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Life cycle assessment of IoT system in Södertälje – The case of textile waste collection and the municipality's recycling stations

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Abstract

Life cycle assessment of IoT system in Södertälje – The case of textile waste collection and the municipality's recycling stations

Internet of things (IoT) is expected to transform the way we live, work, and learn. Using IoT can be a game-changer for municipalities to move towards sustainability. Within the Vinnova financed project, *The inclusive, sustainable, and connected* society, the municipality wants to explore how IoT can enable route optimization and placement planning for increased operational efficiency. The aim of these environmental studies is to enhance the knowledge of the environmental benefits of IoT systems in three parts of the waste collection systems and services provided in the municipality of Södertälje: Waste collection in the city centre (Telge Återvinning), Textile collection (Human Bridge) and Recycling stations (Telge Återvinning).

The LCA results for waste collection in the city centre are documented in Chiew & Brunklaus (2021); while the main LCA results and conclusions for textile collection (part 2) and recycling stations (part 3) are summarized in this report. The results for all three types of waste collection system show that the implementation of the IoT system is quite low (<1%). In this study, the climate impacts of both textile waste collection and recycling stations services per year were identified with LCA. By using the actor analysis, we found that in both the textile waste collection and the recycling stations services, the major climate impacts come from citizens, e.g., in the case of the textile waste collection service. The climate impact of transportation of the citizens to the textile station is 36%, followed by the plastic or paper bags from the citizens is 22% of the total impact of the textile waste, while the transportation of citizens to the recycling stations is even higher, such as 70% of the total impact of the recycling station system. The textile collection and recycling stations showed that citizen's choice has huge impact on the CO2 emission. Re-used and recycled textiles, instead of incinerating can save up to 23-44kg CO2 per kg of new textile produced. The recycling stations collects almost 9kt of waste, which are consumer products (e.g. bicycles, furniture, electronic devices and car decks). Re-used products can save between 100kg CO2 eq per bicycle up to 300kg CO2 eq per electronic devices, such as electric tools or laptop computers, as well as 28kg CO2 eq per car decks.

On the other hand, the service provided by Södertälje has a huge influence on the citizens choice. The "rullande återvinning" (rolling service), in which Telge Återvinning arranged trucks to collect bulky waste closer to the citizen can reduce the emission that is caused by the citizen transportation. In addition, the IoT system installed in the recycling station can provide good information to the citizen to avoid congestion time and paying for an empty visit due to long queue in the recycling stations.

The service provided by Human Bridge and Telge Återvinning can be improved. However, both have already started to implement green choices. The environmental choices already made by Human Bridge (part 2) include the choice of thinner and recycled plastic bags and the choice of green electricity. The environmental choices already made by Telge Återvinning (part 3) include the choice of transportation (HVO instead of diesel) and the choice of green electricity. The recommendations for the future could include better service for the citizens (rolling service) and setting requirements on the service provider, such as in the textile collection (fossil-free transport).

Key words: Internet of things (IoT), textile collection, recycling stations, Life cycle assessment (LCA), actor-based analysis

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Content

Preface

This report describes the results of the life cycle assessments (LCA) studies on the Internet of Things (IoT) solutions for Södertälje municipality for two case studies: textile waste collection service and the municipality's recycling station service. This study has been performed as a screening LCA, meaning rough estimation and assessment of environmental impacts considering the most relevant materials and resources using average data. The results were then compared with reference values in the literature. These two studies were performed in Feb-Nov 2022.

This study was performed by two LCA experts at RISE: Yoon Lin Chiew and Birgit Brunklaus. Yoon Lin Chiew is an experienced LCA practitioner and conducting sustainability assessment in different national and international research projects. Yoon Lin was responsible for supporting in goal and scope definition, analysing the collected data, generating the results, and interpreting the results for part 2.

Birgit Brunklaus is a former Assistant Professor from Chalmers University of Technology and at RISE she is a senior researcher in LCA and social sustainability analysis. She has been leading national and international research projects. She has developed an actor - based LCA method for services (retailers, housing management, IoT services, transport services). She has also developed circular strategies for improved sustainability of municipalities and cities. Birgit Brunklaus was responsible for the design of the study, the initial goal and scope definition, the actor-based analysis, the data collection through interviews and document reviews, generating the initial results for part 2 and 3 and developing the discussion regarding environmental strategies.

Acknowledgement:

We want to thank all the participants that have been involved in the data collection and helping us understand the IoT services the operations for the textile waste collection systems and service at the recycling stations Tveta and Returen. Special thanks go to those that have been involved in the meetings and interviews, such as Andreas Sundberg and Ulrika Sten at Södertälje municipality, Göran Nyström at Human Bridge and Hasan Dincer at Telge Återvinning. Thanks as well to Hanna Lindén for reading the work and Ted Saarikko from Umeå University för valuable discussions.

Gothenburg, 1 February 2023

Other publications in the same project:

LCA report: Life cycle assessment of Internet of Things (IoT) solution in Södertälje municipality – A smart waste collection system. RISE report 2021:91. S_IoT_LCA_report 20211005_final_0.pdf (ri.se)

Vinnova report:Det inkluderande, hållbara och uppkopplade samhället–Nulägesanalys (2021). Det inkluderande, hållbara och uppkopplade samhället-Utvärdering och framtidsanalys (2023).

Paper: The inclusive, sustainable, and connected society – IoT implementation in a Swedish municipality. LCM conf 5-9 Sept 2021. Oral ID 52963. (Springer Book Life Cycle Sustainability. Section: Green digitalisation. E3S Web of Conferences 349, 11006 (2022): https://doi.org/10.1051/e3sconf/202234911006).

Paper submitted: The trash is always greener on the other side: a life-cycle assessment of IoT implementation. Theme: Co-creating sustainable digital futures. ECIS 2023 | Track Descriptions

Summary

Internet of things (IoT) is expected to transform the way we live, work, and learn. Using IoT can be a game-changer for municipalities to move towards sustainability. Within the Vinnova financed project, ***The inclusive, sustainable, and connected* society**, the municipality wants to explore how IoT can enable route optimization and placement planning for increased operational efficiency. The aim of these environmental studies is to enhance the knowledge of the environmental benefits of IoT systems in three parts of the waste collection systems and services provided in the municipality of Södertälje.

a) Part 1: Waste collection system and service provided by Telge Återvinning (WP 1)
b) Part 2: Textile collection system and service provided by Human Bridge (WP4)
c) Part 3: Recycling station system and service provided by Telge Återvinning (WP4)

All three studies support the project by identifying environmental hotspots of the system and services, as well as the benefits of IoT systems to the municipality. The environmental study in part 1 was performed in spring 2021 and includes a full life cycle assessment (LCA) of the IoT system and the city waste collection system, which was modelled in Simapro software. The environmental studies in part 2 and 3 were performed in Feb- Nov 2022. For the part 2 and 3, a screening LCA was performed. The calculation and LCA models are built in Excel spreadsheet. The data collection includes re-using LCA results of the IoT system that was modelled in part 1 and complemented with transport and plastic bag data from Human Bridge and transport data from citizens in part 2, as well as data on citizen visits and sorting data from Telge recycling station in part 3.

The functional units of the three studies are as follows:
a) Part 1: 1 year of IoT system service for city waste collection including 160 litter bins.
b) Part 2: 1 year of IoT system service for 11 textile collection and of 55t of textile waste.
c) Part 3: 1 year of IoT system service for the central recycling station and service, collecting total 8329t of recyclable waste material.

The LCA results for part 1 are documented in Chiew & Brunklaus (2021); while the main LCA results and conclusions for textile collection (part 2) and recycling stations (part 3) are summarized below.

LCA results for textile collections (Part 2):

- The results showed that climate impact of the IoT system is quite low, only 90kg CO_2eq per year; while the whole textile collection is around 100 times higher, about 10.5t CO_2 eq per year.
- The major climate impacts come from the transportation of citizen (36%), followed by the plastic bags and the paper bags (22%) that citizen use for packing textile waste to bring to the textile containers. The recycling center accounts for 18%.
- The sensitivity analysis conducted for citizen transportation showed that if half of citizen used no car, the impact can reduce to 1.9 kg CO_2 eq per year.

- The results also showed that is important to collect textile waste instead of incinerating. Therefore, citizens are encouraged to bring the textile to the textile containers rather than directly throwing it away to the waste container at home. Re-used and recycled textiles, instead of incinerating can save up to 23-44kg CO_2 per kg of new textile produced (Gustav et al., 2019).
- The scenario analysis showed that citizen's choice on where to dispose textile has huge impact on the CO_2 emission; in the future scenario, where more textile wastes are collected for reuse/recycling (7.5kg per person) compared to current scenario (2.5kg per person), there will be a 60% reduction in CO_2 emission in the textile collection in Södertälje.

LCA results for recycling stations (Part 3):

- The results showed that climate impact from IoT system is quite low, only 100 kg CO_2 eq per year, while the whole recycling station and service accounts for around 324t CO_2 per year.
- The major climate impacts (>70%) come from the transportation of citizen to the recycling station (237t CO_2 eq per year), followed by the recycling station (20t CO_2 eq per year) and the transportation after the recycling station to the waste management (49t CO_2 eq per year).
- The "rullande återvinning" (rolling service), in which Telge Återvinning arranged trucks to collect bulky waste closer to the citizen can reduce the emission that is caused by the citizen transportation. In Instead of 13t CO_2 eq per year due to car transport of around 3800 citizens, the rolling service has a reduced impact of only 0,4t CO_2 eq per year.
- The results show also that the recycling stations collects almost 9kt of waste, which are consumer products (e.g. bicycles, furniture, electronic devices and car decks). Re-used products can save between 100kg CO_2 eq per bicycle up to 300kg CO_2 eq per electronic devices, as well as 28kg CO_2 eq per car decks.
- In addition, the IoT system installed in the recycling station can provide good information to the citizen to avoid congestion time and paying for an empty visit due to long queue in the recycling stations.

The discussion and recommendation part include the analysis of the environmental choices made by Human Bridge and Södertälje municipality and Telge Återvinning. The results of the analysis and recommendations are summarized below.

- The environmental choices already made by Human Bridge (part 2) include the choice of thinner and recycled plastic bags and the choice of green electricity. The results showed that climate impact leads to 80% reduced impact for plastic bags and 63% for green electricity (16g CO_2/kwh instead of 43g CO_2/kwh).
- The environmental choices already made by Telge Återvinning (part 3) include the choice of transportation (HVO instead of diesel) and the choice of green electricity. The results showed that climate impact from HVO lead to 85% reduced climate impact and 63% for green electricity.
- The recommendations for future environmental choices or requirements made by Södertälje municipality could include increased service for consumer (rolling service) and the choice of transportation for textile collection and waste management (HVO instead of diesel or fossil free transport).

1 Introduction

To ensure that the development of the concept is in line with Södertälje municipality's environmental goals 2030, RISE support the development process by evaluating the environmental performance of the new concepts. In work package 4, a screening LCA was conducted for the new concepts, where the IoT solutions are implemented to the textile waste collection system and services, which is managed by Human Bridge, and the two recycling stations (Returen and Tveta), which are managed within in the municipality by Telge Återvinning.

The LCA studies were conducted in Feb-Nov 2022. The inventory data are collected from interviews with Human Bridge and Telge Återvinning, recent reports from previous research done by Human Bridge and Telge Återvinning together with research institutes (i.e. IVL reports), as well as internal statistics and environmental documents and other literature. The inventory data and assumption made for the textile waste collection are documented in section 2 and for the recycling station in section 3.

An interpretation meeting was conducted in the project meeting, where the LCA results were also presented and discussed. The LCA results also presented to Human Bridge and Telge Återvinning for feedback. Recommendation on how to improve the service systems are also discussed in this study.

1.1 Textile waste collection system

In Södertälje municipality, there are several organizations that collect clothes and textiles for recycling. Södertälje municipality's ambition is to procure this service and direct the collection to 1-2 organizations. In this pilot study, Södertälje has collaborated with Human Bridge to further investigate the benefits of the IoT system for collecting textiles for recycling. Human Bridge currently has a total of 11 containers for collecting clothes and textiles and they also have agreements to collect at the municipality's recycling stations. These textile waste containers are connected to the IoT systems and located near the resident areas (see appendix for the locations of the textile waste containers). According to the municipality, Telge Återvinning and Human Bridge, there are several challenges in the operation of the cloth and textile collection:

- Over-crowded textile containers lead to littering in the immediate area and to a reduced amount of textiles collected.
- Problems with thefts of the already collected textiles and to economic loss.
- Textile collection and emptying based on a fixed time schedule, not based on needs, when the containers are full. This is neither efficient nor resource smart.

Human Bridge has total about 2,500 textile waste containers deployed in the community, near residential areas, recycling centers and recycling stations, in collaboration with municipalities or private landowners (Human Bridge, 2022). There, the citizens can leave used clothes, shoes and household textiles These containers are located from central of Sweden and southwards. The basic idea is to collect used but functional materials for people who are in need. In 2020, Human Bridge has collected total 12,500 tons of textiles, therefore, it is estimated within 2,500 textile waste containers, which is approximately 5 tons per containers (Human Bridge, 2020). If Human Bridge has a scheduled collection for emptying textile containers once a week, approximately 50 times or trips will be required, so it becomes about 100 kg of textile waste/week can be collected. With our calculation, half a paper bag of textile waste is about 2.5kg and a full paper bag of textile waste is approximately 5kg = 20 households/week. If there are 2 full bags/household, it will be 10kg/week and only 10 households can fit in the same container. (The paper bag includes different types of materials such as cotton or wool products or synthetic products.)

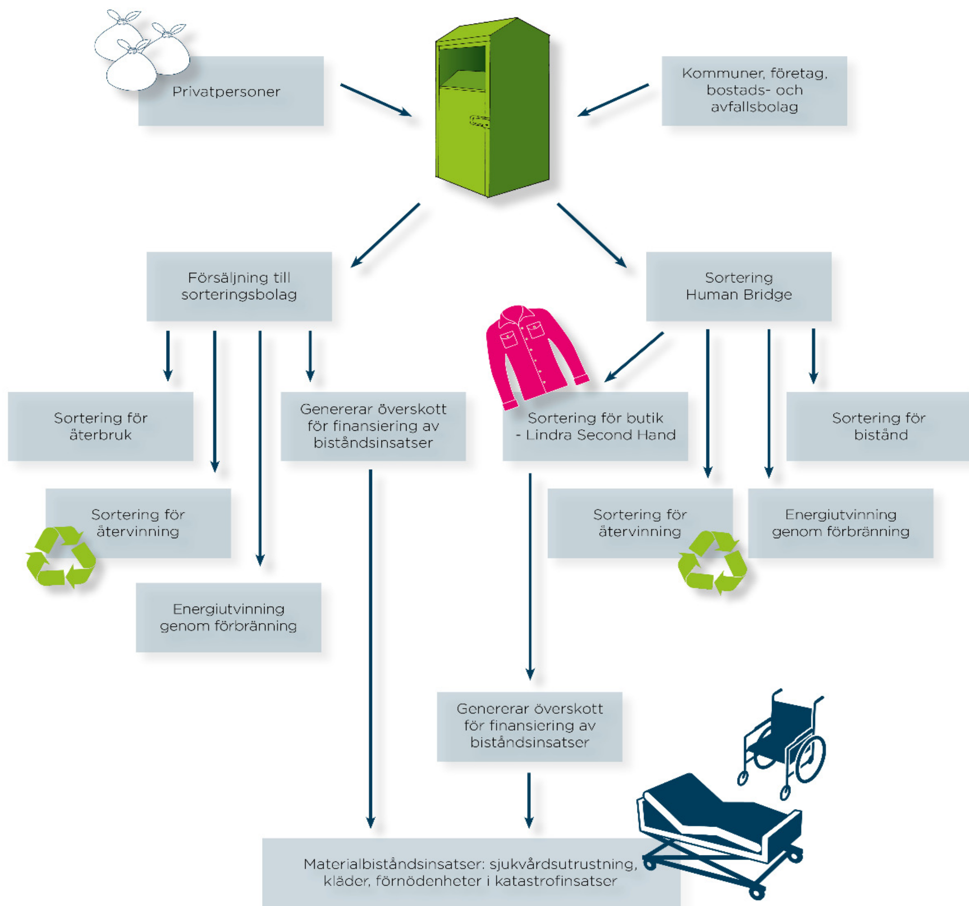


Figure 1: Overview of textile collection services of Human Bridge and distribution of the collected textiles. Source: Human Bridge, 2022

Figure 1 describes the textile collection services and what happens to the collected textiles. The collected textiles are being sorted, and distributed to different class of reuse and recycling for non-usable materials, or sold to enable humanitarian aid (e.g. delivery of clothes, preparation of and delivery of medical equipment, etc.). According to the textile statistics 2020 from Human Bridge, the average distribution of sorting over the year is as follows: Reuse 75%. Recycling 18%. Energy recovery 6%. Other material (packaging etc.) 1% (Human Bridge 2020, Human Bridge 2022).

The implementation, evaluation and validation activities of this textile waste collection service concept are described in Södertälje reports (Södertälje, 2022). The LCA analysis for the textile waste collection system in Södertälje is described in detail in section 2.

Figure 1a: Photographs from a consumer bringing the textiles with a car, textile container (based on steel) and textile transporter from Human Bridge (truck vehicle). Source: Human Bridge 2022

The transport from the household to the textile collection, the textile containers and the transport to the sorting station is shown in Figure 1a. The implementation, evaluation and validation activities of this textile waste collection service concept are described in Södertälje reports (Södertälje, 2022). The LCA analysis for the textile waste collection system in Södertälje is described in detail in section 2.

1.2 Recycling stations

In Södertälje, there are two recycling stations: 1) Returen located in Bolvallsvägen 5 in Moraberg, (Figure 2, left) and 2) Tveta located in Lerhaga (Figure 2, right). Both are managed by Telge Återvinning. These recycling stations collect and take care of household waste from Södertälje municipality and nearby municipalities. The company handles the sorting of bulky waste at the recycling centers Tveta and Returen. The facility at Tveta is subject to a permit in accordance with the Environmental Code. Telge Recycling also has permits for the transport of waste and hazardous waste and offers waste solutions for multi-family buildings, companies, and industries. According to Telge Återvinning, the recycling centers have uneven visitor pressure and many times ended up queues and caused congestion in the recycling centers as citizens have difficulty to judge when it is wise to visit. This situation also contributes to uneven workload to the recycling stations. Therefore, the IoT system is installed in the recycling stations, to monitor the number of visitors and share it with the public to avoid the issue mentioned above. The implementation, evaluation and validation activities for this pilot study are described in Södertälje's report (Södertälje, 2022) and The LCA analysis is described in section 3.

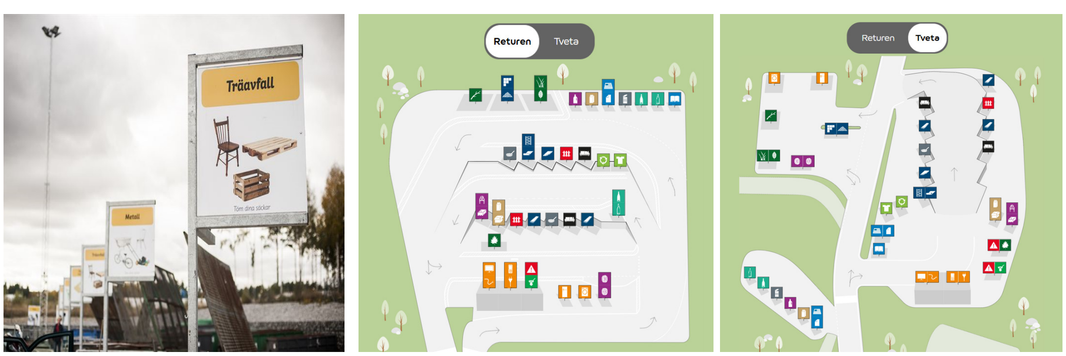


Figure 2 Recycling station (Returen, picture) and the sorting system (Returen, left, Tveta, right)

2 Part 2: Textile waste collection system

2.1 Goal and scope

The objective of the part 2 study is:

(1) to estimate the environmental impact (climate change impact) of the **IoT system for textile collection with 11 sensors** in Södertälje (cradle to gate) and identify the hotspots.

(2) to estimate the environmental impact (climate change impact) of the **current textile collection system** and **future textile collection system,** presumably the amount of textile waste collected from textile waste containers increased threefold. That means it will be increasing of amount of textile waste being recycled and re-used and contributed to decreasing amount of textile waste going to incineration.

2.2 System boundary

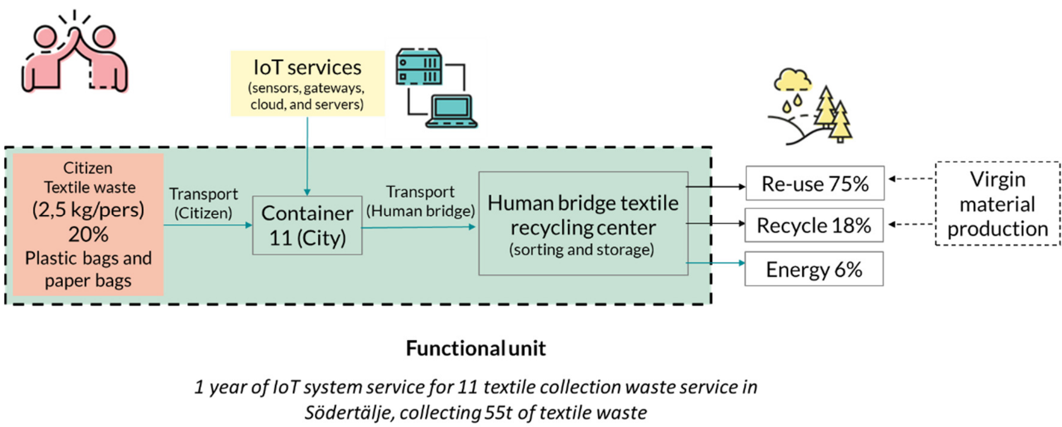


Figure 3 System boundary considered for the LCA for textile waste collection systems (part 2).

The system boundary considered for the part 2 are showed in Figure 3. It includes activities: plastic bags used by the citizen to pack and carry the textile waste from home to textile containers, transportation of the citizen, waste containers (3 m^3), IoT services, transportation arranged by Human Bridge to collect textile waste, operation in the Human Bridge textile recycling center, i.e. electricity used and plastic bags used for packaging and storage. The impact of the transport and impact or credits of reusing, recycling and incinerated the textile for energy purposes are excluded in the study.

In Södertälje, it is estimated total 55t of textile waste can be collected from 11 waste containers annually. According to the recent year's textile waste statistics, each person is collecting 2.5kg of textile waste and 7,5 kg go to incineration (SOU 2020). This is based on: 3,8kg textile go to aid organisations like Human Bridge (SMED 2018), where 2/3 part are reused or recycled, 2.5kg of textile waste go to re-use and recycling and 7.6 kg of textiles go to incineration and 60% could be reused (SMED 2016).

2.3 Scenario analysis

In the scenario analysis, we evaluated the climate impacts of clothing and textile disposal and recycling activities in Södertälje municipality in a year, included the textile collected from the textile waste containers and disposed to the normal municipal solid waste trash bins. The functional unit of the study became 1 year of textile waste collection in Södertälje, collecting 220t of textile wastes. In general, the citizens have two choices of disposing the clothing and textiles:

1) bring clothing and textiles to textile containers that are connected and located nearby the residential area;

2) dispose them to a normal municipal solid waste bins and the city waste truck will transport them to nearby incineration.

For the choice of connected textile waste containers, the activities included are transportation from household to the textile waste containers (citizen), the textile waste containers, the transportation of the textile waste to the sorting station, the operation of sorting and storage activities at the recycling center (Human Bridge) and the transportation of the textile waste to the incineration plant, where textile waste will be incinerated for recovering energy.

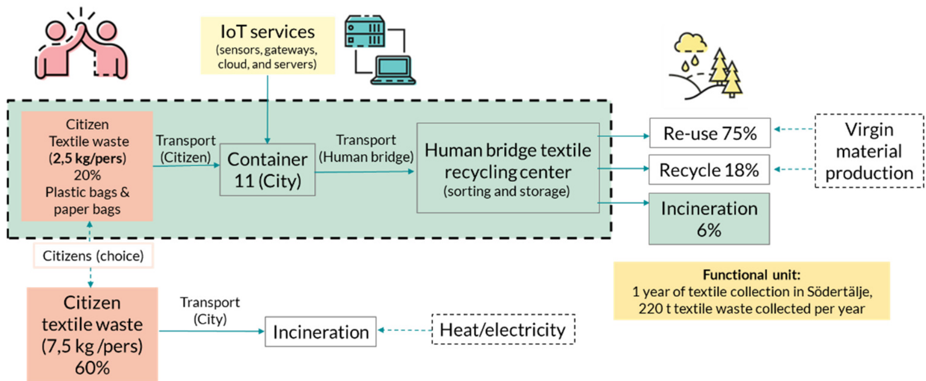
For the choice of disposing to the normal municipal solid waste bins, the activities included are the transportation of textile waste collection from household to the incineration plant (municipality), the emissions of incinerating the textile waste, as well as credits of electricity/heat recovered from the incinerating them (incineration plant). Below describes two scenarios, the baseline scenario, and the future scenario, in order to evaluate the environmental effects of the citizens changing their behaviour.

2.3.1 Baseline scenario

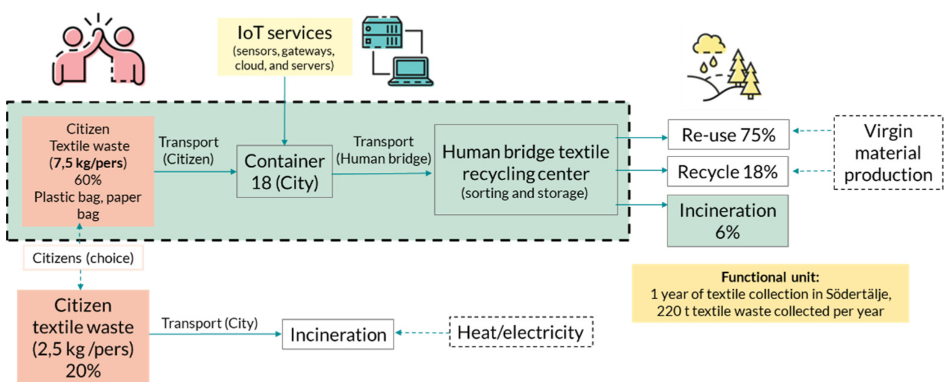
The baseline scenario is reflecting the current situation of the textile collection in Södertälje, where people tend to dispose the textile waste in the normal municipal solid waste bins and less likely to bring them to the textile waste containers for recycling. It is estimated that 2.5kg of textile waste per person are collected from connected textile waste containers; while the normal municipal solid waste bins will collect 7.5kg of textile waste per person, as described in Figure 4(a). In the baseline scenario, out of the 55t textile waste that collected from textile waste containers, only 6% of these textiles are sent to incineration; while 165t of the textile waste collected from the normal municipal solid waste bins, 100% of the textile will be sent to incineration.

2.3.2 Future scenario

The future scenario is reflecting the future situation of the textile collection in Södertälje, where three times the volume of the textile are collected compared to the baseline and the total waste containers increase to 18 bins to meet the demands. The choice of citizen has changed, and it will be more favourable to bring the textile waste to the connected textile waste containers. It is estimated that 7.5 kg of textile waste per person will be collected, as described in Figure 4(b). In the future scenario, the citizens have a higher awareness for recycling textiles, so the total textile waste that is collected from textile waste containers will increase to 165 t/year, only 6% of these textiles are sent to incineration. The citizens will be less likely to dispose the textile wastes to the normal municipal solid waste bins, and only 55t/year of textile wastes will end up being incinerated.



(a)



(b)

Figure 4 System boundary for the textile collection system: a) Baseline scenario: Collection of 55t textile waste using the connected textile containers, and 165t of textile waste from municipal solid waste containers in the household; b) Future scenario: Collection of 165t textile waste from the connected textile containers and only 55t textile waste are collected from the municipal solid waste containers in the household.

2.4 Data and assumptions

Below describes the data and assumptions used for the LCA studies in part 2:

IoT services

During the testing, evaluation, and validation, Södertälje found out that the signal reception for LoRaWan network is under performance. Therefore, it has been decided to apply another similar low power wide area networks (LPWAN) technology, named Narrow Band IoT (NB IoT). Due to the lack of data, it is assumed that the environmental impacts of the cloud service that uses NB IoT has similar impacts with LoRaWan. Data for emissions of the IoT devices and cloud services are taken from the part 1 study and adapted for the sensors installed to the textile waste containers. In total 11 sensors are installed to the textile containers; the gateway, cloud and internet services have the same emissions as calculated in part 1 study.

Textile containers

The textile containers are prepared by the Human Bridge. They are mainly made of steel with some paint. The size of the container is about 3 L, weighted about 415kg. The climate impact of the textile container is estimated from an Environmental Product Declaration of a waste container (EPD, 2021) based on weight basis. According to Human Bridge, the life span of the container is between five and seven years.

Transport of Human Bridge

Human Bridge, truck departs from Globen, Rökerigatan 23, Stockholm and collects the textile waste. The distance from recycling center to Södertälje is 42,8km one-way and 85,6km return, the distance between textile waste containers is estimated using google maps, which is about 12,9km, and the total distance is 98,5km. The emission factors for the truck <3.5t with different load rate are taken from the Network for Transport Measures (NTM, 2022).

Human Bridge textile recycling center

For the operation of the recycling center, the emissions from electricity used and number of plastics bags for packing the textile waste are included. It is assumed that plastic big-bag used for collecting the different fractions of rubber grains are composed of 90% of polypropylene and 10% of polyethylene (Ruban, 2012; Pistonesi, 2017). According to Human Bridge, the recycling center has a fixed electricity and heat priced, which monthly cost approximately 17 800 kr, for 10 000 t of textile waste for area of 850m^2. The amount of electricity used per month is estimated with 6660 kWh by taking the electricity price for area no. 3 and 2.67 Swedish krona per kWh (Eon, 2022). It is assumed that the CO_2 emission factor for the electricity is sourced from the Swedish electricity mix from the grid and it was taken from ecoinvent 3.8 database (Wernet et.al, 2016).

Transport of citizen

In 2021, the population of the city of Södertälje, Sweden is approximately 100 000 persons (Södertälje kommun, 2021). Transportation was estimated from the 2.5 kg of textile waste per person and 2.2 person per household. The transportation of the citizen for collecting 55t of textile waste is about 20 000km per year. The emission factors for the passenger cars are taken from the Network for Transport Measures (NTM, 2022).

Plastics bags used by citizen

The citizen used different types of bags to pack the textile wastes, so it is easier for them to bring the textiles waste to the designated containers. According to an evaluation by Södertälje, it is found that citizen used plastic trash bags (different sizes), plastics bags and paper bags that obtained from the grocery stores (see appendix). In this study, we estimated the bags used as follows:

- 35% plastic bags (city waste trash bags, 90 my, 120 L), made of fossil polyethylene (PE), estimate the bag can fill textile weighted 5.5 kg
- 35% plastic bags (city waste trash bags, 90 my, 120 L), made of recycled PE, estimate the bag can fill textile weighted 5.5 kg
- 15% plastic bags (household trash bags/retail, 14 my, 30 L), made of fossil-PE, estimated the bag can fill textile weighted 2.5 kg
- 15% paper bags(15 L), made of kraft paper, estimated the bag can fill textile weighted 2.5 kg

The weights and emissions of the plastic bags are estimated by our own measurements and taking data from the part 1 (LCA study for city waste collection). For the paper bags, the emission of the kraft paper is estimated 0.455 kg CO2eq of kraft paper per t (Eurosac, 2021)

Table 1 Inventory data for 1 year of IoT services on textile waste collection systems

Items	value	Value	Unit	Comments
Textile waste (Södertälje)		55	t/year	Human Bridge (webpage): Total 12500 t textile waste per year was collected from 2500 waste containers
IoT system (textile)				
sensor (11st)	11	2,3	kg CO2eq	taken from part 1 and adapted to 11 sensors
gateways (outside)	10	51,1	kg CO2eq	taken from part 1 (Chiew & Brunklaus, 2021)
gateways (inside)	2	10,4	kg CO2eq	taken from part 1 (Chiew & Brunklaus, 2021)
Others (cloud services, etc)		27	kg CO2eq	taken from part 1 (Chiew & Brunklaus, 2021)
Transport system (Human Bridge)				
Textile waste container (st)	11	1 547	kg CO2eq	Size 3m^3, weight = 415kg
Truck <3.5t, diesel (km)	5122	930	kg CO2eq	
kg CO2/km, load factor 0%	0,181	403		NTM, 2022
kg CO2/km, load factor 40%	0,191	128		NTM, 2022
kg CO2/km, load factor 100%	0,234	399		NTM, 2022
Recycling center (Human Bridge)				
Plastic bags (Human Bridge), PE 90my, 125L, 100% fossil (kg)	627	1 875	kg CO2eq	Size is 125L, 90my, Black, 80% recycled LDPE, 0,1367kg per piece (Tingstad, 2022)
Electricity and heat used (sek/month)	17800		SEK/month	Annually Human Bridge recycling facility processing 10000 t of textile waste (Miljöhandbok, 2022).

Items	value	Value	Unit	Comments
(in kWh/month)	6660		kWh/month	Estimated by taking average electricity price in Sweden (Eon, 2022)
Södertälje (55t) -(in kWh/year)	440		kWh/year	The electricity for processing 55t of textile waste is estimated.
EF SE electricity mix (in kgCO_2/kWh)	0,0437	19,2	kg CO2eq	Wernet et al., 2016
Transport system (citizen)				
Textile waste (Södertälje) per container (kg textile waste per container)	5000		kg	55 000 kg for 11 containers
Number of citizens for using 11 containers	22000		citizens	55 000 kg for 11 containers and 2,5kg per person.
Car (km)	20000		km	Assumed that 2.2 person per household (SCB, 2022), 50% of citizen use car to transport the textile waste and each car travel 2km
kg CO2/pkm (passenger km)	0,19	3800	kg CO2eq	NTM, 2022
Plastic bags (citizen)	no. of bags used			
35% plastic bags (city waste plastic bag fossil based)	3500	1 432	kg CO2eq	Taken emission data from part 1
35% plastic bags (city waste plastic bag recycled PE)	3500	636	kg CO2eq	Taken emission data from part 1
15% 14my plastic bags(household trash bag/retail), 30L (PE, fossil), 20g per bag	3300	198	kg CO2eq	Weight used own measurement and emission data is taken from part 1
15% paperbags 20-25L(retail), 60g per paperbags	3300	0.09	kg CO2eq	Own measurement, Eurosac (2021)
		2 266	kg CO2eq	
Total		10528	kg CO2eq	

For the scenario analysis, the system boundaries are expanded, below assumptions and data were used to calculate the baseline and future scenarios.

Transportation and emissions of incinerating textile waste

Both baseline and future scenarios include the transportation of the textile waste to the incineration, emissions of incineration of textile waste and credits of energy recovered from incinerating the textile wastes. We assumed that 75% of the textile waste is fossil-based textile and 25% of textile waste is biogenic-based textile. The emission factors for these activities are 0.739kg CO2eq per kg of fossil-based textile, and -0.536 kg CO2eq per kg of biogenic based textile (Roos and Larsson, 2018).

Transportation of city waste truck

For the other choice, the citizen can put the textile waste in the normal municipal solid waste containers. It will not make any different to the route or frequency of the collection. Therefore, it is estimated the emissions of the transportation of the city waste truck are same with the transportation as the Human Bridge truck.

2.5 Results

The climate impacts of the textile waste collection in Södertälje including the IoT system are estimated approximately 10.5 t CO2 per year, assuming that in total 55 t of textile wastes are collected (see Figure 5). The major contribution is the transportation of citizen (36%), and then followed by the plastic bags and paper bags that citizen used for packing the textile waste to bring to the textile container (22%). The textile collection system is contributing 37-41% of the total impact (including the textile containers 10-14% depending on the lifetime, the recycling center 18% and the transport 9 %). The climate impact of the recycling center is mainly due to the consumption of plastic bags used for sorting and packing, and only 5% is contributed by the electricity used for the operation.

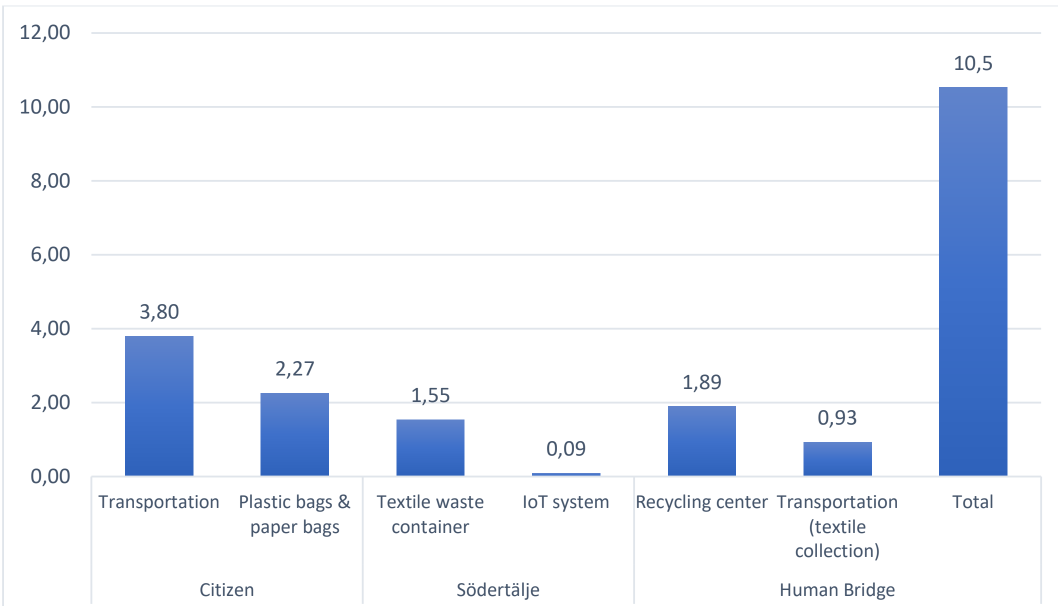


Figure 5 Distribution of the climate impact of the textile waste collection in Södertälje. Total 10.5t CO_2 eq per year and it is estimated from 55 t of textile waste are collected.

For the scenario analysis, the influence of the citizen behaviour was evaluated by assuming that in the future scenario the citizens have more preference in using the textile waste containers, resulting in approximately 7.5 t of textile waste collected per person.

The baseline scenario showed a significant high impact on the choice of disposing textile into the normal household containers (see Figure 6). This is mainly due to the high volume of textile going to incineration and caused high emissions of greenhouse gas.

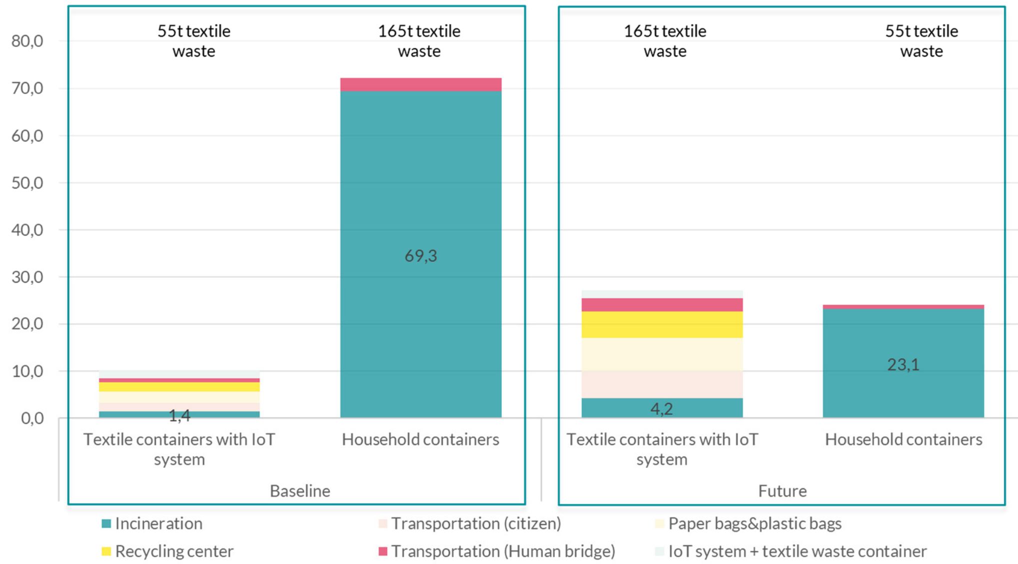


Figure 6 The climate impact of textile waste collection in Södertälje (Baseline/Future scenarios).

In the future, when the citizens change their behaviour and use more the textile containers, the amount of textile waste collected from the textile containers will increase. There will be more textile waste that is recycled and re-used.

This can avoid incineration of textile waste and contributes to a significant reduction in greenhouse gas emission. The total emissions of the textile collection per year in Södertälje will also be reduced from 69 t CO_2-eq to 23 t CO_2-eq, which is about 60%.

2.6 Sensitivity analysis

Several assumptions and data used are uncertain due to lack of real data.

Transportation of the citizen

In this study, the citizens are assumed to be travelling 1km to the textile waste containers and all citizens will use a car (scenario 1). Below several scenarios that are possible are evaluated to justify the assumptions made and to calculate the transportation of citizen. The last scenario is based on a previous study (Brunklaus et al, 2022).

- Scenario 1: (1km, Round trip 2km, all car) =3.8t CO_2eq
- Scenario 2: (2km, Round trip 4km, 50% car) = 3.8t CO_2eq
- Scenario 3: (1km, Round trip 2km, 50% car) =1.9t CO_2eq
- Scenario 4: (1.88km, Round trip 3.76 km, 35% car) = 2.5t CO_2eq

Retail plastic and paper bags used by the citizen

The emissions for the retail plastic or paper bags used by the citizen to pack the textile waste might be overestimated. 100% of the impact of the used retailer bags (plastic bags and paper bags) is accounted for. Following the modelling rules of recycling in lifecycle assessment (Ekvall et al., 2020), it is only 50% of these bags accounted to the second life, according to 50:50% method, or zero impact should be allocated to the second life due to the cut off method.

2.7 Recommendation

Table 2 describes the activities that can be done by different actors, such as citizen, the municipality of Södertälje and service provider (Human Bridge) to improve and to reduce the climate change impacts of the textile waste collection system.

Table 2: Potential reduction of CO_2 emission in the system

Activity (Actor)	Recommendation	Reduction
Transport (citizen)	Increase number of waste containers (reduce the distance from 2km =>1.5km) Transport without car (i.e. bicycle, walking) Telge can increase waste transport services (rullande återvinning)	-25% -100% -50%
Plastic bags (citizen)	Recycled plastic bags, e.g. multiple use for plastic bags, plastic containers	-up to75%
Recycling center (Human Bridge)	Use recycled plastic bags (80% recycled PE, 20% fossil PE)	- up to 50%
Textile waste containers (Human Bridge)	Longer life span, from 5 to 7 years and up to 10 years (Based on Human Bridge experience)	-30-50%
Transport (Human Bridge) – Current and future scenarios	Optimizing the textile collection route (based on route optimisation at FTI). Use environmentally friendly fuel for the truck that collects textile waste (e.g. HVO)	-10-20% (Recycling, 2022) -83% (more analysis in the the discussion)
Setting demands on actors and activities (Municipality)	Setting demands on actors (consumers and on service providers) on transport, plastic bags and recycling center (already done)	From 25 % to 100% (more analysis in the the discussion)

It is recommended that citizen bring the textile waste to the textile waste containers without car and re-use plastic bags or paper bags that obtained from the grocery store or shopping. To further improve the emissions from the recycling center, Human Bridge should consider using recycled plastic bags in the operations of sorting, cleaning, packing and storing the textile wastes. According to Human Bridge, it is worth to investigate in prolonging the longer life span of the textile waste containers. According to the Packaging Collection Service FTI, using the data collected from sensors can optimize the collection route, which can contribute to 10-20% reduction in CO2 emissions. In the future, Human Bridge should consider to invest in using vehicle (truck) that used hydrogenated vegetable oil (HVO), which will reduce the emissions by approximately 80%. More analysis on green choices (Human Bridge) and recommendations are made in the discussion chapter.

2.8 Conclusion

The climate impact of the IoT system is quite low, only 90kg CO2eq per year; while the whole textile collection is around 100 times higher, about 10.5t CO2 eq per year. The major climate impacts come from the transportation of citizen (36%), followed by the plastic bags and the paper bags (22%) that citizen use for packing textile waste to bring to the textile containers. The recycling center accounts for 18%. The sensitivity analysis conducted for citizen transportation showed that if half of citizen used no car, the impact can reduce to 1.9 kg CO2 eq per year.

The textiles can be re-used or recycled instead of incinerated. It is important to collect textile waste instead of incinerating. Therefore, citizens are encouraged to bring the textile to the textile containers rather than directly throwing it away to the waste container at home. Re-used and recycled textiles, instead of incinerating can save up to 23-44kg CO2 per kg of new textile produced (Sandin, et al., 2019)

The scenario analysis showed that citizen's choice on where to dispose textile has huge impact on the CO2 emission; in the future scenario, where more textile wastes are collected for reuse/recycling (7.5kg per person) compared to current scenario (2.5kg per person), there will be a 60% reduction in CO2 emission in the textile collection in Södertälje.

3 Part 3: Recycling station system

3.1 Goal and scope

The objective of the third study (Part 3: ÅVS):

(3.1) to estimate the environmental impact (climate change impact) of the **IoT system installed at recycling stations, with 65 sensors** in recycling station (Tveta and Returen) and identify the hotspots.

(3.2) to compare the **current sorting system** with the **future sorting system** (including IoT system for planning and service). Based on Reuse and recycling. Based on “Avfalls plan”. Increase Reuse and Recycling. Decrease Incineration.

3.2 System boundary

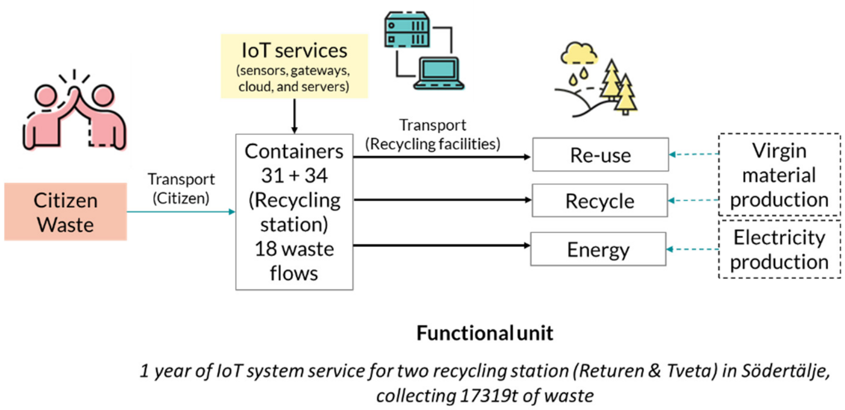


Figure 7 System boundary considered in the LCA of two recycling stations

Two recycling stations (Tveta and Returen) in Södertälje are considered in this study. According to Telge Återvinning, the total amount of waste is 17319t collected from these recycling stations. The activities included in the LCA calculation are the transportation of citizen to bring the waste to recycling stations, the IoT services installed in the containers and the sensors to monitor the number of visitors to recycling stations, the operations in the recycling stations, which involved some electric forklift, machinery for pressing the bulky trash, etc., as well as the transport of waste to final waste treatment center. Telge Återvinning is now taking measures to get the residents of Södertälje to recycle and not dump their waste. They have started ‘rullande återvinning’ and are sending trucks and leave containers in various locations around the municipality (currently, up to 20 spots) to collect bulky wate, hazardous waste and items for recycling during spring/autumn.

3.3 Scenario analysis

Telge Återvinning plan to increase the rolling service and to include recycling stations without personal needs and longer opening hours, since sensors and connected containers are taking care of the type of waste and the number of visitors.

In the scenario analysis, we evaluated the climate impacts of the recycling activities in Södertälje municipality in a year, included the operation at the recycling stations, the "rolling service" and the transport to the final treatment center. The functional unit of the study became 1 year of recycling waste collection in Södertälje, collecting 17319 t of recycling wastes (and 124470 visits per year or 325 visits per day). In general, the service and the citizens have two choices of recycling:

1) transport the waste to the recycling center that are connected and located further away from the residential area;

2) collect waste in rolling recycling that are running nearby the residential area and the rolling waste truck will transport them to the recycling station.

Below describes two scenarios, the baseline scenario, and the future scenario, in order to evaluate the environmental effects of the service provided and the citizens changing their behaviour.

The baseline scenario is reflecting the current situation of the recycling collection in Södertälje, where people tend to drive the car to the recycling center and keep on waiting for their turn, since the que of cars is quite long. Also, the amount of re-used materials is quite low in the baseline scenario. It is estimated that 17319 t of total recycling material is collected (124479 visitors) and a small number of visitors are using the rolling service (3786 visitors) in the baseline scenario.

The future scenario is reflecting the future situation of the recycling collection in Södertälje, where all the visitors are using the rolling service (124470 visitors) compared to the baseline (3786 visitors) and the transportation of the recycling service increases to meet the demands. The choice of citizen has changed, and it will be more favourable to bring the recycling waste to the rolling service or the new recycling station without personal ("obemannade ÅVC") that do have longer opening hours and are located closer to the residential area. The transport of citizens will decrease while the transport of the recycling service will increase.

3.4 Data and assumption

Below describes the data and assumptions used for the LCA studies in part 3:

IoT services

Data for emissions of the IoT devices and cloud services are taken from the part 1 study and adapted for the sensors installed to the recycling stations (Tveta and Returen). Total 69 sensors are installed: 31 sensors installed at waste containers and 2 for citizen car estimation at Returen, and 34 sensors installed at waste containers, and 2 sensors for citizen car estimation at Tveta; the gateway, cloud and internet services are the same emission as calculated in part 1 study.

Waste containers

The recycling stations owned total 65 waste containers, with size of 10 m^3 and each of these containers weighted approximately 700kg. The life span of the waste containers is expected to be 15 years. The climate emissions of the waste containers were estimated about 3.271kg CO2eq per mass of the waste containers (EPD, Norge, 2021)

Operations at recycling stations (Tveta and Returen)

For the operation of the recycling stations (Tveta and Returen), the emissions from electricity used and internal transports are included.

In the recycling stations, sometimes the wastes are bulky and Telge Återvinning operators have to have machines to press the waste in the containers, so it makes room to fill more waste. These machines are using electricity. The first screening study uses existing data from a similar recycling station, such as the Packaging Collection Service (FTI). Handling the storage and baling uses 2.6 kWh/tonne material (Brunklaus and Löwgren, 2022). The emissions factors are taking from Swedish electricity mix (Ecoinvent version 3.8).

Internal transportations, such as transportation of trucks between two recycling stations are also included. The first screening study uses existing data from a similar recycling station, such as Packaging Collection Service (FTI). Transports are using 0,75 liter diesel/tonne material (Brunklaus and Löwgren, 2022). The emission factor is taken from the NTM for truck with load 3.5t that uses diesel (NTM, 2022).

Transportation of rolling recycling truck service

In addition to the connected waste containers, Södertälje arranges additional textile collection services during spring and autumn. 4 weeks in spring and 4 weeks in autumn. This service is estimated as 15% of total textile collected in a year.

Telge Återvinning arranged rolling recycling truck in different locations (now up to 20 locations) to collect waste during spring or autumn. It is assumed that 2 trucks are used for this operation. The distance from the collection point to the recycling stations (Tveta/Returen) is about 10km for rolling service in the city central (15 locations) and 50km for rolling services in the outskirts of the city (5 locations). The emission factor is taken from the NTM for truck with load 3.5t that uses diesel (NTM, 2022).

Transportation of waste-to-waste treatment facilities

Most of the waste collected in the recycling stations will be transported to waste treatment facilities located Stockholm (30km distance). Some wastes do have longer transport distances, such as metal will send to Stena, which located at Järna or Ulricehamn, plastics waste will send to Motala for recycling, paper will be send to Fiskeby, etc. (100-200km). The distances are derived from the locations and google maps. The emission factor is taken from the NTM for truck with load 3.5t that uses diesel (NTM, 2022).

Transportation of citizen to recycling stations

It is assumed a longer distance for citizens to travel to the recycling stations. It is estimated that 80% of the visitors coming from the city centre (94 900 visitors, 10km distance) and 20% of the visitor coming from outside the city centre (23725 visitors, 50km distance). The emission factor is taken from the NTM for cars (NTM, 2022).

Transportation of citizen to rolling recycling truck

It is assumed shorter distance for citizens to travel to the recycling spots. It is estimated that the rolling service is stopping nearby the residential area and no transport is needed, in a walking distance of 500m up to 1 km.

Table 3: Inventory data for 1 year of IoT services on recycling stations of Tveta and Returen.

Items	value	value	Unit	Comments
Total waste collected		17319	t/year	Telge's annual statistic for recycling, 2021 (Telge, 2022)
IoT system (installed at recycling stations)				
sensor (Tveta, sorting)	69	14,6	kg CO2eq	31 (Returen) +34 (Tveta) +4 sensors (citizen car estimation)
gateways (outside)	10	51,1	kg CO2eq	Gateways taken from part 1 (Chiew & Brunklaus, 2021)
gateways (inside)	2	10,4	kg CO2eq	Gateways taken from part 1 (Chiew & Brunklaus, 2021)
Others		27	kg CO2eq	Others taken from part 1 (Chiew & Brunklaus, 2021)
TOTAL		103	kg CO2eq	
Trp system (Telge)				
Container 10m^3, 20m^3 (1st recycling station: 31, 2nd: 34)	65	9 922	kg CO2eq	10m^3 container, weighted 700kg
Truck, diesel (km), 3.5 t truck		49 123	kg CO2eq	ÅVC Returen +Tveta for details (Telge, 2022)
kg CO2/km, load factor 0%	0,226		kg CO2eq	NTM, 2022 (EU average)
kg CO2/km, load factor 20%	0,240		kg CO2eq	NTM, 2022 (EU average)
TOTAL		8351	kg CO2eq	
Recycling centre				
Electricity used	135877		Kwh/ Year	Electricity used at Moraberg x2 (Telge, 2022)
EF SE electricity mix (in kgCO_2/kWh)	0,0437		kg CO2eq	Wernet et al., 2016
TOTAL		11.9	kg CO2eq	
Trp system (citizen), load below 3 m3				
Waste per car visit ÅVC		136	kg/car	Total waste per number of visitors per year.
Number of citizen (per ÅVC)		124479	person per year	325 visitors per day (2021, Interview from Hassan), take reference, tveta+returen =8989+65881 (Returen); 8329+58598(tveta), 2021
Car (km)	1244790		km	2 x 5 km x visitors per year travel to ÅVC (Telge, 2022)

Items	value	value	Unit	Comments
kg CO_2/pkm, passenger car	0,118	146 885	kg CO2eq	NTM, 2022 (EU diesel car, wtw-data)
kg CO_2/pkm, passenger car	0,19	236 510	kg CO2eq	NTM, 2022 (EU average car, wtw-data)
Transport (Rolling recycling services)				
Centrum (15 spots)		600	km	10 km x 2 trucks (<7,5 ton) x 15 spots x 2 (spring/autumn)
Outskirts (5 spots)		1000	km	50 km x 2 trucks (<7,5 ton) x 5 spots x 2 (spring/autumn)
Truck, diesel, <7.5t truck	0,244	1600	km	
kg CO2/km, load factor 0%	0,268	429	kg CO2eq	NTM, 2022 (EU average, Diesel)
kg CO2/km, load factor 20%	0,302	73	kg CO2eq	NTM, 2022 (EU average, 100% HVO)
Transport from citizens using their cars instead of "rullande återvinning"				
Centrum (80%)		30288	km	According to the newsletter from (Telge, 2020), approx. 3786 citizens use the rolling recycling services. 3786*0,8*10 = 30 288 km (centrum 50x more km)
Outskirt (20%)		37860	km	3786*0,2*50 = 37 860 km (more kg per citizens, from 1,3 kg/visit to 10 kg/visit)
TOTAL		68148	km	
kg CO_2/pkm, passenger car	0,19	12 948	kg CO2eq	NTM 2022, EU average
Transport from citizen using their car to the main two recycling stations				
Centrum(80%)		995832	km	10 km x 94 900 besökare = 949 000 km (80%) IDAG CENTRUM ÅVC
Outskirts (20%)		1244790	km	50 km x 23 725 besökare = 1 186 250 km (20%) IDAG UTANFÖR
TOTAL		2240622	km	
kg CO_2/pkm, passenger car	0,19	425718	kg CO2eq	NTM 2022, EU average

3.5 Results

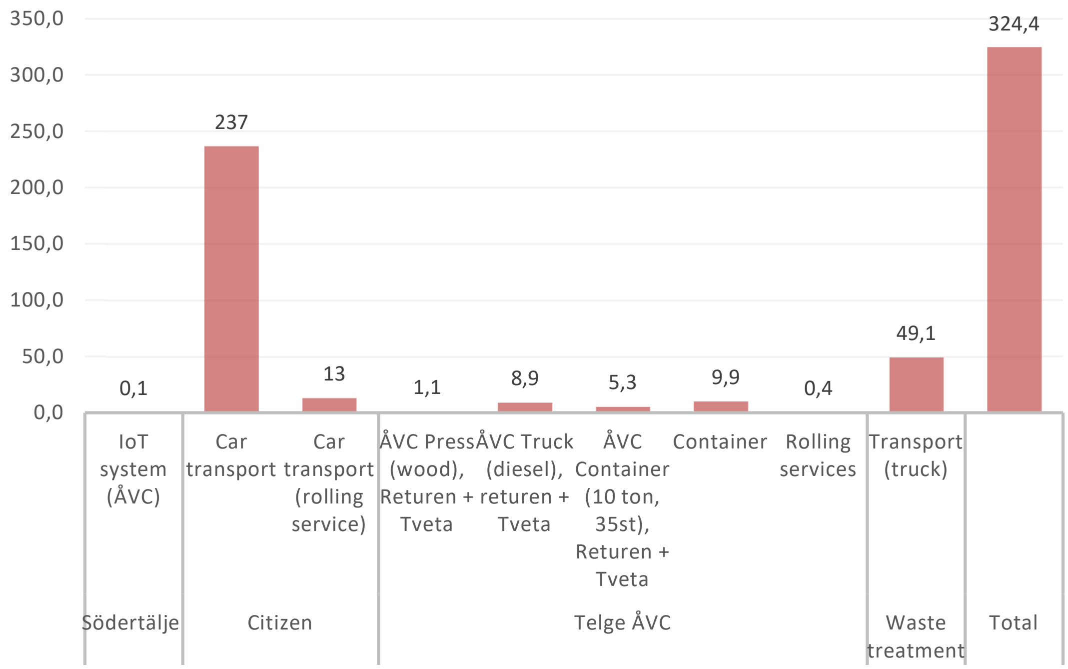


Figure 8 Climate impact of recycling stations (Tveta and Returen) in Södertälje – t CO_2 eq/year

The climate impact of the recycling station (Tveta and Returen) service contributes total 324.kg CO2 equivalent per year. The major emission is contributed from citizen car transport to visit the recycling station, contributed 237 t CO2eq per year (70% of the total CO2 emission). This follows by the emissions from the trucks that transport the waste-to-waste treatment facilities, which fuelled by diesel, approximately 50 t CO2eq per year. The emissions caused by the recycling stations, such as internal transportations, electricity used for operations, waste containers and rolling services are insignificant.

The rolling service means reducing the climate impact from citizens (13t CO2eq) to rolling service (0,4 t CO2eq). The scenario analysis shows that increasing the rolling services from 3786 visitors to 124479 visitors means reducing the climate impact from 425,7 t CO2eq to 13,09 t CO2eq (only 3%) and increasing the climate impact from 0,4 t CO2eq to 13,08 t CO2eq (30 times). That means shifting the burden from citizens to the municipality. The overall climate impact reduces from 429,7 t CO2eq to 27,7 t CO2eq (only 6,4%).

The IoT system contributes merely 100kg CO2 eq per year, which is 0.03% to the total CO2eq per year. That means that the climate impacts from the IoT system is quite low.

Environmental benefits of the waste collected in recycling stations are certain, and from literatures reported climate impacts for consumer products are listed in Table 4. Recycling the consumer products can avoid producing new consumer products, which will avoid emission of production of consumer products. Recycling stations in Södertälje annually collect 8989 ton of waste (based on statistics in 2021, Telge 2022), that means almost 9 kilo ton of various consumer products.

Table 4: Climate change impact for different consumer products.

Consumer products	Climate impact of production (kg CO2 eq per unit)	Reference/comments (annual waste)
Bicycle	100-200	80 t bikes waste means **800 t CO2eq** (TREK 2022, 10kg/bike or 13 kg e-bike)
Office chair or sofa	75-85	1 000 t furniture waste means **4-8000 t CO2eq** (EPD 2022, 4-8 kg CO2/kg)
Electronic device	30-300	337 t E-waste means **12 806 t CO2eq** (IVL 2019, 38 kg CO2eq/kg)
Mobile or laptop computer	80-300	337 t E-waste means **67,4 kt – 168, 5 kt CO2eq** (HP,200kg CO2eq/kg) (IPhone, 500kg CO2/kg)
Bok	1,2	63,8 t (x2) book waste means **63,8 t CO2eq** (IVL 2019, 0,5 kg CO2eq/kg)
Car deck	28	38,56 t car deck waste means **19,28 t CO2eq** (EPD Michelin, 56,7 kg/deck, 0,5 kg CO2/kg)

3.6 Recommendation

Table 5 describes the activities that can be done by different actors, such as citizen, the municipality of Södertälje and service provider (Telge Återvinning) to improve and to reduce the climate change impacts of the recycling waste collection system.

Table 5: Potential reduction of CO_2 emission in the recycling system

Activity (Actor)	Recommendation	Reduction
Transport (citizen)	Transport without car (i.e. bicycle/walking) Telge can increase waste transport services (rullande återvinning)	-100% -50%
Electricity (Recycling station) – Current and future scenarios	Use environmentally friendly electricity for operations at recycling station (e.g. vind)	-63%
Transport (Recycling station) – Current and future scenarios	Optimizing the textile collection route (based on route optimisation at FTI). Use environmentally friendly fuel for the truck that collects textile waste (e.g. HVO)	-10-20% (Recycling, 2022) -83% (see discussion)
Transport (Waste treatment) – Current and future scenarios	Optimizing the textile collection route (based on route optimisation at FTI). Use environmentally friendly fuel for the truck that collects textile waste (e.g. HVO)	-10-20% (Recycling, 2022) -83% (see discussion)
Improving the green service Setting demands on actors and activities (Municipality)	Improving the green service (rolling service). Setting demands on actors (citizen and on service providers) on transport, el and recycling station (already done)	From 25 % to 100% (more analysis in the discussion)

It is recommended that citizen bring the recycling waste to the rolling recycling stations without car. Instead walking and using the bicycle are recommended. To further improve the emissions from the recycling stations, Telge Återvinning should consider using green electricity (wind or water-powered electricity), which reduce the emissions by 63%, and green transport (fossil-free), which will reduce the emissions by approximately 83%. More analysis on green choices (Telge Återvinning) and recommendations are made in the discussion chapter.

3.7 Conclusion

The climate impact from IoT system is quite low, only 100 kg CO2 eq per year, while the whole recycling station and service accounts for around 324t CO2 per year. The major climate impacts (>70%) come from the transportation of citizen to the recycling station (237t CO2 eq per year), followed by the recycling station (20t CO2 eq per year) and the transportation after the recycling station to the waste management (49t CO2 eq per year).

The “rullande återvinning” (rolling service), in which Telge Återvinning arranged trucks to collect bulky waste closer to the citizen can reduce the emission that is caused by the citizen transportation. In Instead of 13t CO2 eq per year due to car transport of around 3800 citizens, the rolling service has a reduced impact of only 0,4t CO2 eq per year.

The recycling stations collects almost 9kt of waste, which are consumer products (e.g. bicycles, furniture, electronic devices and car decks). Reu-sed products can save between 100kg CO2 eq per bicycle up to 300kg CO2 eq per electronic devices, as well as 28kg CO2 eq per car decks.

In addition, the IoT system installed in the recycling station can provide good information to the citizen to avoid congestion time and paying for an empty visit due to long queue in the recycling stations.

4 Discussion

In addition to the connected waste containers, Södertälje arranges additional textile collection services during spring and autumn. 4 weeks in spring and 4 weeks in autumn. This service is estimated as 15% of total textile collected in a year.

Södertälje’s efforts to achieve the Environmental goal 2030 are as follows:

-application green electricity, thinner plastics, green transports (textile collection)

- application green electricity and green transports (recycling station)

Actor based analysis

The actor-based analysis is based on the environmental efforts made by Human Bridge and Södertälje municipality and Telge Återvinning. The results of the analysis and recommendations are summarized below.

The environmental choices already made by Human Bridge (part 2) include the choice of thinner and recycled plastic bags and the choice of green electricity (Miljöhandboken Human Bridge, 2022-05-30). The results showed that climate impact leads to 80% reduced impact for plastic bags and 63% for green electricity (16g CO2/kwh instead of 43g CO2/kwh). Figure 9 shows the effect of green choices (Green plastics and green electricity reduced the climate impacts at the recycling center from 1,89 to 0,83 kg CO2eq).

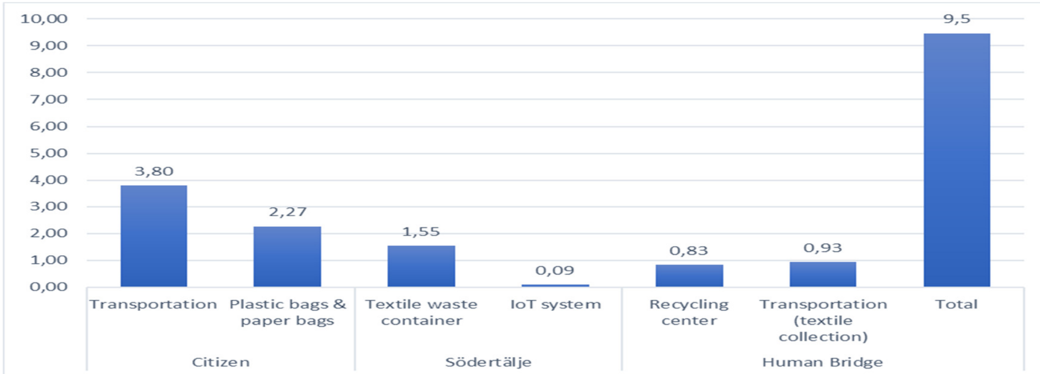


Figure 9: Climate impact of textile collection service (green choices) – t CO_2 eq/year

The environmental choices already made by Telge Återvinning (part 3) include the choice of transportation (HVO instead of diesel) and the choice of green electricity (Telge Återvinning, 2022). The results showed that climate impact from HVO lead to 85% reduced climate impact and 63% for green electricity. Figure 10 shows the effect of green choices (real electricity data increases the climate impact from 1,1 to 11,9 kg CO2eq, while green transports reduced the climate impact from 8,9 to 4,6 kg CO2eq).

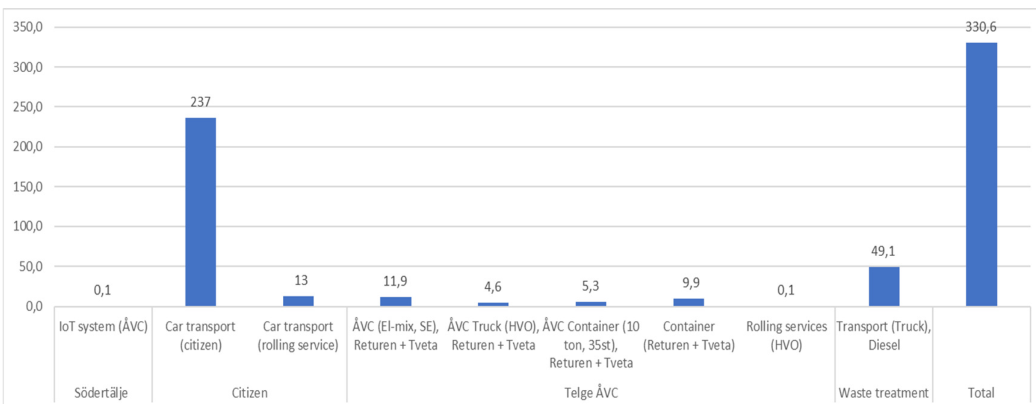


Figure 10: Climate impact of recycling service (green choices) – t CO_2 eq/year

The recommendations for future environmental choices or requirements made by Södertälje municipality could include increased service for consumer (rolling service) and the choice of transportation for textile collection and waste management (HVO instead of diesel or fossil free transport).

Future research

It is worthwhile to evaluate and compare the current schedule-based textile collection with the future demand-based textile collection system (including IoT system for planning and service). The transportation for collecting textile waste will be based on demand collection, not based on "Avfalls plan".

For the recycling stations, it is also important to collect real data in the recycling stations to estimate the environmental benefits of the current sorting system (with IoT system) and also find out improvement possibilities. For example, a survey to collect the real data for times, distances, and transport of the citizens to the collection station, amount of waste sorting for reuse and recycling (recycling waste kg/person), etc. will be very input to the study.

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6 Appendix

Figure below showed the locations of the connected textile containers in Södertälje.

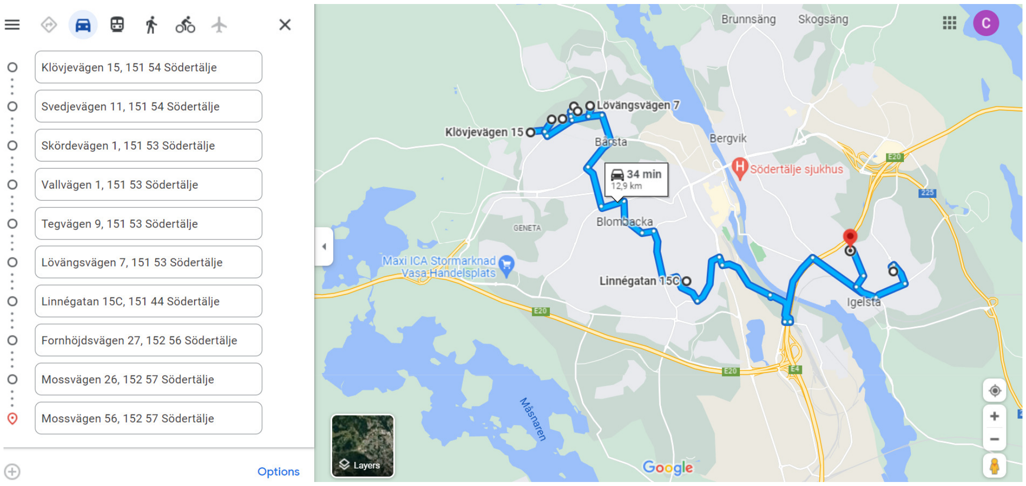

Figure 11: Locations of the textile waste containers in Södertälje.

Figure 12: Textile waste collected in the textile waste containers in different locations (pictures taken from Södertälje's report of control of sensors' measurement quality, dated 11 Aug 2022).

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