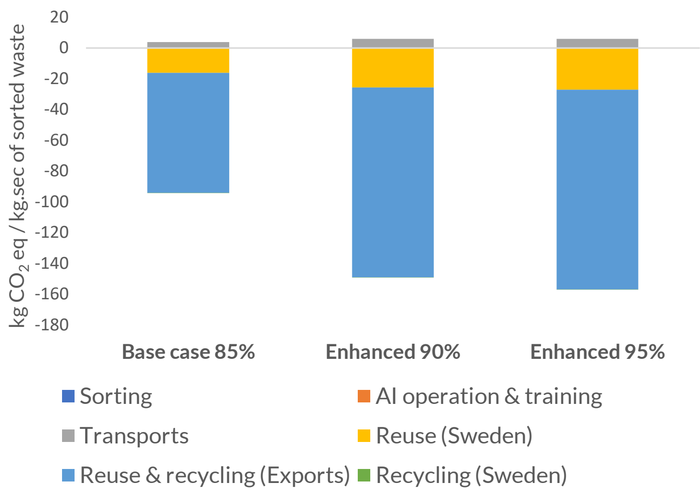

Figure 12 Results of the LCA including the downstream effects for climate change, per kg-second of sorted waste

The results in Figure 12 show the climate effects from AI enhanced sorting per kg-second of sorted waste, a different functional unit. The speed of sorting is an important aspect of the process and its function, especially in a future with increasing flows of textile waste collected. The results show that besides the potential benefits of increased reliability, the implementation of an AI tool can also lead to environmental benefits while delivering a more time efficient function.

Gap analysis – barriers to circular business models

A business model can be defined as how companies do business, or how companies convert resources and competence into economic value. Circular business models integrate value creation from all three sustainability dimensions and generate profits while keeping the value embedded in products and materials even after they have been used. This can be achieved in different ways; by extending the service life of products or by reintroducing them into production processes.

The type of circular models studied in this project focus on value recreation and delivery, through collection and resale models capitalizing residual value of discarded garments. Barries for the implementation of circular business models can be classified as market and institutional barriers, value chain barriers and organizational barriers. Based on existing literature and the results from this work package, the following barriers have been identified:

- Market and institutional barriers:
    - Unclear policies about use of AI, globally.
    - Uncertainty in customer demand and economic value of re-use garments and recycled fibers.
    - Poor awareness of the environmental benefits from enhanced sorting.
    - Negative perceptions of AI, including costs of implementation.
    - Lag due to adaptation of stakeholders to new models.
- Value chain barriers:
    - Complexity of global trade of textile waste.
    - Dependencies between value chain actors in textile waste export trade.
    - Risk aversion with innovative partnerships using novel solutions.
- Organizational barriers:
    - Unclear business case for AI-tools.
    - Lack of technical knowledge and capabilities in organisations, especially small or non-profit organisations.
    - Negative perceptions of AI among personnel.
    - Availability of financial resources for implementation of AI stations.

This project has focused on removing the technological barriers towards the implementation of enhanced sorting. However, other barriers remain. Another positive outcome of the project is demonstrating that some organizational barriers can be removed by training and proper design of AI stations.

Gap analysis – policy and regulation

The most relevant policy decision in recent years for circular textile business models is the EU Strategy for Sustainable and Circular Textiles, adopted in 2022, with a holistic perspective on textiles life cycles and aiming to address the ways textiles are produced and consumed in Europe. The strategy is framed in the European Green Deal the Circular Economy Action Plan (CEAP). A proposal for Ecodesign for Sustainable Products Regulation (ESPR) was introduced as part of the CEAP. The ESPR will set new requirements and restrictions regarding the life cycle performance of products and introduce a Digital product passport (DPP) to improve data transparency of products. The proposal of the Green Claims Directive means to tackle greenwashing by making green claims reliable, comparable, and verifiable and will be supported by the Product Environmental Footprint (PEF) and more specifically the PEFCR for garments and footwear. Finally, a proposal for a corporate sustainability due diligence directive (CSDDD) was adopted in 2022, aiming to introduce sustainability aspects into the strategy of companies by requiring them to communicate the negative impacts of their supply chain inside and outside of Europe.

Another body of relevant regulation comes from the waste management side. An 2018 amendment of the Waste Framework Directive, ordered that the textile waste shall be separately collected by start of 2025. A proposal to amend the directive again came in 2023 adding the Extended Producer Responsibility (EPR) for the textile sector giving SMEs some relief by establishing higher requirements on large companies. Moreover, the adoption of the Waste Shipment Regulation (WSR) created restrictions on exporting of waste requires follow-ups to ensure proper management of the exported waste. A secondary goal of the Regulation is to boost material recycling, as it also includes restrictions on incineration. The Regulation also establishes requirements for efficient and digitalised transport of waste.

The use and development of Artificial intelligence has boomed in recent years due to the appearance of chatbots such as ChatGPT. The EU recently adopted the 2024 Artificial Intelligence Act to set a common framework for the use and supply of AI systems in the EU. The framework adopts a risk-based approach, regulating mostly AI applications of high risk or limited risk.

Based on the results from this work package and a review of the existing policy framework, the following gaps have been identified:

- The clearest gap is that none of the textile or waste specific regulations nor proposals mention specifically the use of AI and its complexities. The proposed amendment to the waste framework directive does mention the need for scaling up sorting and the implementation of automation but does not rely into the specifics.
- While the AI act implements strict regulations, its risk-based approach means that low risk applications will not be subject of regulation. Since the models developed for sorting in this project fall into the lowest risk category, there are still no regulations applicable, only the option to comply with certain requirements voluntarily. This means that responsibilities of different stakeholders are not clear.

- The current environmental profile of the implementation of AI tools for textile sorting, as demonstrated in the LCA results, are significant since the current status of textile sorting for circularity is quite low, meaning that there is significant room for improvements, low-hanging fruits in other words. In the future, where improvement potential is less obvious and the AI models rely on significant amounts of data, the energy required to store and update the AI tools may increase. Increasing energy consumption in combination with diminishing returns in environmental mitigation may change the environmental case for AI models. Future policy should tackle this issue and establish requirements for energy efficiency and renewable energy supply for data centres.
- The aforementioned regulations could be clearer about the implementation of subsidies for SMEs, microenterprises or even non-profit organisations to facilitate adoption of advanced technologies such as AI. Even as the EPR regulation includes reliefs on SMEs, it could be clearer in other regulations, especially those targeting the textile sector. Europe has high ambitions towards circularity and textile waste flows to sorting stations will most likely increase, but the large majority of companies performing the sorting nowadays do not have the means to large investments.
- The organisations that are currently carrying out the sorting in Europe have very mixed missions but still hold very valuable know-how in their work force. A transition to more modern AI-enhanced sorting should include actions to preserve this know-how and manage this work force so their livelihoods do not get affected negatively by technification. Moreover, these adoption pathways should also consider training needs for new technologies. In the case of sorting, sorting personal would need training on the use of advanced tools such as AI enhanced stations.
- More advanced sorting technologies for large scale adoption in Europe would require a harmonised and consolidated coding systems for textile waste stream to be adopted in the EU. This would also facilitate data sharing along the value chain of textile waste. This is particularly sensitive for textile waste value chains since many actors exist outside Europe where the regulations are not very clear.
- The implementation of AI-enhanced sorting would bring complexities concerning data sharing, security and the protection of sensitive information. AI training requires large amounts of data, but the rights and responsibilities for data collection needs to be regulated.
- A pathway towards enhanced sorting should also account for chemical safety and content of substances of very high concern. A harmonisation with chemical regulations may be needed. This is also important for the safety of sorting personnel.
- Consumer awareness and perceptions about AI need to be managed. AI is a complex topic globally and many consumers may have strong feelings about its use in the product they acquire.

6.4. Conclusions

The results from this work package demonstrate that the implementation of an AI sorting station will most likely result in environmental benefits downstream. The environmental impacts from the AI tool would be offset by achieving as little as 1% of increased reliability in sorting in all impact categories. This result is highly dependent on the assumptions concerning the fate of the textile waste. Still, given the low rate of recycling and reuse achieved currently in Europe, the potential to improve is significantly high.

Even as reuse is the preferred alternative for management of textile waste, not all garments are reusable and more fibre-to-fibre and monomer-to-monomer recycling will be needed in the future. Most of the technologies for recycling available today depend heavily on the availability of quality feedstock, and sorting is key to be able to separate textile waste in different streams for specific recycling purposes. In a future where more recycling is achieved, enhanced sorting will be a requirement both in terms of reliability and time efficiency due to the high volumes of waste that will be processed.

Finally, this chapter identifies policy gaps concerning the use of AI for enhanced sorting of textile waste, as well as barriers to implementing such business models. The main policy gaps are the unclear regulation of low-risk applications of AI, requirements to energy supply for data centres and financing for adoption, specially for SMEs. Meanwhile, the most prominent business model barriers are the unclear policies, the lack of knowledge and know-how, negative perceptions of AI and the complexities of global trade in the textiles sector.

Appendix 1 – LCA data

This appendix presents a summary of the data used for the LCA carried out in WP6.

Sorting AI training and tool

Table 2 Data used for modelling AI training and tool

Description	Amount	Unit	Dataset
Hardware and energy use for AI data collection:			
Laptop	1	Pc	Computer, laptop {GLO}| market for computer, laptop | Cut-off, S
Web camera	2	Pcs	Electronics, for control units {RER}| electronics production, for control units | Cut-off, S – *used as proxy*
Electricity	0.019[11]	kWh	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S
Hardware and energy use for AI training:			
A100 GPU[12] machine (about 1.4 kg per pc)	1	Pc	Electronics, for control units {RER}| electronics production, for control units | Cut-off, S – *used as proxy*
Desktop computer	1	Pc	Computer, desktop, without screen {GLO}| market for computer, desktop, without screen | Cut-off, U
	1	Pc	Display, liquid crystal, 17 inches {GLO}| market for display, liquid crystal, 17 inches | Cut-off, U
	1	Pc	Keyboard {GLO}| market for keyboard | Cut-off, U
	1	Pc	Pointing device, optical mouse, with cable {GLO}| market for pointing device, optical mouse, with cable | Cut-off, U
Electricity input for AI training	55.2[13]	kWh	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S
Electricity input for additional AI training	64[14]	kWh	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S

[11]Estimated use per hour, assuming an average use of 6.5 hours per day based on Ecoinvent dataset for computer laptop operation.

[12]The GPU has a power rating of 400 W and it is estimated that about double of that i.e. 800 W is required for the whole computing system, including data read and write as well as transfer.

[13]About 69 hours in total estimated for the AI training based on data from RISE. Estimated total electricity required for the AI training is thus 0.8 * 69 = 55.2 kWh.

[14]About 80 hours estimated additional time for the AI training based on data from RISE. Estimated total electricity required for the AI training is thus 0.8 * 80 = 64 kWh.

Sorting

Table 3 Data used for modelling sorting

Description	Amount	Unit	Dataset
Manual sorting:			
Electricity	22800[15]	kWh	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S
AI sorting:			
Desktop computer	1	Pc	Computer, desktop, without screen {GLO}| market for computer, desktop, without screen | Cut-off, U
	1	Pc	Display, liquid crystal, 17 inches {GLO}| market for display, liquid crystal, 17 inches | Cut-off, U
	1	Pc	Keyboard {GLO}| market for keyboard | Cut-off, U
	1	Pc	Pointing device, optical mouse, with cable {GLO}| market for pointing device, optical mouse, with cable | Cut-off, U
Web camera	1	Pc	Electronics, for control units {RER}| electronics production, for control units | Cut-off, S – *used as proxy*
Electricity	0.085[16]	kWh	Electricity, low voltage {SE}| market for electricity, low voltage | Cut-off, S

Waste flows and fate

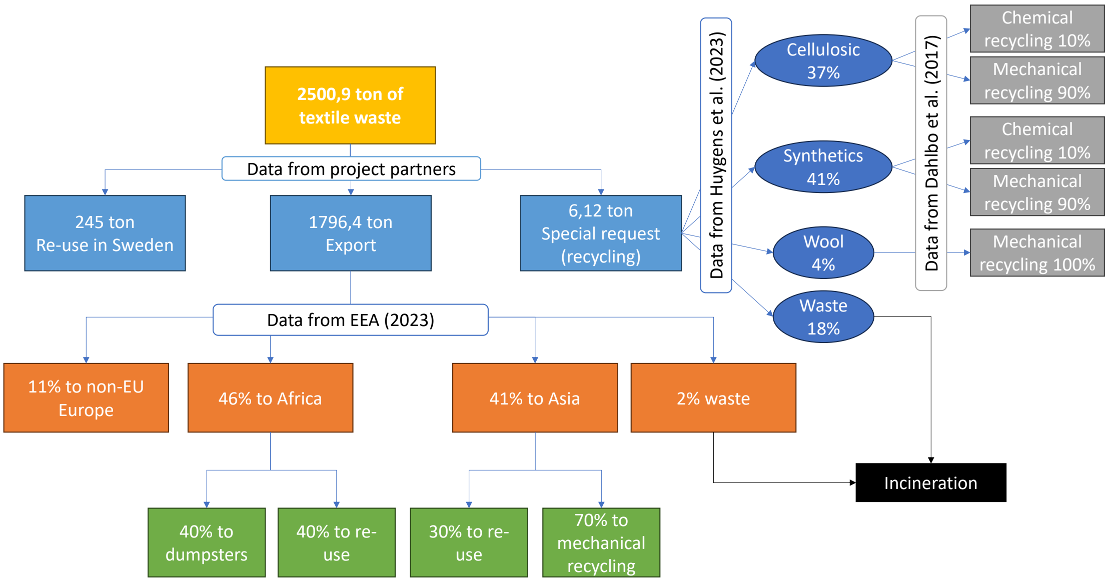

Figure 13 Assumed flows and fate of textile waste streams modelled for the downstream part of the LCA system

[15] Estimated yearly electricity use for sorting activities for the year 2023 at a sorting facility of one of the project partners
[16] Estimated use per hour, assuming an average use of 5.5 hours per day based on Ecoinvent dataset for computer desktop operation.

Transport distances and modes

Table 4 Data used for modelling transports, from Treszpacz et al., (2023) for exports and from own data collection for re-use in Sweden

Scenario	Distance	Transport mode
Re-use in Sweden	300 km	Road transport with lorry 16-32 ton, EURO6
Re-use in Europe	1150 km	Road transport with lorry 16-32 ton, EURO4
Export to Africa	1150 km	Road transport with lorry 16-32 ton, EURO4
	6282,8 km	Sea transport – freight ship
	441,9 km	Road transport with lorry 16-32 ton, EURO3
Export to Asia	1150 km	Road transport with lorry 16-32 ton, EURO4
	10465,6 km	Sea transport – freight ship
	524,0 km	Road transport with lorry 16-32 ton, EURO3

Recycling processes

Table 5 LCI data for mechanical recycling of cotton (from Duhoux et al., 2021)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Textile waste	1	ton	
Electricity	500	kWh	Electricity, medium voltage {GLO}| market group for electricity, medium voltage | Cut-off, S (abroad) Electricity, medium voltage {SE}| market for electricity, medium voltage | Cut-off, S (in Sweden)
Tap water	20	kg	Tap water {RoW}| market for tap water | Cut-off, S (abroad) Tap water {Europe without Switzerland}| market for tap water | Cut-off, S (in Sweden)
Outputs:			
Cotton fibre	0,0475	ton	
Hard components to waste, credits removed	0,05	Ton	Scrap steel {Europe without Switzerland}| treatment of scrap steel, municipal incineration | Cut-off, S
Dust to waste	0,03	Ton	Waste textile, soiled {RoW}| treatment of waste textile, soiled, municipal incineration | Cut-off, S (abroad) Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration | Cut-off, S (in Sweden)
Fluff to waste	0,87	Ton	Waste textile, soiled {RoW}| treatment of waste textile, soiled, municipal incineration | Cut-off, S (abroad) Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration | Cut-off, S (in Sweden)

Inputs and outputs	Amount	Unit	Dataset
Virgin cotton (avoided product, 30% substitution rate applied)	0,0475	ton	Fibre, cotton {GLO}| market for fibre, cotton | Cut-off, S

Table 6 LCI data for chemical recycling of cotton (from Lidfelt et al., 2022)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Sorted clothes	1,12E+00	kg	Cotton waste to chemical recycling
Methanol	7,53E-04	kg	Methanol {GLO}| market for methanol | Cut-off, S
Natural gas	1,62E-02	m3	Natural gas, low pressure {RoE}| market for natural gas, low pressure | Cut-off, S
Lime	1,02E-02	kg	Lime, packed {Europe without Switzerland}| market for lime, packed | Cut-off, S
Sand	2,74E-04	kg	Sand {GLO}| market for sand | Cut-off, S
Chemical organic	2,18E-03	kg	Chemical, organic {GLO}| market for chemical, organic | Cut-off, S
EDTA	1,96E-04	kg	EDTA, ethylenediaminetetraacetic acid {RER}| EDTA production | Cut-off, S
Magnesium sulfate	8,17E-05	kg	Magnesium sulfate {RER}| magnesium sulfate production | Cut-off, S
Malusil	1,27E-03	kg	Malusil {RER}| malusil production | Cut-off, S
Sodium hydroxide	2,48E-02	kg	Sodium hydroxide, without water, in 50% solution state {GLO}| market for sodium hydroxide, without water, in 50% solution state | Cut-off, S
GCC slurry	3,92E-03	kg	Ground Calcium Carbonate (GCC) - slurry, uncoated, at plant, RER S
Electricity	6,14E-02	MJ	Electricity, medium voltage {SE}| market for electricity, medium voltage | Cut-off, S
Heavy fuel oil	9,55E-03	kg	Heavy fuel oil {RER}| market group for heavy fuel oil | Cut-off, S
Hydrogen peroxide	7,08E-03	kg	Hydrogen peroxide, without water, in 50% solution state {RER}| market for hydrogen peroxide, without water, in 50% solution state | Cut-off, S
Light fuel oil	3,47E-05	kg	Light fuel oil {Europe without Switzerland}| market for light fuel oil | Cut-off, S
Oxygen (liquid)	2,08E-02	kg	Oxygen, liquid {RER}| market for oxygen, liquid | Cut-off, S

Inputs and outputs	Amount	Unit	Dataset
Sodium chlorate	1,02E-02	kg	Sodium chlorate, powder {RER}| market for sodium chlorate, powder | Cut-off, S
Sodium formate	1,62E-04	kg	Sodium formate {RER}| market for sodium formate | Cut-off, S
Sodium sulfate	6,81E-04	kg	Sodium sulfate, anhydrite {RER}| market for sodium sulfate, anhydrite | Cut-off, U
Sulfur dioxide	5,29E-05	kg	Sulfur dioxide, liquid {RER}| market for sulfur dioxide, liquid | Cut-off, S
Sulphuric acid	2,31E-02	kg	Sulfuric acid {RER}| market for sulfuric acid | Cut-off, S
Wood chips	9,89E-02	kg	Wood chips, dry, measured as dry mass {RER}| market for wood chips, dry, measured as dry mass | Cut-off, S
Outputs:			
Recycled cotton fibres	1,12	kg	
Substituted virgin pulp (substitution rate 100%)	1	kg	Sulfate pulp, bleached {RER}| market for sulfate pulp, bleached | Cut-off, U
Textile waste	0,12	kg	Waste textile, soiled {RoW}| market for waste textile, soiled | Cut-off, S

Table 7 LCI data for mechanical recycling of synthetics (from Duhoux et al., 2021)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Textile waste	1	ton	
Electricity	500	kWh	Electricity, medium voltage {SE}| market for electricity, medium voltage | Cut-off, S
Tap water	20	kg	Tap water {Europe without Switzerland}| market for tap water | Cut-off, S
Outputs:			
Spinnable fibres	0,25	ton	
Hard components to waste, credits removed	0,05	ton	Scrap steel {Europe without Switzerland}| treatment of scrap steel, municipal incineration | Cut-off, S
Dust to waste	0,03	ton	Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration | Cut-off, S
Fluff to waste	0,87	ton	Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration | Cut-off, S
Virgin polyester (avoided product,	0,0475	ton	Fibre, polyester {GLO}| market for fibre, polyester | Cut-off, U

Inputs and outputs	Amount	Unit	Dataset
30% substitution rate applied)			

Table 8 LCI data for mechanical recycling of wool (from Lidfelt et al., 2022)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Wool waste	1254,4	kg	
Electricity, high voltage	4941,36	MJ	Electricity, medium voltage {SE}| market for electricity, medium voltage | Cut-off, S
Water	44,3	L	Tap water {Europe without Switzerland}| market for tap water | Cut-off, S
HDPE, laminated	2,3	kg	Polyethylene terephthalate, granulate, amorphous {Europe without Switzerland}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U
Steel wire	0,9	kg	Steel, unalloyed {GLO}| market for steel, unalloyed | Cut-off, U
PET strap	0,5	kg	Polyethylene terephthalate, granulate, amorphous {Europe without Switzerland}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U
Alkyl benzoate (Glycerine used as proxy emollient)	0,5	kg	Glycerine {RER}| market for glycerine | Cut-off, U
Outputs:			
Wool fibre	1000	kg	
Water, to wastewater treatment	0,0443	m3	Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, S
Short wool fibres, to municipal waste	68,4	kg	Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration | Cut-off, S
Substitutes virgin polyester fibers for fleece (80% substitution rate applied)	1000	kg	Fibre, polyester {GLO}| market for fibre, polyester | Cut-off, S

Table 9 LCI data for chemical recycling of polyester, production of DMT and ethylene glycol (from Lidfelt et al., 2022)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			

Inputs and outputs	Amount	Unit	Dataset
Textile waste	1,052	kg	
EG	0,1	kg	Ethylene glycol {GLO}| market for ethylene glycol | Cut-off, U
Catalyst (NaCO3)	0,00005	kg	Soda ash, dense {GLO}| market for soda ash, dense | Cut-off, S
Methanol	0,1	kg	Methanol {GLO}| market for methanol | Cut-off, S
Thermal energy (LFO)	13,7	MJ	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U
Thermal energy (natural gas)	3,44	MJ	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U
Outputs:			
Dimethyl terephthalate (DMT)	0,621	kg	
Ethylene glycol (EG)	0,279	kg	
EG for reuse	0,09	kg	
Cotton waste	0,05	kg	Waste textile, soiled {CH}| treatment of waste textile, soiled, municipal incineration | Cut-off, S
Waste for incineration/recovery	0,12	kg	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration | Cut-off, S

Table 10 LCI data for chemical recycling of polyester, repolymerisation (from Lidfelt et al., 2022)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Dimethyl terephthalate (DMT)	0,875	kg	
Ethylene glycol (EG)	0,334	kg	Ethylene glycol {GLO}| market for ethylene glycol | Cut-off, U
Electricity grid mix	0,698	MJ	Electricity, medium voltage {SE}| market for electricity, medium voltage | Cut-off, U
Heat	1,63	MJ	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U
Liquid nitrogen	0,03	kg	Nitrogen, liquid {RER}| market for nitrogen, liquid | Cut-off, U
Steam production	0,94	kg	Steam, in chemical industry {RER}| market for steam, in chemical industry | Cut-off, U
Outputs:			

Inputs and outputs	Amount	Unit	Dataset
PET granulates	1	kg	
Waste plastic	0,0023	kg	Waste plastic, mixture {CH}| treatment of waste plastic, mixture, municipal incineration | Cut-off, S
Municipal solid waste	0,0009	kg	Municipal solid waste {SE}| treatment of municipal solid waste, incineration | Cut-off, S
Average incineration residue	0,0004	kg	Sewage sludge, 70% water, WWT, WW, average {Europe without Switzerland}| treatment of sewage sludge, 70% water, WWT, WW, average, municipal incineration | Cut-off, S
Hazardous waste	0,0001	kg	Hazardous waste, for incineration {Europe without Switzerland}| market for hazardous waste, for incineration | Cut-off, S
Substituted PET granulates (substitution rate 100%)	1	kg	Polyethylene terephthalate, granulate, amorphous {Europe without Switzerland}| polyethylene terephthalate, granulate, amorphous, recycled to generic market for amorphous PET granulate | Cut-off, U

Production of new garment

Table 11 LCI data for substituted production of a new garment, finishing (from Lidfelt et al., 2022)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Cotton fabric	1	kg	Textile, woven cotton {GLO}| market for textile, woven cotton | Cut-off, U
Water, river	59,82	kg	Tap water {Europe without Switzerland}| market for tap water | Cut-off, U
Detergent/wetting agent average (II)	0,05	kg	From Mistra Future Fashion database
Fluorescent whitening	0,06	kg	Fluorescent whitening agent, distyrylbiphenyl type {GLO}| market for fluorescent whitening agent, distyrylbiphenyl type | Cut-off, S
Formic acid	0,01	kg	Formic acid {RER}| market for formic acid | Cut-off, S
Hydrogen peroxide	0,07	kg	Hydrogen peroxide, without water, in 50% solution state {GLO}| market for | Cut-off, S
Lubricant, average	0,08	kg	From Mistra Future Fashion database
Peroxide stablizer, average (III)	0,002	kg	From Mistra Future Fashion database
Sodium hydroxide	0,025	kg	Sodium hydroxide, without water, in 50% solution state {GLO}| market for sodium hydroxide, without water, in 50% solution state | Cut-off, S

Inputs and outputs	Amount	Unit	Dataset
Softener, average (IV)	0,03	kg	From Mistra Future Fashion database
Sulphuric acid	0,02	kg	Sulfuric acid {RER}| market for sulfuric acid | Cut-off, U
Electricity	2,52	MJ	Electricity, medium voltage {TR}| market for electricity, medium voltage | Cut-off, U
Heat	30	MJ	Heat, district or industrial, other than natural gas {GLO}| market group for heat, district or industrial, other than natural gas | Cut-off, S
Outputs:			
Finished fabric	1	kg	
COD, Chemical Oxygen Demand	0,0002	kg	Emission to water, elementary flow
Water, river	44,865	kg	Emission to water, elementary flow

Table 12 LCI data for substituted production of a new garment, confectioning (from Lidfelt et al., 2022)

Inputs and outputs	Amount	Unit	Dataset
Inputs:			
Finished fabric	1,176	kg	From finishing
Water	0,18	kg	Tap water {Europe without Switzerland}| market for tap water | Cut-off, S
Sowing thread	0,0035	kg	Fibre, cotton {GLO}| market for fibre, cotton | Cut-off, S
Confectioning template	0,05	kg	Kraft paper {RER}| market for kraft paper | Cut-off, S
Packaging film	0,02	kg	Packaging film, low density polyethylene {GLO}| market for packaging film, low density polyethylene | Cut-off, S
Corrugated board box	0,06	kg	Corrugated board box {GLO}| market for corrugated board box | Cut-off, S
Electricity	9,7596	MJ	Electricity, medium voltage {SE}| market for electricity, medium voltage | Cut-off, S
Heat	0,07	MJ	Heat, district or industrial, other than natural gas {Europe without Switzerland}| market for heat, district or industrial, other than natural gas | Cut-off, S
Outputs:			
Garment (substitution rate for re-use of 60%)	1	kg	
Cotton waste to incineration	0,176	kg	Waste textile, soiled {RoW}| market for waste textile, soiled | Cut-off, S

Appendix 2. Application for the project

AI for resource-efficient circular fashion

1. Potential

1.1 Purpose and objectives

The main objective of this project is to identify, design and develop data-driven AI/ML[1]-solutions for the textile second hand sector, with an explicit focus on automation of reuse sorting processes. The overall purpose is to enable a sizable increase of the utilization rate per garment, thus offsetting the need for new production. This simple yet powerful concept has an intrinsic potential to significantly decrease national and global GHG[2] emissions, and is the key theme of this project. E.g., if only 5 percent of Europe's textile consumption is substituted by circulated alternatives, the climate impact reduction would be 4 percent, meaning a reduction of 19 million tonnes CO_2, yearly[3].

In the project, two well-established research environments, Wargön Innovation (textiles) and RISE (AI and IoT, UX, LCA[4]), will work alongside a number of textile domain experts, employing a cross-sectorial approach. Project results include increased resource efficiency and circularity of textiles as well as the creation of societal benefits, e.g. new jobs and a more efficient and quality-assured education for textile sorters. The project will also support the UN Sustainable Development Goals (SDG) by addressing activities connected to the below SDGs as described in section 2.1:

- SDG 8.3 Promote policies to support job creation and growing enterprises
- SDG 8.4 Improve resource efficiency in consumption and production
- SDG 12.5 Substantially reduce waste generation

The project goal is well in line with the goals in the National Research Programme for Climate[5] which includes the Global Climate Agreement (Paris agreement), the UN Sustainable Development Goals, as well as EU and Swedish climate goals. In June 2017, Sweden stated that by 2045 Sweden will have zero net emissions of GHG aiming for a fossil-free welfare society. Swedish territorial emissions as carbon dioxide equivalents were about 53 million tonnes in 2016[6] of which 4,2 million tonnes can be connected to the Swedish textile consumption (2017)[7].

1.2 State of the art

AI/ML-solutions to boost volumes of second-hand garments on the market

In early 2000s, the global consumption of textiles was about 55 million tonnes per year. By 2019, it had increased to 111 million and is forecasted to increase to 146 million tonnes in 2030. In 2017, Ellen MacArthur Foundation estimated that textile production accounted for 1,2 billion tonnes of GHG emissions per year as CO_2 equivalents[8] where of the Swedish textile consumption corresponds to about 3,5%[9]. it was also shown that the average number of times a garment is worn before it ceases to be used has decreased by 36% during the same period. LCA studies on Swedish textile consumption has shown that 80% of a garment's climate impact and 92% of the toxicity occurs in the early stages of production[10]. This was confirmed in a UNEP report[11] including LCA analysis on global scale stating that 75% of the climate impact occurs in the production phase of apparel: however they also stated "*While emissions from apparel disposal do not stand out as a hotspot to be addressed, increasing re-use, repair/repurposing and closed-loop recycling will decrease climate emissions across all stages of the value chain*." In addition, it has been shown that if the textile life span (appr 2 years today) is increased by a factor three, the total environmental

[1] Artificial intelligence, Machine Learning
2 Green House Gas (GHG), Overview of Greenhouse Gases | Greenhouse Gas (GHG) Emissions | US EPA
[3] Extrapolated on numbers from: Final Report_Mistra Future Fashion_working document.indd, 2020
[4] Internet of things, User Experience & Life Cycle Assessment
5 https://formas.se/download/18.7e040f53167c64b3cd313e85/1549956098631/strategisk-agenda-klimat-formas.pdf
6 Fördjupad analys av svensk klimatstatistik 2017 - Naturvårdsverket (naturvardsverket.se)
7 SOU 2020:72, Producentansvar för textil – en del av den cirkulära ekonomin - Regeringen.se
8 Ellen MacArthur Foundation, A new textiles economy: Redesigning fashion's future,(2017, http://www.ellenmacarthurfoundation.org/publications).
[9] Swedish governement, SOU 2020:72,
10 Mistra Future Fashion, 2019.
11 UN Environment Programme (2020). Sustainability and Circularity in the Textile Value Chain - Global Stocktaking. Nairobi, Kenya.

impact is reduced by 70% [12]. Hence, as the use phase of a garment is prolonged, a substantial decrease in GHG emissions can be achieved when the corresponding new production is offset. The project aims to narrow its activates to the top of the waste hierchacy (sort-reuse), which includes exploring and piloting AI/LM-based concepts for problem owners needs defined in e.g. large scale textile sorting facilities, e-commerce settings and for retail and rental/subscriptions models.

EU identifies textiles as a *priority product category* for the circular economy[13]

Textiles is the fourth highest pressure category in the EU in terms of use of primary raw materials and water (after food, housing, and transport), and fifth for GHG emissions (EEA)[14]. Europeans consume about 11 million tonnes of textiles per year and as of today, only 2,8 million tonnes are collected for reuse or recycling[15]. The same is true on a global scale where only 20% of the yearly textile consumption is collected whereas 80% is incinerated or ends up in landfills [16]. To address this a new European Waste Directive has been put forward where it states that by January 1, 2025, EU member states are obliged to have systems in place for separate collection of textiles, which will drastically increase the collected textile volumes and the need for textile sorting for both reuse and recycling.[17] In Sweden, 75 000 tonnes of textiles per year is discarded and becomes residual waste and input material for central heat power plants; hence, the Swedish EPA has set the following suggestions for national goals[18] regarding collecting and sorting of used textiles:

- The amount of textiles in the residual waste shall be decreased by 60% compared to year 2015 (corresponding to +45 000 tonnes in collected volume, consumption today is about 141 000 tonnes).
- 90% and collected textile volume shall be prepared for reuse or recycling according to the waste hierarchy, and recycling into new textiles shall be prioritised over downcycling.

Gap in textile sorting capacity for reuse and recycling

Textile sorting facilities will be crucial when collected textile volumes increase in Europe, and as of today only a few European countries host large-scale reuse sorting facilities, run by companies such as Boer Group, Texaid and Soex. In these facilities, manual labour-intensive sorting is conducted for (primarily) reuse markets in Eastern Europe, Asia and Africa. Generally, there are large variations in sorting capacity: from small facilities of about 5 tonnes per day to larger sorting plants of 50 tonnes per day or more. The total textile sorting capacity in Europe is 1,85 million tonnes per year (ref 15), and the percentage of reusable items in the sorted goods is about 50-60%[19]. When it comes to recycling, only about 1% are currently recycled back into new textile fibers: the rest is downcycled low-value products, incinerated or in worst-case scenario, sent to landfill.[20]

Generally, today's sorting methods are at their best semi-automatic with very low utilisation of digital tools, and most of the textile sorting is still performed manually. This is especially true for reuse sorting which is often based on the skills of individual textile sorters, second-hand retail staff or e-commerce market-place staff etc. This is very different from other types of reuse markets (cars, household goods etc.) where marketplaces are used to aggregate the second-hand goods and display the price, quality and provenance, which makes it easy to compare with similar products giving each item a specific identity. An introduction of AI/ML-based expert systems and associated data sets for second-hand apparel sorting processes can give not only complementing data about brand name, quality and provenance, but also a possibility for a suggested price range for a given market based on image analysis and/or made transactions, and more.

There are of course other sorting technologies with broad industry relevance currently being developed. The two most prominent initiatives are presented in the Table below. Both technology bases will complement the above-mentioned AI/ML concepts well, and vice versa.

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12 Sandin et al. 2019
13 Sustainable Products in a Circular Economy - Towards an EU Product Policy Framework contributing to the Circular Economy, Brussels, 4.3.2019 SWD(2019) 91 final
14 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=PI_COM:Ares(2021)67453
15 Recycling-Hubs-FIN-LQ.pdf (euratex.eu)
16 Study for the German Federal Ministry for Economic Cooperation and Development (BMZ)
17 Textiles in Europe's circular economy — European Environment Agency (europa.eu)
18 Swedish Environmental Protection Agency, 2019 www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Avfall/Textilavfall/
19 Study for the German Federal Ministry for Economic Cooperation and Development (BMZ)
20 A-New-Textiles-Economy.pdf (ellenmacarthurfoundation.org)

Tech base	About	Pros	Cons	Status
NIR/ FTIR	Textile material sorting technology [21][22]	Enables automated large-scale material sorting on fiber type and color.	Only usable for single fabric material. Multi-layered (jackets etc) needs manual sorting.	*On the verge of being technology is commercially available.*
RFID/ NFC	Tags or product ID that carry large amount of data [23][24]	(i) Enables a more nuanced and automated reuse and recycling sorting (ii) New business models for brands (iii) Better control in value chains	Textile product needs CE marking, electronics hinders recycling processes	*Used in hang tags by actors such as H&M and Gina Tricot.*

AI and textiles state-of-the-Art – datasets for used clothes are missing

AI and in particular Computer Vision is a technology that enables a computer to recognize items in an image. AI is used more and more in the fashion industry: both to make the supply chain, including the design process, more efficient, but also to enhance the customer experience.

H&M has launched Body Scan Jeans[25] within their brand Weekday. The service combines 3D scanning and algorithm-generated patterns to give the customer best fit for jeans. In October 2020, Zalando announced[26] that they had acquired the Zurich-based computer company Fision. They use computer vision in an App for body scan and virtual dressing rooms giving the customer possibilities to see how a garment fit.

On research level, there are many initiatives to use digitalization as a means to solve challenges for the fashion industry. The PhD thesis “Does it really fit?: improve, find and evaluate garment fit”[27] shows that digital tools can be used by both product developers and customers to find the right size. In May 2020, a research team from Greece and UK published their study “Towards Fashion Recommendation: An AI System for Clothing Data Retrieval and Analysis”[28] where they focus on to developing an AI system for product designers in the fashion industry. They base their work on data collection and data clustering, and also points out that large companies such as Google, Amazon, Hugo Boss, Tommy Hilfiger and IBM use and develop digitalisation within the whole value chain for fashion but are specifically interested in focusing on the design process including trend analysis.

Cheng et al[29] have comprised an extensive survey on the topic Fashion meets computer vision and finds that there are four main areas, i. e. Detection, Recommendation, Synthesis and Analysis. (1) Detection is all about detecting what is worn and how the models pose. (2) Recommendation is the process of recommending what to wear. (3) Synthesis are different methods to predict what a person would look like wearing a certain style, and finally (4) Analysis among other things tries to predict what people will want to wear. The authors have gone through an extensive set of publicly available datasets that can be used to train machine-learning models. There are a significant amount of datasets in all four categories. However, something that the authors have missed, or more likely that does not exist, is a dataset with used clothes and in particular looking at the state of a garment, i. e. is the quality consistent everywhere, how worn is the garment, etc. This is something that would be of a paramount interest to the second hand industry as well as to promote circular economy.

Regarding judging the state of garments (quality, wear and tear), there is recent published work that looks at the state of the art of using computer vision to detect defects of produced textiles in textile manufacturing[30],[31]. In summary, significant research has been reported to detect defects in fabrics by using both traditional methods as well as learning-based approaches. Current trends are that deep learning is

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[21] Siptex | Sysav – tar hand om och återvinner avfall
[22] Fibersort - Automated system to sort textiles, based on fiber type
[23] Home | circular.fashion - Products of Today, Resources of Tomorrow
[24] Informationssystem för framtidens textilier (RFID) | RISE
25 Weekday - Body Scan Jeans SE
26 Zalando förvärvar bolaget Fision för utveckling av kroppsscanning med mobilen | Zalando (mynewsdesk.com)
[27] Does it really fit? : improve, find and evaluate garment fit (diva-portal.org)
[28] Towards Fashion Recommendation: An AI System for Clothing Data Retrieval and Analysis (nih.gov)
29 Fashion meets computer vision: a survey, W-H Cheng, S. Song, C-Y Chen, S C Hidayati, J. Liu, arXiv:2003.13988v2 [cs.CV] 28 Jan 2021
30 Fabric Defect Detection in Textile Manufacturing: A Survey of the State of the Art, C. Li, J. Li, Y. Li, L. He, X. Fu, J. Chen, Security and Communication Networks, vol. 2021, Article ID 9948808, 13 pages, 2021. https://doi.org/10.1155/2021/9948808
31 "Fabric Defect Detection Using Computer Vision Techniques: A Comprehensive Review,. A Rasheed, B. Zafar, A. Rasheed, N .Ali, M. Sajid, S. H. Dar, U. Habib, T. Shehryar, M. T. Mahmood, Mathematical Problems in Engineering, vol. 2020, Article ID 8189403, 24 pages, 2020. https://doi.org/10.1155/2020/8189403

becoming more and more popular, however, real-time defect detection is still a huge challenge due to requirements for high speed and computational cost. Also, the lack of public data sets is a challenge.

An additional method that can be used to detect the state of a garment is to analyze the fibers in the fabric. There are several destructive and non destructive tests available. Here, we are interested in non destructive tests. In particular, Fourier transform infrared (FT-IR) spectroscopy is a commonly used method, however, computer vision of microscopy images is also a possible candidate. The FTIR method will determine the type of fabric whereas computer vision can likely also be used to detect the state of wear of a used fabric. We have not found any references looking at this. It thus appears that using computer vision in different ways can advance the state of the art in this field, in particular as a way to judge the state of a garment, if it is fit for reuse as well as to give an indication in what price range the garment is placed.

RISE Applied AI and IoT has the relevant experience to perform this job. Similar projects and challenges has been worked on recently. In particular, the Vinnova project Open image database for plant cultivation aims at create a large open database for crops. This database can be used to train machine learning (computer vision) models to find where a certain crop grows in a field and also keep track of its health and status. We expect that learnings and methodologies from this and other relevant projects can be employed in the textile sphere as well.

Challenges and a shift towards circular consumer consumption patterns

The project ambition with AI/ML-solutions to prolong the lifetime of garments and, hence, decrease GHG emissions, also has other positive effects, e.g., more effective and efficient sorting processes, job creation, teaching platforms for new textile sorters etc. However, conflicts may arise when implementing digital and AI/ML-based systems in a traditionally manual business, as personnel can be reluctant to new technology. Textile sorting in the future may also face difficulties with conflicting interests when it comes to brand owners, charities, confidential information etc. Other obstacles that we may face in the project is difficulties to detect quality and smell, challenges to gather enough and accurate data on prices and trends, and long-term, to secure an updated dataset. The latter is addressed in WP 4 (Open Source data set) and WP 6 (Business analysis and impact assessment).

Finally, consumer behaviour and their associated acceptance rate of buying second hand is a general challenge for the industry. We firmly believe that by introducing effective AI/ML-models, we can contribute to a more competitive, on-point and profitable textile-reuse industry, which in turn will increase the acceptance rate and willingness to shift to more circular buying patterns. This is synergetic with the expected growth of the sector. A recent report projects that the U.S. second-hand market will double in 5 years and triple in 10 years – $28 billion in 2019 to $80 billion in 2029,[32] with a similar outlook in Europe.

1.3 Your solution

To create solutions that provide actual value, the project will apply a user-driven design process where competencies in AI, UX, reuse models for textiles and climate impact know-how merge in close collaboration with problem owners and users. Based on identified needs of problem owners and users[33] operating in the circular textile value chain we will design, develop and pilot AI/ML-concepts, see Figure 1. The main goal is to improve the efficiency and effectiveness of chosen processing steps within reuse textile sorting, e.g., support for the user; second hand price setting, brand recognition, trends based on geography and demography, seasons, garment quality (wear and tear) and price for garment as new (connect to other data sets). A specific project output, in parallel to pilot results, will be a structured, annotated and scalable open data set for second-hand garments. The data set is a baseline for continuous refinement of pilot AI/ML concepts and algorithms, as well as a starting point for increased data volume gathering. To ensure that the technical solution meets the user's needs, are useful and accessible, we will develop design concepts of interaction models and interfaces between AI/ML, and users that illustrate how and in what context the user can interact with the technical solution. The design concepts are evaluated with users (focus groups and

32 ThredUp Resale Report, 2020
33 textile sorting facilities, second hand e-commerce and retail stores, consumers

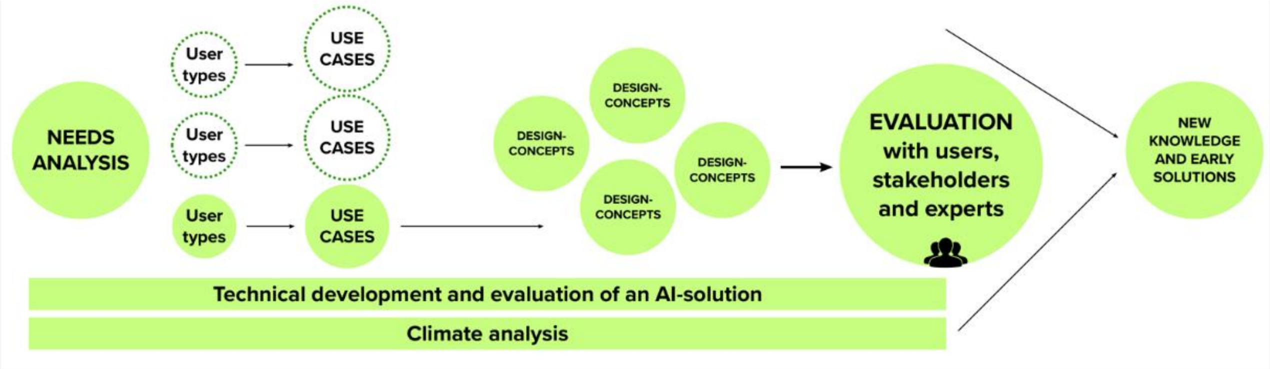

Figure 1. Illustration of the innovation process - the work takes place in close collaboration between the different areas of competence and roles.

interviews) from the following usability perspectives; efficiency (potential to improve), acceptence (perceived usefulness and satisfaction), motivation (sense of control and comprehension), trust (estimate ability support goal). We also evaluate the potential for the solution to increase sound ergonomics.

To ensure that the introduced AI/ML concepts generate positive effects on both society and climate, the project will take a holistic approach based on systemic evaluation with life cycle assessment (LCA) to corroborate the environmental savings in terms of conserved resources and reduced pollution with the developed solutions. The technology developed in the project will enable the textile stakeholders to extract a larger value for a lower cost from the textile "waste" stream - leading to a stronger circular business. The major environmental impact is in offsetting new production, as described in Section 1.2. Assuming that 10% of Sweden's textile consumption of new production is substituted, hence increasing the use phase per circulated garment, the climate impact would be reduced with 8% leading to a reduction of 336 000 tonne CO_2 per year. Extrapolating this scenario to Europe would mean a reduction of 38 million tonnes CO_2, yearly. This project will not only be beneficial to Sweden's climate goals, it will also give broader societal benefits. This includes supporting Sweden's up and coming second hand/reuse industry including the creation of new jobs. In time, the project will lead to a new design paradigm in Swedish fashion, the design of more durable sustainable clothes. This has already started; however, it will be reinforced with assistance from this project.

1.4 The AI content of the project

AI/ML is the core in our proposed project. As described in section 1.1-1.3, there is a huge need to automate the reuse sorting processes and enable new and more on-point business models for both existing and new companies in the growing circular textile economy. In short, we aim to use AI/ML to mimic and, in time, outperform particular human skill sets in chosen textile sorting processing steps.

The project aims to use machine learning, in particular computer vision. The features to work with will be identified in the user studies (WP 3) to enable maximum benefit for the problem owners, users and stakeholders. Features could be brand, quality of the garment, trends etc. Image classification techniques such as CNNs (Convolutional Neural Networks) will be used to, e.g., detect type of garment. Another promising technology is semantic segmentation where the system attempts to semantically understand each image in a pixel: it can be used to try to detect the state of a garment, or in a garment. CNNs are also of interest here, however, for these types of problems, FCNs (Fully Convolutional Networks) are more efficient. We will also investigate new technologies that arise during the project (AI is an extremely fast moving field).

As has been described in section 1.2, there exist a significant number of datasets (labeled and non-labeled for fashion). These are of various types, quality and use. In particular one set named Deepfashion2[34] can be used to train models for garments detection. Deepfashion2 and the other datasets that has been found all contain new garments. To train machine learning models for used garments, it will be necessary to create a new dataset with used garments, and thereafter use transfer learning with the dataset Deepfashion2 as a starting point. The project is particularly well suited to do this, bearing in mind that several project partners receive and sort several tonnes of textiles on a daily basis. In the beginning of the project, a data gathering

[34] Y. Ge, R. Zhang, L. Wu, X. Wang, X. Tang, and P. Luo. 2019. A Versatile Benchmark for Detection, Pose Estimation, Segmentation and Re-Identification of Clothing Images. In CVPR.

station will be setup at Wargön Innovation where images of used garments will be captured. These images will thereafter be processed and annotated by RISE. At a later stage, replicas of the data gathering stations will be set up at two partner sites (Myrorna, BjörkåFrihet) to accelerate data collection.

Energy consumption for use of AI is a real concern. Energy is consumed while training machine learning models but also when using them (inference). Most of the energy consumed when using AI is during the training process, hence the focus of the estimate below. As shown in section 1.2, there exist many datasets related to fashion in general. This means that so called transfer learning techniques can be used to train machine learning models also for used garments. Transfer learning shortens the training process by starting with an existing model for one problem and optimize it for a related problem. It is estimated that transfer learning saves about 90 % of the compute time and thereby energy consumption. Currently, there are no standardized models to estimate energy consumption during training, however, some estimations have been made to relate data center computer costs with CO_2 emissions. In this project, the aim is to use existing office-based equipment comprising of several Nvidia GPUs. Depending on the needs owner analysis, we estimate that we will train up to 10 machine learning models throughout the project. We further estimate that we will run the Nvidia GPUs for maximum one week each per model which means maximum 10 weeks of runtime, using a maximum of 5 GPUs at a time. Typically, the latest Nvidia GPUs runs at 350 W, which means 8,4 kWh per 24 hours[35]. This means that the total power consumption would be 2940 kWh. Using the energy mix recommended by Energimyndigheten in 2014, this represents a CO2 level of 138 kg[36]. If we can show that AI can be used to prolong the life of garments these emissions are negligible in comparison to the savings. In section 1.3, we estimated to save 336 000 tonne CO_2 per year in Sweden alone. In addition, there are many other gains related to use of chemicals and other types of pollution in textile production, which the LCA (WP 6) will include in the final report.

1.5 The objectives of the project

The project has two overall objectives:

1. The creation of a structured, annotated and scalable open data set for second hand garments, including:
    a. Defined and accepted AI/ML needs for key stakeholders, e.g. textile sorters, second hand e-commerce and retail stores, and associated AI algorithms.
    b. A minimum of 20 000 garments in the dataset, representing a normal distribution of textile goods collected by Sweden's charity organizations.
    c. Open Source data set available for use by stakeholders as a means to train machine learning models for use in their specific businesses.
2. Proof of concept for a specific product group, i.e. sweaters, and a minimum of two high impact potential AI/ML user needs.
    a. Evaluation of "AI vs human" pilots.
    b. Communication event on textile consumption patterns. (popular education, e.g. in a Red Cross flagship store).
    c. A minimum of 10 000 garments of the chosen product group in the dataset, in addition to previous mentioned 20 000 pieces.

Milestones

A. Needs owners screening finalized. Understanding and identifying practical user needs and challenges wherein AI/ML can effectuate most value [M6]
B. First version of design concepts on AI/ML solutions. Developed and evaluated with needs owners (UX) [M12]
C. Proof of concept - initiation [M18]
D. Proof of concept - Assessment of AI/ML system vs human precision [M28]
E. First version of open data set structure established [M28]
F. Summarizing report on impact, results and recommended next steps [M30]

The project also aims to strengthen collaboration between public and private organisations, between AI researchers and fashion industry stakeholders and between established climate research environments. Apart

35 https://wccftech.com/nvidia-rtx-3090-gpu-tgp-350w/
36 https://www.energimyndigheten.se/fornybart/hallbarhetskriterier/hallbarhetslagen/fragor-och-svar/vaxthusgasberakning/

from the collaboration that will take place in the project, two workshops will be organized [M9, M21] with the purpose of spreading knowledge from the project, to get input on the plans of the project and to interchange successful AI implementations between various fields of climate research. We imagine that this project might be different than other climate research initiatives. The project participants are especially well suited to organize these events, given the wide reach of the consortium.

1.6 Commercialization/utilization

The project vision is to enable a wide range of stakeholders, beyond the project consortium, to connect, utilize and contribute to the Open Source data set that has been produced in the project. By the end of the project, it will be published at a public platform/data catalogue. Notably, although the raw data will be public, company specific AI/ML-algorithms will not, hence a market driven incentive to build effective concepts for this important stakeholder group is enabled. Moreover, the consortium expects several spin-off projects to continue to build and refine the structure and pilot concepts, which will strengthen the bond between the project's research environments and partners even deeper in the future.

The ownership of the structure is not yet fully defined, as it partly depends on how the (Swedish) EPR will be implemented. E.g. if a non-profit textile material company will be established, which is assessed as likely[37], it is probably the best legal home for the Open Source data set. Another solution, which has been employed for other similar initiatives, e.g., Kollektivtrafiken datalab - KoDa, is that the dataset is hosted by RISE[38]. They have the capacity and experience to establish a consortium that could own, run and maintain the data set. The subject of ownership is addressed in WP 4 in the project.

1.7 Future effects

As described in Section 1.2, it is a clear ambition for the EU, as well as for the Swedish EPA, to adhere to the waste hierarchy for circular textiles. Textiles differs from many other EPR-materials where recycling often is the only route of choice (paper, plastic, glass etc). Hence, introducing and promoting solutions that contribute to automation of the textile <u>reuse</u> sector is of great importance, both to highlight the difference between different "waste streams" as well as attracting investments to an, from a digital perspective, underserved sector. Long term effects of a large open data set and associated AI/ML-algorithms include:

- A more competitive, on-point and profitable existing textile reuse industry, leading to an accelerated investment rate and increased volume capacity. This in turn leads to:
  - A higher acceptance rate of second-hand garments amongst consumers.
  - The utility rate per kilo produced textile increases, decoupling consumption from material production.
- New companies (such as project partner HackYourCloset (HYC)) can enter the market, offering new services built on AI/ML-supported solutions, increasing professionalism of the sector.
- Legislators are equipped with SotA knowledge and tools to strengthen the circular policy framework, with the climate as a key stakeholder.

All the above effects share one denominator, **offsetting new production**. This is by far the most important piece in the puzzle to build a sustainable textile industry. Scalability wise, the chosen model of an Open Source data set is specifically formulated for a high dissemination level. The project consortium, represented by Sweden's largest second hand actors (BjörkåFrihet, Myrorna and The Swedish Red Cross) and multi-international companies (HackYourCloset,Texaid plus Sellpy in the ref. group), also creates a very good basis for national and international dissemination of successful pilot results and more.

1.8 Increased equality

The task of sorting textile can be demanding, both mentally (knowledge-intensive) and physically. In the current situation it can be hard for the sorting industry to replace the existing personal in case of sick leave, vacation or parental leave for example due to long introductions/educations before new personal can start working. For the same two reason the work can also be challenging (not to say exclusive) for people with a reduction of physical, mental or intellectual capacity. The project group sees potential that an AI-solution can support users both in discission making and physical tasks, which can contribute to a more accessible, inclusive and ergonomic work environment. To create solutions that are inclusive we explore, for example, how natural interfaces (NUI), such as voice interaction and gesture interaction, can create a complement to

[37] TEKO; Svensk handel Stil, 2021
[38] https://www.ri.se/en/what-we-do/projects/koda

manual interactions, visual design and touch screens. The design concepts can contribute with an important human perspective in the transition to automatic/semi-automatic systems supported by AI and can enable more users to work in with textile sorting. The design concepts will be developed with support from The Seven principles of Universal design[39] and Protected grounds of discrimination[40]. The design concepts and AI/ML solution will be evaluated with users and analyzed with an inclusive and equality perspective.

The task of sorting textile can be demanding, both mentally (knowledge-intensive) and physically. In the current situation it can be hard for the sorting industry to replace the existing personal in case of sick leave, vacation or parental leave for example due to long introductions/educations before new personal can start working. For the same two reason the work can also be challenging (not to say exclusive) for people with a reduction of physical, mental or intellectual capacity. The project group sees potential that an AI-solution can support users both in discission making and physical tasks, which can contribute to a more accessible, inclusive and ergonomic work environment. To create solutions that are inclusive we explore, for example, how natural interfaces (NUI), such as voice interaction and gesture interaction, can create a complement to manual interactions, visual design and touch screens. The design concepts can contribute with an important human perspective in the transition to automatic/semi-automatic systems supported by AI and can enable more users to work in with textile sorting. The design concepts will be developed with support from The Seven principles of Universal design[41] and Protected grounds of discrimination[42]. We also evaluate the potential for the solution to increase good ergonomics.

Also, Wargön Innovation has been part of the Yes Way program[43] and will provide knowledge and methods of how to make sure to include the equality perspective in both the project work and the project communication as well as dissemination.

2. Feasability

2.1 Activity plan

WP 1: Project management (WI). Budget: 0,9 MSEK **Period:** M1-M30 **Activities:**Maintain overall control of the project and ensure timely delivery of outputs with high quality; Ensure flow of information within the project; Coordination with Vinnova to manage agreed actions, handle any legal issues (consortium agreement, reporting); Financial control of the project: Budget and resources, payments and requisitions; Establishing and coordinating project and reference group meetings. **Goals and milestones:** Detailed project plan [M3]; Implemented project in accordance with goals, budget and schedule [M30]; Project and reference group meetings conducted [M30]; Final report [M30] **Efforts and resources:** Senior project Manager, specialist on circular textile value chains and competence in equality (the Yes Way)
WP2: Communication (WI). Budget: 0,5 MSEK **Period:** General communication activities: M1-M30, Consumer consumption events [M20-M28] **Activities:** Responsible for internal and external communication in accordance with the communication plan; Consumer consumption pattern-oriented events, Promoting and educating on second hand benefits. (Activities connected to SDG 8.3) **Goals and milestones:** Detailed communication plan [M3], Open webinar on AI and textile reuse [M26]; (Red Cross) in-store event, e.g. sales trial [M28], Final conference, dissemination of results [M30] **Efforts and resources:** Communication officer, Project partners' platforms and communicators, physical (stores) as well as virtual (SoMe etc), competence in equality (the Yes Way)
WP3: UX-design (RISE Prototyping Society) Budget: 2,0 MSEK **Period:** M2-M16 **Activities:** The main goal is to understand the users needs and analyze them through; Interviews, observation & workshops together with problem owners; Identify user types and use cases; Mapping of use cases, technology and climate value (in collaboration with other WP´s); Creation of design proposals (concept of user interfaces and

[41] http://universaldesign.ie/What-is-Universal-Design/The-7-Principles/
[42] Protected grounds of discrimination | DO
[43] https://www.theyesway.se/

interaction models between users and the AI-solution, as mock-ups/illustrated concepts); User evaluation of design proposal . (Activities connected to SDG 8.4, SDG 12.5)
Goals and milestones: Problem owners screening [M2-M6]; AI/ML Design proposal [M7-M13]; User evaluation of design proposal [M12-M16]
Efforts and resources: UX designer at RISE, Interaction designer and competence in equality at RISE. Problem owners like Swedish Red Cross, BjörkåFrihet, Myrorna, HackYourCloset and ShareTex to be engaged in need findings and analysis as well as other UX design processes

WP4: Open data set (RISE, Applied AI and IoT) Budget: 3,0 MSEK
Period: M1-M28
Activities: Create a data set is the main activity, to be able to that we need to: Collect data online; Collect data from HYC, Myrorna, Texaid, Swedish Red Cross & BjörkåFrihet; Setup of imaging station; Creation of image dataset; Selection of database solution; Selection of data sharing solution; Annotation of images; Ownership model investigation and selection; . (Activities connected to SDG 8.4)
Goals and milestones: Collected data [M2-16]; Imaging station setup [M2]; First version of image data set [M8]; Second version of image data set [M16]; Open annotated image database created [M28]
Efforts and resources: Internet of Things Researcher (Ph D) at RISE, Machine learning engineer (M Sc) at RISE, Semantic database Researcher (Ph D) at RISE

WP5: POC – product group (RISE, Prototyping Society and Applied AI and IoT) Budget: 1,5 MSEK
Period: M15-30
Activities: We will develop prototypes and test them with users. Development of prototype ML concept 1 (based on needs analysis); Development of prototype ML concept 2 (based on needs analysis); Write guidelines for tests; Set up tests with users at the problem owners locations; Analysis and evaluation of the tests. (Activities connected to SDG 8.4)
Goals and milestones: Finished prototypes [M16-M24]; User tested [M24-M28]; Analysis and evaluation [M28-M30]
Efforts and resources: UX-designer, Interaction designer, Internet of Things Researcher (Ph D); Machine learning engineer (M Sc) Semantic database Researcher (Ph D) Users (staff) at Swedish Red Cross, Texaid BjörkåFrihet, Myrorna, HackYourCloset and ShareTex will take part in the user testing.

WP6: Impact assessment (RISE, IVF Support WI). Budget: 1,0 MSEK
Period: LCA [M12-M28]; Business assessment [M3-M28]; Policies and legalization [M29-30]
Activities: Life cycle assement (LCA) will be the main method used to evaluate the environmental impact; Responsible for the customer value proposition for the project's pilots that can achieve a predictable and sustainable model and commercial trajectory based on alignment to evidenced customer needs; Conducting a policy, and regulatory gap analysis, national, regional and European Commission directed recommendations that incentivizes best practices with regards to AI and textile reuse models. (Activities connected to SDG 12.5)
Goals and milestones: LCA report [M28]; Circular Business Models and Business Plan [M28]; Policy & Regulatory Report and Recommendations [M28]
Efforts and resources: Researcher at RISE IVF, Relevant life cycle inventory databases will be used, e.g. ecoinvent via SimaPro

2.2 Equality

To create solutions that provide societal value, the project will apply user-driven design process where competencies in AI, UX, reuse models for textiles and climate impact know-how work in close collaboration with problem owners and users. Traditionally, work in the textile domain is more often performed by woman[44] and the development of new technology is more often performed by men[45] and this is something that we will pay special attention to during the project. Therefore, we aim to to create a safe and creative space where a user of any gender and previous experience can participate and contribute. We strive to create inclusion and equality in both composition of user groups and the solutions.

In order to get a deeper understanding of to whom, where and how an AI-support can create value in textile sorting processes the project begins with a needs analysis where problem owners and users take part in interviews, observations and workshops. The problem owners' participation in the project group ensure the access to users and facilities for need finding and testing during the project. Based on the needs analysis, the project group estimates in which area the project can create the most value, both for the users, society and the environment.The user case (or cases) that we choose to explore creates a starting point for further

[44] https://euratex.eu/facts-and-key-figures/
[45] http://www.ikompassen.se/ikompassen-2018/

exploration of technical AI-solutions in a close collaboration with design concepts of interfaces/interaction models and analysis of climate value. Both design concepts and technical solutions are evaluated by users. The feedback from users is complemented with an equality analysis based on the method Perspective cards (which highlight the statutory grounds for discrimination) and seven principles for universal design. Other methods that we use in the process are personas, NOVA cards and checklists for inclusive communication. We continuously use and develop methods to promote inclusion, equality and gender equality.

2.3 Validation and verification

As described in Section 1.3 and WP 6, climate analysis will be a key component developing and setting up the AI/ML concepts, analysing the potential effect both during and in the final stage of the project. Furthermore, an analysis will be performed regarding the environmental and social impact of large-scale diffusion in the Swedish and European textile industry of the solutions developed in the project, and to what extent the scaled-up solutions contributes to making the textile industry sustainable. This knowledge will feed into policy recommendations (WP 6 delivarable).

3. Participating organizations

Partner	Contribution	Expertise and experience
WARGÖN INNOVA-TION (part of Innovatum Science Park.)	- Project manager - Communication activities - Pilot plant for textile sorting, capacity 500-1000 tonnes/year, photo station to be set up for image and data collection - Business potential assessment	- Advanced textile sorting for reuse, remake and recycling - Frequently engaged in national and international collaborations and projects, large network - Collaborates with business, start-ups, academia, institutes, public organizations, NGOs and civil society. - Competence in business analysis
RISE Research Institutes of Sweden	- **UX design team**: methodology for concept identification and design. - **Sustainability team**: LCA. - **AI team**: creation of annotated data sets, build prototypes, train machine learning models, create AI pilot use cases	- Interaction design, innovation, enhanced user experiences. - Implementing AI and IoT solutions - IoT, AI, Machine Learning, Computer Vision, RFID / NFC, Computer Ontologies. - Life cycle analysis, environmental product declaration (LCA and EPD), circular economy and chemical issues.
HACK YOUR CLOSET	- Problem owner - Involved in concept design process - Collect data - Conduct PoC	- Sweden's largest shared closet - Sustainability, clothing industry, circular business models. - Network: collaboration with brands and charity organizations, market presence in France
SWEDISH RED CROSS	- Problem owner Involved in concept design process - Supports the project with garments to analyse at Wargön. - Conduct PoC	- One of the largest second-hand actors in Europe, and in Sweden. - 280 second hand shops in Sweden - Local presence, dissemination capability. - Processes around 5 000 tons of collected textiles yearly.
BJÖRKÅ-FRIHET	- Problem owner Involved in concept design process - Collect data - Conduct PoC	- 50 years of experience in second hand and solidarity work. - Facility for reuse sorting of 4 000 tons of collected textiles per year.
MYRORNA	- Problem owner - Involved in concept design process - Collect data - Conduct PoC	- Experience, 120 years of selling second hand. - Expertise: Textile collection and sorting (6 000 tonnes, approximately 10 000 exported unsorted)
TEXAID	- Problem owner Involved in concept design process	- Swiss-based charity-private partnership organization, started 1978 - Process 90 000 tonnes annually, 1 200 employees
SHARETEX	- Problem owner: material perspective - Involved in concept design process	- Textile recycling, fiber blends - Dyestuff chemistry

A reference group will also be connected to the project and will meet at least twice a year. Participants in the reference group represents a broad set of stakeholders and constitutes of Cecilia Tall (Teko, trade association for textiles), Fredrik Viksten (AI Sweden), Jonas Larsson (Borås school of textiles), Jennie Rosén (Swedish fashion Council), Therese Persson (Sellpy).

3.1 Actor table

Name on organisation	**Type of actor** *(business, academy, public sector etc)*	**Competence and contribution in the project**
RISE	Research Institute	UX, AI and IoT, LCA assessment, Innovation processes
Wargön Innovation	RTO (Research and Techonlogy organisation)	Project manager, Pilot plant for textile sorting, communication, Innovation process
Red Cross	NGO (Non-Governmental Organization)	Problem owner, Experience and needs connected to second-hand clothes (sorting and selling)
Myrorna	NGO (Non-Governmental Organization)	Problem owner, Experience and needs connected to second-hand clothes (sorting and selling)
BjörkåFrihet	NGO (Non-Governmental Organization)	Problem owner, Experience and needs connected to second-hand clothes (sorting and selling)
Future Closets AB / HackYour Closet	SME	Problem owner, Experience and needs connected to second-hand clothes (rental service)
Texaid	Charity-private partnership organization	Problem owner, Experience and needs connected to second-hand clothes (sorting and selling)
ShareTex	SME	Problem owner, requirements and consequences for feedstock to recycling processes.

3.2 Problem owners

The project has six problem owners represented in the project. Their expertise, experience and expected contribution in the project are briefly described in Section 3 and 3.1. Two organisations, **Myrorna** and **BjörkåFrihet**, have (relatively speaking) large scale manual sorting capabilities in Sweden. Together, they sort approximately 10 000 tonnes of textiles per year. **The Swedish Red Cross** currently have a more decentralized model, as both collection and sorting are conducted in each of their 280 second-hand shops, separately. **Texaid** has textile sorting facilities in Switzerland and Germany and processes 90 000 tonnes of second-hand goods annually. **Hack Your Closet** offers a subscription service based on second hand clothes, with a monthly “renewal” of the customer's wardrobe. **ShareTex** is a chemical textile recycling startup, founded by the same team as Tree-to-Textile[46] (backed by H&M and Ikea). All problem owners will be involved from the very start of the project, as described in Section 1.3 and illustrated in Figure 1. As their needs will be thoroughly explored (WP3 UX design), we expect to clearly identify where and how AI/ML can have maximum positive impact for each organisation. With this said, nuances in needs have already been expressed, which will act as an initial guideline in where to begin. For example, the charity organisations indicate that their main needs can be found in trends and price setting, alongside automating monotonous and repetitive/heavy (ergonomics) tasks. Hack Your Closet favours garments that are of good material quality, to last many rental cycles, which indicates a focus on wear and tear aspects. They are also interested in mix-and-match solutions to build customer relevant combinations of outfits from a wide array of garments. Finally, ShareTex is interested in identifying garments suitable for their recycling process, a route that eventually all garments must take.

Successful pilot results will be possible to integrate in the piloting organizations, depending on what product group and what AI/ML concepts are chosen. Moreover, the Open Source data set can be used as a baseline for continuous refinement and development of new algorithms and models, as previously described. This is likely to be conducted in spin-off projects for the charity organisations, while Hack Your Closet and ShareTex intend to and/or already have hired AI/ML competence.

3.3 Project constellation

The partners’ competences are truly interdisciplinary and complementary. Wargön holds significant competence related to how the fashion industry affects the climate and what can be done to minimize its climate impact. Wargön also has a flexible pilot plant for textile sorting with a capacity of 500-1 000 tonnes/year, including SotA technology installed e.g. a Fibersort NIR detector. The charities and SMEs are problem owners with deep knowledge about the second hand business, what sells and what does not sell.

[46] https://treetotextile.com/"TreeToTextile | Tree to Textile

They will have a strong influence on the AI pilots that will be developed and ensure that they are useful to their operations. RISE brings UX, AI, innovation process methodology as well as sustainability/climate competence into the project. Both Wargön and RISE has a long experience in running complex, multidisciplinary projects where different stakeholders collaborate while addressing complex challenges.

The added value for Wargön and the problem owners is primarily a deepened understanding of AI and its possibilities. Likewise, the RISE team (UX+AI) will attain a stronger textile value chain and climate understanding, which can be utilized in future projects. Overall, we are convinced that the project will lead to a long term, strong collaboration and solutions that can have a significant impact on the climate.

3.4 Gender equality

Among the project group the distribution is eight women and eight men. The work of this application has taken place in close collaboration between the project group, with competence in AI, UX, climate and textile, in both in planning and in writing. The distribution in decision-making positions are two women and two men; Project manager (F), responsible for UX (F), AI (M) and climate assessment (M). Work performed by women amounts to 65% of the total 11 202 projects hours.

3.5 Dissemination

There is a large interest from many stakeholders to digtalise and automize the reuse textile sorting process, as well as to looking into possibilities to develop their own businesses by using data driven insights for used garments. The project aims to disseminate the project results so that as many as possible can make use of the new knowledge and solutions, e.g., to train AI/ML models etc, both national and international.

The following dissemination activities will be carried out in the project:

- Dissemination by using the project partners and Vinnova platforms and newsletters when applicable
- Use SoMe continousely during the project time
- Arrange in-store event in Swedish Red Cross shop
- Open webinar on AI and textile reuse
- Workshops connected to section 1.5
- Internal communication (meetings, workshops, news letters etc)
- Conference at project end

The project team already today have established relations with below organisations, and will during the project keep contact to further reach stakeholders that can have an interest in project results, and also to give feedback during the project period.

- Textile&Fashion 2030 (national initiative for circular textiles)
- STICA (The Swedish Textile Initiative for Climate Action)
- AI Sweden
- Swedish EPA
- Organisations covered by the reference group (Teko, Swedish Fashion council, Borås school of textiles)

Also, Sweden launched their strategy for digitalisation in 2017, and in addition to that, the region Västra Götaland (west Sweden) launched their new regional development strategy in March 2021 identifying digitalisation and circular business models as two of four longterm priorities. This project strongly supports both strategies, and also paves the way national and regional investments and development projects within circular textiles and AI/ML solutions.

4. Describe other aspects relevant to the project.

As many actors in the second hand sector are non-profit organizations, it is to some extent difficult for them to motivate investments in new technology, especially at an early stage. Therefore projects such as this is crucial for this particular stakeholder group, where joint technology development can be conducted. Lastly, Eutratex recently published a report stating that textile circularity will be very important in creating new green jobs. Estimates indicate that around 20 jobs could be created for every 1000 tons of textiles collected, sorted and recycled, ultimately creating up to 120.000 jobs in the European Union.[47]

[47] Recycling-Hubs-FIN-LQ.pdf (euratex.eu)