KTH ROYAL INSTITUTE OF TECHNOLOGY

AL227X Degree project in *Industrial Ecology*

Second cycle, 30 credits

Second-hand furniture and climate impact

LCA modeling to explore potential emission savings of reused furniture

KOLBRÚN HRAFNKELSDÓTTIR

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Second-hand business model and climate impact

LCA modeling to optimize potential emission savings of reused furniture

KOLBRÚN HRAFNKELSDÓTTIR

Supervisor

Rajib Sinha

Examiner

Monika Olsson

Supervisor at Ingka Circular innovation team, IKEA

Daniel Haltia and Anna Sinclair

Degree Project in AL227X

KTH Royal Institute of Technology

School of Architecture and Built Environment

Department of Sustainable Development, Environmental Science and Engineering

SE-100 44 Stockholm, Sweden

Samanfatting

Att implementera en cirkulär ekonomi har föreslagits för att kunna adressera miljöutmaningar orsakade av överproduktion och konsumtion av produkter. Återanvändning är ett cirkulärt mått som rankas högt i avfallshanteringshierarkin och är särskilt relevant för passiva och slitstarka produkter som möbler. Återanvändning av möbler har potential att bidra till att minska koldioxidutsläppen hos företag. Denna avhandling syftade till att undersöka potentialen om återanvändning kan bidra till att minska klimatförändringen. En Excel-modell utvecklades för att utforska olika återanvändnings-scenarier ur ett livscykelperspektiv som räknar ut potentiella undvikna utsläpp genom att sälja begagnade möbler. Resultaten visade att återanvändning av möbler resulterade i cirka 40 % minskad klimatpåverkan, även om det berodde på second-handhandelns egenskaper. Vidare identifierades second-handmöbelhandelns egenskaper som påverkar utsläppen av växthusgaser, t.ex. som ersättningstaket, second-handtransport och variation av sålda varor. Ett förbättrat scenario genom att optimera möbelhandelns egenskaper kan spara upp till 80 % av klimatpåverkan. Resultaten visade att återanvändning avsevärt skulle kunna bidra till företagens klimatåtaganden, även om det inte kan vara den enda begränsningsåtgärden för att nå koldioxidneutralitet.

Nyckelord

Cirkularitet och avkolning, Klimatpåverkan från möbler, Återanvända möbler, Möblers miljöpåverkan, Klimatpåverkan av begagnade produkter, Begagnade produkter, växthusgasutsläpp från begagnade produkter.

Abstract

A circular economy has been suggested to be able to respond to environmental challenges caused by over-production and consumption of products. Reuse is a circularity measure ranked high in the waste management hierarchy and is especially relevant for passive durable products such as furniture. Reusing furniture has the potential to contribute to the decarbonization of companies. This thesis aimed to explore the potential of reuse contribution to climate change mitigation. An Excel model was developed to explore different reuse scenarios from a life cycle perspective, accounting for potential avoided emissions by selling second-hand furniture. The results indicated that reusing furniture resulted in about 42% reduced climate impacts, although it depended on the characteristics of second-hand trade. Furthermore, the second-hand furniture trade characteristics that influence the GHG emissions were identified, such as replacement rates, second-hand transport, and variability of items sold. An improved scenario by optimizing the furniture trade characteristics can save up to 80% of climate impact. The results indicated that reuse could significantly contribute to the climate commitments of companies, although it cannot be the only mitigation measure to reach carbon neutrality.

Keywords

Circularity and decarbonization, Climate impact of furniture, Reused furniture, Furniture environmental impacts, Climate impact of second-hand, Second-hand products, GHG emissions of second-hand.

Acknowledgments

I would like to express my special thanks of gratitude to my patient supervisor Rajib Sinha that guided me wisely in this difficult task. I am thankful for my advisors from IKEA Daniel Haltia and Anna Sinclair who gave me this golden opportunity to do this thesis project despite my hesitation in the beginning. I want to thank especially Maja Wiprächtiger for guiding me to very helpful research papers and suitable measures to fulfill this projects aims. Her recently published article was especially relevant for this thesis project and contributes greatly to the understanding of environmental impacts of second-hand products. Special thanks to my opponent Minna-Maria Kristiina and examiner Monika Olsson for the detailed and helpful feedback on my thesis report that showed they obviously took their time to read my report in detail. I want to additionally thank my family and friends for their emotional support through these stressful times of my life especially the Northern Sweden group. I want to send my great appreciation to all the people that attended my final seminar for good suggestions, interesting questions, and encouraging words. Lastly, special thanks to my Wednesday group for inspiring me every week with wise words and building my emotional strength further.

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List of abbreviations

CO_2: Carbon dioxide

CO_2e: Carbon dioxide equivalent

EOL: End-of-life

EV: Emission value

FLCE: Full life cycle emission

GHG: Greenhouse gasses

HFB: Home furnishing business

LC: Life cycle

LCA: Life cycle assessment

LE: Life extension

LEP: Life extension period

MFA: Material Flow Analysis

PAs: Product Areas (sub-categories of the home furnishing business)

PAE: Potential avoided emissions

Pb: the probability that the second-hand purchase is replacing a new purchase

PCS: Potential climate savings

PUE: Product use emissions

RR: Replacement rate

WMH: Waste management hierarchy

WWF: World wildlife foundation

1. Introduction

Overconsumption and linear manufacturing are one of the drivers of human-caused environmental change such as climate change, resource depletion, and accumulation of large amounts of waste. Climate change is one of the most pressing concern of current times (IPCC, 2022). Material production causes more than 50% of current global greenhouse gas (GHG) emissions (Wiprächtiger et al., 2022). About 90% of the environmental impact of products occurs in the manufacturing stage (Landeta-Manzano et al., 2017). Worldwide cultures of consumption of products have had serious consequences for sustainability, the environment, and the well-being of individuals. Current market trends show impulsive consumption of non-essential goods is common (Fook and McNeill, 2020). Products tend to be discarded before the end of their technical lifetime and current generations have been referred to as the throwaway society (Böckin et al., 2020).

Science on sustainability has suggested the circular economy as a measure to mitigate the challenges of the throwaway society (Böckin et al., 2020). A circular economy strives for sustainable and responsible consumption and production. Resources move in a circular flow instead of the current common linear flows (Smol et al., 2020). The circular economy aims to keep products, components, and materials, in use if possible and make value of all their lifespans. Ultimately it seeks to decouple global economic development from finite resource consumption (Duque-Ciceri et al., 2018). Circularity measures have been referred to as the four to nine Rs such as reduce, reuse, and recycle (Böckin et al., 2020). The European Commission's Waste Framework Directive 2008/98/EC developed the Waste management hierarchy (WMH) to prioritize waste management measures. Measures that promote circularity are ranked higher than those that do not. The main measures are ranked from best to worst respectively: prevention, reduction, reusing, recycling, and lastly final disposal such as landfilling or incineration (Gharfalkar et al., 2015).

Reuse closes the loop for circular economy and mitigates the generation of waste and resource consumption (Böckin et al., 2020). Reuse is a circularity measure and ranked high in the WMH and can significantly reduce environmental impacts (Castellani et al., 2015). Reuse should be one of the first steps in increasing the resource efficiency of consumption items since it does not require a lot of resources or energy (Castellani et al., 2015). Reuse has environmental, social and economic benefits such as providing consumption items at affordable prices and supplying jobs to the community (Fortuna and Diyamandoglu, 2017). Several scientific studies have concluded that reusing is more environmentally beneficial than recycling (Sandin et al., 2019).

Circular economy has been suggested as having a good potential to reduce several of the environmental impacts of industries (Kaddoura et al., 2019). Industries cause significant environmental impacts and need to adapt work ethics for nations to be able to meet the United Nations Sustainable Development Goals. Larger corporations have a responsibility to improve environmental performance because of their significant contribution to the problem. They should also set an example for other companies to follow their lead, since they have the resources to do so (Atkinson, 2000). The furniture industry causes significant environmental impacts such as GHG emissions, resource depletion, and waste production (Castellani et al., 2015, Curran, 2010, Dietz, 2005, Hartini et al., 2019). Currently, researchers estimate that about 10 million tonnes of furniture are discarded annually in Europe, and only 10% is recycled. Furniture is often poorly designed, short-lived, and of low-quality materials (Cooper et al., 2021). Prolonging the lifetime of products, e.g. by reusing, contributes to resource efficiency, especially for passive products such as furniture (Böckin et al., 2020). Reuse has been identified to be able to reduce climate impacts, one of humanities greatest concerns. Life cycle assessment (LCA) of chairs has indicated that about 79%-96% of the climate impact stems from materials extraction and waste management. With reuse, material extraction and waste management such as incineration and landfilling are avoided to some extent (Fortuna and Diyamandoglu, 2017).

IKEA is currently the world's largest furniture manufacturer and is responsible for about 4% shares of the global furniture market (Statista, 2021). Therefore, IKEA has the potential to be an important contributor to mitigating human caused environmental change (IKEA, 2021a). IKEA currently yields significant environmental impacts. This project will focus on IKEA's climate impact. According to their 2021 sustainability report, its carbon footprint was around 26.2 million tonnes of GHG emissions. About 52% of IKEA's climate footprint stems from furniture materials. IKEA seems conscious of this fact and has thus set ambitious commitments of reaching a fully circular value chain by 2030. IKEA is additionally committed to become climate positive by 2030 (IKEA, 2021d). To achieve those ambitions IKEA has implemented several actions one of which is reusing furniture. Their first second-hand store opened in November 2020 in the world's first second-hand mall, ReTuna, in Eskilstuna, Sweden (IKEA, n.d.b, ReTuna, n.d.). This action is beneficial for circularity since the product lifespan is expanded, the products are saved from final disposal, and resource consumption required to produce new items can be avoided (Fortuna and Diyamandoglu, 2017). Although, it is not clear how this circularity action could play a role in their climate commitments, if reuse can be considered as a sink for carbon emission, or if it causes additional emissions. Reuse enterprises such as IKEA's second-hand store have been identified as being the reuse platform causing the highest level of emissions (Fortuna and Diyamandoglu, 2017).

The decarbonization potential lying in transforming linear economic models into closed-loop industrial ecosystems has recently started to be addressed (Nikas et al., 2022). Research has indicated that by going from a linear to a circular model about a 20-30% decrease in climate impact can be gained (Bolin et al., 2017). Although, there is a huge research capacity needed to inform on the role and potential of the circular economy for climate change mitigation (Nikas et al., 2022). This thesis project focuses on addressing and exploring that. Several studies have analyzed the climate impact of reuse often analyzing the contribution of reuse as a sink for carbon emissions (Fortuna and Diyamandoglu, 2017, Castellani et al., 2015, Nørup, 2019, Farrant et al., 2010, Wiprächtiger et al., 2022). Although, most of the studies analyze the climate impact of reusing clothing or a mix of clothing and furniture. Few studies have analyzed reuse potential as a carbon sink for the furniture industry, how to estimate that, and what variables are important.

Reuse is often referred to as second-hand trade. Second-hand trade refers to all activities associated with second-hand business models. In this study IKEA's second-hand store in ReTuna was used as a representative case study for second-hand furniture trade. This study used an LCA Excel model that was built on comparative and attributional LCA approach.

1.1. Aims and Objectives

The thesis aims to assess and explore the potential of reuse contribution to climate savings from a life cycle perspective and how current and future developments of second-hand trade could play a role in the climate commitments of companies. The aim of the project will be fulfilled with the following objectives.

1) Develop an Excel-based model to support estimating climate savings of selling second-hand products.
2) Estimate the share of second-hand sales for IKEA to reach the climate targets by utilizing the developed model.
3) Investigate strategies to maximize climate savings of second-hand sales.

2. Case description and theoretical background

This section will present required background information. The representative case for second-hand trade, IKEA ReTuna, is presented in section 2.1. Additionally, the climate commitments and circularity actions of IKEA with a special focus on second-hand trade. State of the art literature on how to assess the climate impact of circularity actions such as reuse was researched, and the results will be presented in section **Erreur ! Source du renvoi introuvable.**.

2.1. Case description, IKEA and ReTuna

IKEA is currently the world's largest furniture manufacturer. IKEA is at the forefront of the global ready-to-assemble furniture market (Statista, 2021). IKEA has 459 stores in 54 markets in the world. The IKEA business is defined as the business activities performed by all entities operating under the IKEA brand. The company does not only produce furniture but has various other activities such as producing food and working with various organization for societal change. The focus of this project will be on the furniture production (IKEA, 2021d). IKEA sells a wide variety of furniture items, and they categorize their items based on the function and the household room the items are used in. The furniture item categories are called Home Furnishing Business (HFB). There are 21 different HFBs and each is further sub-categorized to 208 Product Areas (PA) (IKEA of Sweden, 2022a). IKEA's value chain includes sourcing and extracting raw materials, manufacturing, and transporting products, store operations, customer travel to stores, product use in customers' homes, and product end-of-life (EOL) (IKEA, 2021d).

2.1.1. Climate and circularity actions of IKEA

IKEA has committed to becoming climate positive by 2030 and states that the climate commitment is a key element of its sustainability strategy, People and Planet Positive (IKEA, 2021d). Carbon neutrality is having a perfect balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks such as the ocean, plants, and trees, or net-zero emissions (European Parliament, 2019). The World Wildlife Foundation (WWF, n.d.) states that it is not enough to strive for carbon neutrality since it would still take hundreds of years for our climate to regulate and start to cool. This is due to the amount of GHG already in our atmosphere. If we truly want to reverse human-caused climate change, we not only need to reduce our emissions, but we also need to draw down the emissions already in the atmosphere. Climate positive is, according to the WWF, going beyond reductions of emissions to restore our climate (WWF, n.d.). Although, there are currently no official accounting frameworks that would underpin a corporate climate positive claim and some scientists have said the concept is vague and abstract (Jorisch, 2021, Ny and Thomson, 2021)

In IKEA's 2021 sustainability report IKEA states that they are in "steady progress towards our 2030 commitments". In the report, IKEA has summarized the climate footprint of their overall value chain where they separate the emissions based on 10 sources: materials, food ingredients, production, product transport, IKEA retail & other operations, co-worker commuting business travel, product use at home, product end-of-life, and other. IKEA states that its goal is to reduce the emissions from its overall value chain by 15% from a 2016 baseline. According to their sustainability report, the footprint of their overall value chain was 27.7 million tonnes of carbon dioxide equivalent (CO_2e) in 2016. In 2021 IKEA had already decreased its carbon footprint to 26.2 million tonnes of CO_2e. To reach their goal of a 15% decrease in emissions they need to reduce their carbon footprint to 23.6 million tonnes CO_2e. They have set certain goals for several of their 10 sources of emissions. In the sustainability report, IKEA states that about 5.3 million tonnes of CO_2e emissions are absorbed from the atmosphere through forestry (IKEA, 2021d).

IKEA states that they will achieve their climate commitments by three main means “using more materials and food ingredients with a low climate footprint, striving towards electrification or 100% renewable energy and continually improving the efficiency of their products that use energy, and promoting sustainable choices in transforming into a circular business”. Materials make up the largest part of their climate footprint, so IKEA needs to take actions related to their materials. IKEA has taken several actions to achieve its commitments, for example, using only energy-efficient LED bulbs, starting the transition into 100% renewable energy, and repurposing their industrial waste for new products. IKEA also aims at removing and storing more carbon through forestry. This is achieved by improving sustainable management practices within forestry and agriculture and by prolonging the life of products and the carbon storage in renewable materials (IKEA, 2021d).

IKEA aims to transform into a circular business by 2030 and working to ensure not only prolonged life of products through, reuse, repair, and recycling but also to ensure that the products are designed to be recycled from the beginning. This is to avoid products ending up in landfills or incineration. The goal is for the products to become a source of secondary raw materials or as secondary products for them or others to use. They have taken several actions to achieve that. IKEA has started designing their products for circularity and are testing more circular services such as creating markets for second-hand items to prolong product life (IKEA, 2021d, IKEA, n.d.d).

This thesis was related to IKEA’s circularity action of creating markets for second-hand items which will be further discussed in the following sub-section (IKEA, 2021d, IKEA, n.d.d). This circularity action not only plays an important role in IKEA’s circularity commitment but additionally has the potential to play a role in IKEA’s climate commitments since it could reduce the environmental burden of their raw material use (Nikas et al., 2022). IKEA could impact the product EOL emissions where they have seen an increase of 1% compared to the baseline scenario (Castellani et al., 2015, IKEA, 2021d). Emissions from producing new items might be avoided to some extent (Fortuna and Diyamandoglu, 2017, Castellani et al., 2015, Sandin et al., 2019)

2.1.2. IKEA second-hand and ReTuna

IKEA states on their webpage that “the most sustainable furniture is furniture that already exists” and that buying returned or previously owned furniture is better for the planet. One of the projects developed to contribute to this, is IKEA’s second-hand store, which opened its door to customers in November 2020. The store is in the world’s first second-hand mall, ReTuna, in Eskilstuna, Sweden (IKEA, 2021d).

The furniture flow at IKEA’s second-hand store consists of eight main stages, see Figure 1. The collection is primarily from donations, e.g., items that get dropped off at one of ReTuna’s drop-off points or saved by IKEA’s Circular Hub, stage (1-2) in Figure 1. Additional furniture items are brought from IKEA’s regular stores that have visual or functional flaws or have reached the End-of-Sales. At ReTuna employees sort the IKEA furniture from other furniture and IKEA reviews the condition of the items, stage (3) in Figure 1. The IKEA ReTuna employees collect those in suitable condition for repair and resell, stage (3) (IKEA, 2021b, IKEA, 2021c). The repair stage mainly consists of cleaning the furniture and minor repairs that are found feasible. Individual parts can be replaced with IKEA original spare parts from other second-hand items or new spare parts, stage (4-5). The items are checked for quality and safety before going into the store, stage (6). The pricing is done based on the item’s original prices and current condition, stage (7). The furniture is then brought forth in the second-hand shop and sold to a new owner that brings it to their home, stage (8) in Figure 1 (IKEA, n.d.b, IKEA, 2021b, IKEA, 2021c).

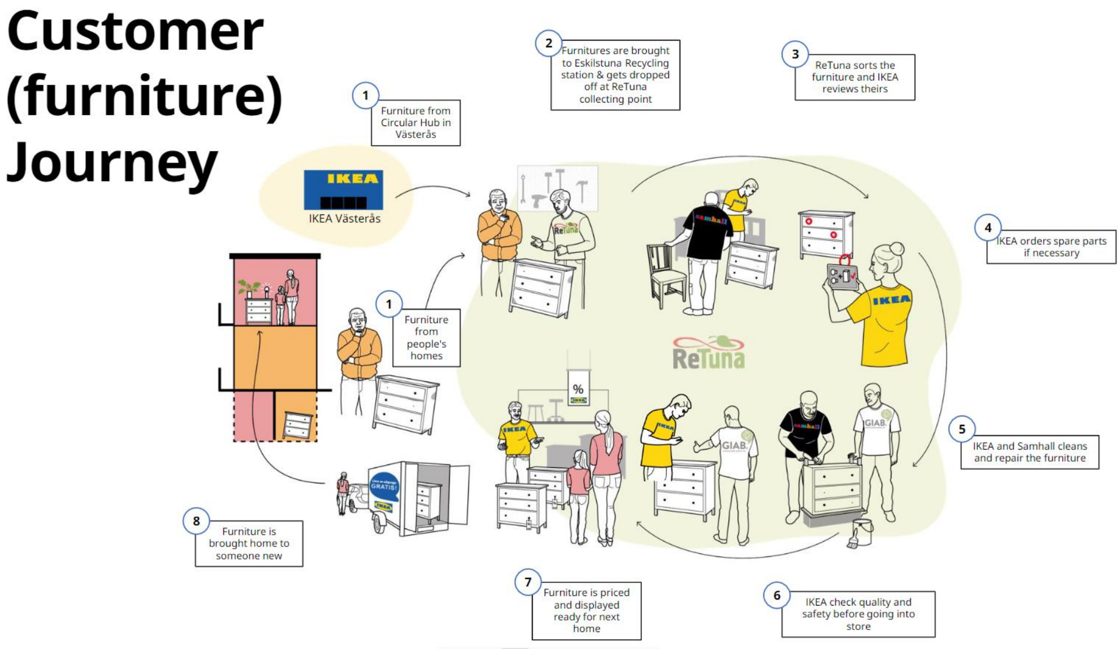

Figure 1 Customer (furniture) journey of the second-hand furniture sold at IKEA's second-hand store. Published with permission, from (IKEA, n.d.a).

IKEA recently introduced a Buyback & Resell service where customers can sell their used IKEA furniture. IKEA buys the used furniture back from the customer and sells it to a new owner. They accept only unmodified, completely assembled second-hand IKEA furniture. If the items are eligible for buyback customers can use the Buyback estimator tool to get estimates on the price they could get. The owner must clean the furniture and bring it to the Exchange and Returns section of their nearest IKEA store. An employee will compare the condition to the estimate and set a final buyback price that they then pay the customer with an IKEA refund card. IKEA then sells the furniture in Circular Hubs such as the one in ReTuna. If IKEA does not accept the furniture IKEA offers the owner to recycle it for them (IKEA, n.d.e).

In the Buyback & Resell service IKEA does not accept: non-IKEA products, products that have been used outside such as outdoor furniture, hacked or modified products, mattresses and bed textiles such as blankets and mattress protectors, sofas and armchairs, other soft furnishings such as pillows or towels, items containing glass, kitchens including benchtops, cabinets and fronts, PAX wardrobes and accessories, other over-sized items, appliances or other electrical items, children's and baby products such as cots, mattresses and changing tables, nor unassembled products or parts. Although the IKEA second-hand store has an extended accepted range which includes armchairs, plates, cutlery, glasses, and children's furniture. The Buyback & Resell service is currently available at IKEA stores nationwide excluding planning studios and IKEA Lab (IKEA, n.d.e, Haltia and Sinclair, 2022b).

2.1.3. IKEA's future intention with reuse

As mentioned in section 2.1.2 IKEA is developing more circular services making healthy and more sustainable living accessible and more affordable. They state that every product must be designed to be reused, refurbished, remanufactured, and eventually recycled. They have assessed over 9,500 products for their circular capabilities to gain insight into their current performance. They aim at assessing all their products for their circularity capabilities. The Buyback service was recently introduced and as mentioned in the previous section, IKEA does not accept all types of furniture. Those furniture might reach the second-hand store in ReTuna via other donation paths, but it is not clear if that furniture has the potential to be reused in future versions of second-hand IKEA stores (IKEA, n.d.d, IKEA, n.d.e).

2.2. The potential of circularity to decarbonize

The efficiency and environmental benefits of circularity measures have been assessed with the help of LCA or Material Flow Analysis (MFA) (Böckin et al., 2020, Krystofik et al., 2018, González-García et al., 2011, Kaddoura et al., 2019, Landeta-Manzano et al., 2017, Geyer et al., 2016). Reuse is a circularity action ranked high in the WMH. Selling reused items is often referred to has second-hand sales. Several studies have assessed the potential environmental benefits of second-hand consumption items such as clothing or furniture. Many of which do so with the help of LCA (Castellani et al., 2015, Lidenhammar, 2015, Sandin et al., 2019, Privett, 2018, Nørup, 2019). The focus of this study was the climate impact of second-hand furniture. Climate impact of furniture is commonly estimated with LCA (Wang et al., 2016, Curran, 2010, Dietz, 2005, Wenker et al., 2018). Research is still lacking in estimating the climate impact of second-hand furniture but LCA is applicable (Castellani et al., 2015, Fortuna and Diyamandoglu, 2017).

Second-hand sales are commonly considered to have environmental benefits. Although, second-hand sales would not be possible without new item sales (Castellani et al., 2015). The environmental benefits of reusing consumption items are mainly because of two factors: the benefits from the avoided EOL scenario and the avoided production of new products. Avoiding the disposal of goods in landfills or incineration directly contributes to a reduction in emissions to air, land, and water. The avoided production reduces the need for resources and energy. The avoided production assumes that a sale of a reused product replaces a sale of a new product to some extent, and therefore the production of a new product is avoided. Due to avoided manufacturing of new products reuse has been considered a "sink" for GHG emissions (Fortuna and Diyamandoglu, 2017). The assumptions of avoided EOL and avoided production of new items is, in LCA, called the avoided burdens approach (Geyer et al., 2016).

2.2.1. Avoided impacts

The majority of studies on the environmental benefits of reused products incorporate the avoided burdens approach and that emissions and energy in the production phase are avoided (Fortuna and Diyamandoglu, 2017). The avoided impacts are compared to the LC impacts of second-hand trade (Castellani et al., 2015, Nørup, 2019, Privett, 2018). Second-hand purchases do not always substitute purchases of new items, in some cases, second-hand purchases are additional buys (Castellani et al., 2015, Nørup et al., 2019, Farrant et al., 2010). Studies on the environmental benefits of reuse have incorporated a method that allocates only a proportion of the impacts of producing the items, as avoided impacts. A proportion variable is used and is referred to as *the replacement rate*, rate of substitution, or diffusion rate. This report will hereafter refer to this variable as replacement rate (RR) (Nørup et al., 2019, Wiprächtiger et al., 2022).

2.2.2. Replacement rates

RR is a recent concept used in LCA studies addressing environmental benefits of reuse and repair. RR has been defined differently between studies. Privett (2018) defined RRs for repaired items in a certain economy to be mainly influenced by two factors. The probability (Pb) of an individual not buying a new product and the repaired product life extension (LE) as a fraction of its original designed life. Wiprächtiger et al. (2022) analyzed the environmental benefits of reusing clothing and furniture and used a method with similar arguments as Privett (2018) study. Although, the LE was called substitutability and included not only the difference in lifespan but also institutionally prescribed functionality that accounted for restrictions or regulations dictated by authorities. Wiprächtiger et al. (2022) study included additionally differences in the use phase of new and second-hand products which was especially important for products consuming energy in-use phase. The diffusion factor, substitutability, and effects on use phase impacts, were found essential in assessing the impacts of waste prevention strategies

RR is a critical factor in LCA studies on the environmental benefits of second-hand trade. Fortuna and Diyamandoglu (2017) developed a framework that incorporated MFA and an optimization model to assess the optimal case of the reuse scheme in terms of GHG emissions. The framework revealed that the benefits of reuse were still obtained for RRs as low as 5%. Any RR of ≥40% resulted in emission reduction and RR >55% results in insignificant negative emissions from reuse. For RR = 0 recycling would be preferable over reuse from a climate perspective.

Determining RRs can be difficult due to the many factors influencing it. Behavior studies have been conducted to estimate RRs (Fortuna and Diyamandoglu, 2017). The behavior studies often consist of interviews or surveys of customers (Nørup et al., 2019, Castellani et al., 2015, Farrant et al., 2010). Nørup et al. (2019) found that the economic situation of consumers and the demographics of the area affected the RRs. Consumption habits affect RRs and are highly dependent on the individual and the type of product bought (Kleinhückelkotten and Neitzke, 2019).

Several studies have set RRs for clothing, other textile products, or electronics. Nørup et al. (2019) analyzed RRs of second-hand textiles in African countries with interviews with consumers. The RRs were lower than expected likely because many consumers interviewed did not have the purchasing power to buy new clothing and therefore their second-hand purchases did not replace the purchases of new items. They concluded that the RRs of textiles in Africa were on average 45±4%. Farrant et al. (2010) estimated that the RRs of garments were about 60% to 80% in Sweden, Estonia, and Africa. Ovchinnikov et al. (2014) studied if remanufactured cell phones replaced purchases of new cell phones which seemed to be the case for 40% of the purchases.

Research is currently lacking in estimating RRs of furniture items but they are likely higher than for clothing since furniture items are more durable products and durable products have higher RRs (Böckin et al., 2020). Castellani et al. (2015) set RRs based on product types after conducting surveys on customers. They estimated that RRs for furniture could be around 35% but furniture accessories (mostly made from glass) had about 84% RR. According to Nørup et al. (2019) research, RRs for household textiles were about 47% although it was found to be higher in countries with higher purchasing power. Angolans had the highest purchasing power and also the highest RRs of about 67%. This was expected to be even higher in European countries.

Privett (2018) estimated that repair cafés resulted in about 88.4% of the items repaired would have been replaced by a new item if it had not been repaired. Privett included mostly home appliances and other electronic items in their analysis but also some furniture items. The Pb of an individual not buying a new product following a repair was evaluated with a behavioral study that simply asked the customers if the repair prevented a new product purchase. They used a single Pb for all items but mentioned that in reality, different items have a different probability of replacement. The LE was not evaluated since it was found to be insufficient quantitative data or information on it. A sensitivity analysis indicated that shorter LE resulted in higher emissions. A very short LE could result in increased emissions instead of avoided emissions. But Privett (2018) concluded that the benefits exceed the additional impacts if the LE is over one year.

Research has identified several measures to increase RR. Choosing to buy second-hand instead of new is usually a more sustainable consumption choice and about 25% of consumers in the US reported considering sustainability when making a purchase (Skonberg and Thorbecke, 2022). Older consumers are more likely to buy items they need instead of buying items to follow trends. So, appealing to older consumers could increase RR (Edbring et al., 2016). Thomas (2011) developed an analytical model to determine the relationship between the demand for new goods and the demand for used goods. The results suggested that if used products were sold for the same price as new products, used goods can replace sales of new goods nearly one for one. So, Thomas (2011) model indicated that the RRs were in proportion to the ratio of used to the new price. The closer the second-hand items price is to the original price the higher the RRs. Although, raising the price of second-hand items could decrease the appeal of second-hand purchases for consumers with lower purchasing power. Price is the main driver of purchases in the furniture industry and raising prices might drive several consumers away from purchasing second-hand (Landeta-Manzano et al., 2017).

Second-hand enterprises contribute to their communities socially by providing products to consumers at lower prices which is lost by raising prices (Fortuna and Diyamandoglu, 2017). Environmental benefits of reuse are only achieved if a second-hand purchase replaces a new item to be purchased. Although, the social benefits of reuse are still achieved without the purchase replacing a new item purchase because of the affordability of second-hand items (Geyer et al., 2016). A lack of information on the quality of second-hand goods drives down the prices (Thomas, 2003). Implementing second-hand trade in higher income countries could result in higher RRs (Nørup et al., 2019). This does not go in hand with maximizing the social benefits of second-hand trade. Second-hand sales are more socially beneficial for countries with lower purchasing power (Fortuna and Diyamandoglu, 2017). Maximizing environmental benefits is more important in countries with higher purchasing power since high-income countries drive human-caused environmental change such as climate change (Hoshiar and Englund, 2018).

The success of second-hand trade is highly dependent on the RRs (Thomas, 2003, Kaddoura et al., 2019, Privett, 2018). RRs should be investigated for each specific case since demographics, budget, shopping habits, the durability of items, institutional restrictions, type of products, and reuse behaviors of individuals affect the replacement of purchases. Finding measures to increase RRs will have significant effects on the environmental benefits of reuse (Nørup et al., 2019, Thomas, 2003, Wiprächtiger et al., 2022, Castellani et al., 2015, Fortuna and Diyamandoglu, 2017).

2.2.3. Additional impacts

Reuse activities do cause impacts, especially from repairing or refurbishments of products and the additional transport (Castellani et al., 2015). Reuse can also cause rebound effects because, as mentioned in the previous section, second-hand products are usually more affordable than new products. Rebound effects are when reduction of expected benefits happens due to behavioral feedback. For example when money is saved by buying cheaper products is spent on something else instead therefore only moving the environmental footprint from one source to another (Privett, 2018, Wiprächtiger et al., 2022). Wiprächtiger et al. (2022) and Privett (2018) included rebound effects in their analysis. The rebound effects were found to affect the environmental benefits of reuse and repair.

Repairing and remanufacturing might require significant intervention for example the replacement of spare parts. Studies have shown that repairing products could cause higher emissions than replacing the items (Böckin et al., 2020, Privett, 2018). The replacement of parts has been shown to be one of the main causes of environmental impacts in repairing furniture items (Nadal, 2014). Although not all repairs require spare parts (Kaddoura et al., 2019). An LCA study conducted in Sweden analyzed the environmental benefits of repair of three passive durable products such as furniture. All the products required minimal repair. The result showed great potential to improve environmental performance and the climate impact was reduced by about 45-72% for all the analyzed cases (Kaddoura et al., 2019). The Swedish Society for Nature Conservation showed that renovating furniture instead of buying new can decrease climate impact by 48-62%. Repairing one’s own product was found to decrease GHG emissions by 97% in comparison to the climate impact of buying new (Lexén et al., 2021). Nadal (2014) performed a comparative LCA on replacement vs. repairing of warehouse wrack system. Technicians' transport and tooling showed to be responsible for about 85% to 98% of the impacts of repair service.

The environmental gains of repair were found to be from 30% to 60% depending on the distance traveled to the site of intervention. This indicates the important role transportation can take in circular economy solutions (Nadal, 2014).

Transportation is an important part of the environmental effects of furniture and circularity measures. Optimizing transportation distances and choosing more environmentally friendly transportation methods and fuels are important in minimizing the environmental effects of furniture (Iritani et al., 2015). Most LCA studies on the climate impact of circular actions include the impacts of transport (Böckin et al., 2020, Castellani et al., 2015, Iritani et al., 2015, Fortuna and Diyamandoglu, 2017, Sandin et al., 2019, Privett, 2018, González-García et al., 2011, Kaddoura et al., 2019). The benefits of product LE for passive durable products can be counteracted by transportation (Böckin et al., 2020). Fortuna and Diyamandoglu (2017) showed that for certain conditions recycling and incineration can be more environmentally beneficial than reuse because of the important role transport plays. User transport of reused clothing might cause environmental impacts exceeding the benefits of avoided production unless the use phase is sufficiently extended (Sandin et al., 2019).

The transports depend highly on the second-hand platform. Emissions from online platforms have been found to be significant since such item exchanges require further travels than items from direct exchanges. Although, the longer transport distances of online platforms did not show to be as significant to the emissions as the impact caused by the energy use in reuse enterprises in the US (Fortuna and Diyamandoglu, 2017). This is likely not the case for Sweden since in 2020 around 30% of Sweden's energy came from fossil fuels while around 80% of the US energy came from fossil fuels in the same year (Ritchie et al., 2020). Castellani et al. (2015) allocated the transports of the raw materials and transports of the manufactured product to the first LC of second-hand items. But second-hand trade has additional transports that are not a part of the first LC and need to be accounted for to evaluate the climate impact of second-hand furniture.

The GHG emissions from second-hand transportation can be controlled by several measures. Transportation distances is an important factor and affect the level of emissions. Distances that secure emissions from reuse to be lower than emissions from recycling should be analyzed to identify whether it is more suitable to reuse or recycle a product. A study on reusable grocery packaging found that distances over 1200 km would cause more significant emissions than producing new packaging. Choosing vehicles that cause less emissions and have more efficiency has a good potential to reduce GHG emissions (Fortuna and Diyamandoglu, 2017). Travel modes e.g., traveling by walking, cycling, public transport, or with a private vehicle, has shown to significantly affect environmental effects caused by transport. Public transport has been shown to have lower environmental pressures compared to those of a private vehicles (Sinha et al., 2019). Alternatives to transportation that rely largely on fossil fuels are often preferable on a climate perspective. Battery electric vehicles charged using renewable electricity are a promising alternative for short-distance transportation. However, longer distances of transportation will likely continue to rely on liquid or gaseous fuels because of the storage capacities. Alternative fuels such as H_2, biogas, and dimethyl ether all show significant improvements in GHG emission from transportation in comparison to fossil fuels (Bongartz et al., 2018).

3. Method

The methodology of this project was adapted based on previous research on how to assess the climate impact of reused consumption items such as furniture As research indicated LCA and MFA are suitable methodologies to conduct such analysis (Böckin et al., 2020, Krystofik et al., 2018, González-García et al., 2011, Kaddoura et al., 2019, Landeta-Manzano et al., 2017, Geyer et al., 2016). Data suitable to conduct an MFA was not available. Based on the complexity of the problem the methodology to assess the potential climate impact savings of second-hand trade was built on LCA. For an LCA, the goal and scope of the project needed to be defined, the life cycle inventory (LCI) needed to be accounted for, and lastly, the impact assessment and interpretation needed to be conducted where suggested improvements could be identified. In this section, the goal and scope of the project will be defined and the LCI conducted will be explained. In the result and discussion sections, the impact assessment and interpretation will be conducted.

3.1. Goal and Scope definition

The goal of this LCA was to estimate the potential climate savings for second-hand business models and how they could be adapted to increase the emissions saved. The study investigated if and to what extent second-hand sales could result in a reduction in GHG emissions. The GHG emissions of IKEA's second-hand trade were compared to the *Potential avoided emissions* (PAE) by second-hand sales. This thesis relied strongly on the assumption that second-hand sales replace purchases of new items to some extent. To reach the goal of the study a comparative and attributional LCA will be carried out on the impact category global warming potential because the aim of the study. Hotspots in GHG emissions of second-hand trade will be identified to recommend potential improvements to increase emissions saved. The study analyzed how second-hand trade could play a role in the climate commitments of corporate companies such as IKEA (IKEA, 2021d).

The study was a comparative LCA since it compares the PAE to the additional emissions from second-hand business models such as IKEA's. The study was attributional since it aims to determine the potential climate impacts of the two types of sales (Curran, 2015). The results of this study are intended to give IKEA's decision-makers insights into the impacts of second-hand business and how it potentially contributes to their environmental commitments. Reuse contributes to circularity (Nikas et al., 2022), but this study aims to analyze if reuse could also contribute to climate mitigation. The results are intended to be a tool for decisions made within IKEA on second-hand business developments. The results can also be beneficial for other companies that have the potential to implement second-hand trade or reuse schemes. The main intended audience was IKEA's staff and decision-makers and potentially the furniture industry. The results are additionally interesting for consumers of second-hand products.

3.1.1. Functional unit

LCA studies commonly calculate the climate impact of consumption items in kg CO_2e emissions per product, per kg product, or monetary unit such as the cost of the item (Isacs et al., 2016, González-García et al., 2011, Hartini et al., 2019, Carlsson-Kanyama et al., 2019). Using a monetary unit can be sensitive for reasons such as fluctuations in economic markets. Research on the links between climate actions and economic activities is still lacking (Isacs et al., 2016). Using a monetary unit for the case of IKEA was especially uncertain since IKEA sells its furniture items at a cheaper price than the average price of furniture in the current market (IKEA, n.d.c). The climate impact of consumption items is commonly measured per kg product which was found to be more suitable and not as sensitive (González-García et al., 2011). The functional unit of this study needs to be able to give the collection of furniture sold in the second-hand shop a fair representation. The present study compares the climate impacts of producing, selling, and discarding the weight of one million items to, emissions caused by selling the weight of one million second-hand items. The collection of furniture or the number of furniture sold from each furniture category, to be used for analysis was set based on sales data from conventional IKEA stores.

The functional unit of this study was therefore set to be the weight of 1,000,000 items. The climate impact was estimated in tonnes of CO_2e generated by selling and buying the weight of 1,000,000 items.

3.1.2. System boundaries and impact assessment method

Second-hand items can be considered to have more than one LC. The first LC stages were found to be the production of the items from raw materials, their sale, and transport, the use stage of the first owner, and final disposal. The second LC stages were found to be those associated with the second-hand furniture trade. The second life stages were found to be the transport of the donations to the second-hand store, collection of the second-hand items, cleaning, and repair of the collected items, the commerce, consumer transport to their new homes, and their final disposal. Commerce refers to impacts from the physical store such as from energy use of the facility. For simplifications and the scope of this project, only one reuse cycle was considered.

LCA studies on climate impact of reuse consider a part of the GHG emissions of the first LC to be PAE and the emissions of the second LC to be additional emissions (Castellani et al., 2015, Thomas, 2003, Nørup, 2019, Curran, 2010, Fortuna and Diyamandoglu, 2017). Several studies also associate the GHG emissions from the avoided EOL scenario to be avoided. Although, the later named assumption was questionable since the reused items will at some point end up in final disposal. Reuse is merely an internal step for discarded products before reaching EOL waste management such as incineration or landfilling (Fortuna and Diyamandoglu, 2017). Because of the scope of this project the EOL scenario was considered as avoided emissions. The PAE was compared to the additional emissions. Therefore, the system was split into two main stages: the PAE (associated with the first life stage) and additional emissions (associated with the first reuse cycle). The initial flowchart of the system to be analyzed is displayed in Figure 2. The flow chart is separated by PAE and additional emissions of the second-hand trade. The PAE correlate with the first LC of furniture and the additional impact correlates with the first reuse cycle of the furniture. The system boundary was defined similarly to Castellani et al. (2015). This study will not consider rebound effects in the numerical analysis although, rebound effects will be discussed.

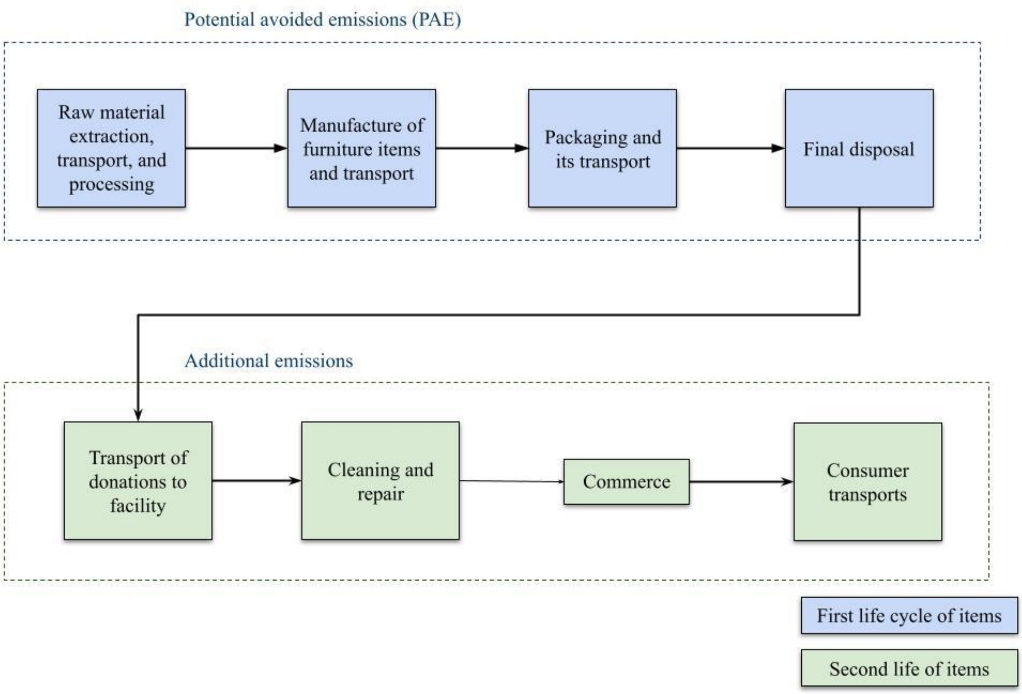

Figure 2: System boundaries (Inspired by the system boundary of Castellani et al. (2015).

Previous research that estimates the difference in emissions between producing new items and selling second-hand items often disregards the effects related to commerce. This is because the energy consumption of the housing and cash registers has been found neglectable in comparison to the energy use of the transportation (Castellani et al., 2015). Furthermore, the climate impact of IKEA's *Retail and other operations* was less than 2% of the overall climate footprint of IKEA (IKEA, 2021d). Therefore, for simplifications, the climate impact of commerce was disregarded in this analysis.

3.1.3. Assumptions

The new and second-hand products are assumed to be sold in Sweden and manufactured and packaged in IKEA's manufacturing facilities around the world. The products are assumed to be used and disposed of in Sweden. Since IKEA produces a large range of products it will not be possible to build an LCA model for each of the furniture categories, so, secondary data will be used for the first LC of the items. Transports are accounted for from IKEA ReTuna's sources of second-hand furniture to the store in ReTuna, Eskilstuna, Sweden. IKEA's store in Kungens Kurva, Stockholm was used as a representative for conventional IKEA stores, and transports are accounted for regarding that. The temporal boundary was one business year of IKEA for September 2020 to August 2021.

3.1.4. Data quality requirements

For fulfilling this project's aim, it was attempted to collect the most recent data available and not more than 10 years old for the reliability of the results. Data on footprint of product, services and transports for Swedish conditions and consumers of IKEA stores in Sweden was used. In case of lack of data from Sweden, the data from Europe and then the rest of the world was considered for transports in Ecoinvent3 (Wernet et al., 2016). For simplifications, some processes were disregarded, so, the model was a simplified version of the real-world case. The results might vary if changes are made in the assumptions. The data gathered in this study includes various GHG emission values (EV), distances, and various sales data from IKEA.

The GHG EVs included emissions values for the full LC of furniture items, EVs for transportations, and EV for repairs of furniture. EV data was retrieved from secondary sources. EVs for the full LC of furniture were in kg CO_2e per kg product retrieved from Carlsson-Kanyama et al. (2019) and will be further discussed in section 3.2.1. The EVs for the repair and cleaning were in kg CO_2e per cost product (in SEK) and were also retrieved from Carlsson-Kanyama et al. (2019), further discussed in section 3.2.3.1. The EVs for the different transportation paths were in kg CO_2e per ton-km or per km and retrieved and adapted from Wernet et al. (2016) and Sinha et al. (2019), further discussed in section 3.2.3. Data on distances were retrieved from Google Maps (2022) or IKEA's sales data (Ingka, 2021b).

IKEA sales data was firsthand data received directly from IKEA's representatives. The sales data used for this analysis included data from IKEA in Sweden or Ingka, a franchise branch of IKEA, and data from IKEA's second-hand store in ReTuna. The sales data was from IKEA's 2021 business year. The ReTuna sales data was from the first year IKEA ReTuna was open or from November 2020 to October 2021. The data on the top 10 sold items in each PA was used to estimate the average weight of the furniture items and was retrieved from IKEA of Sweden (2022b). That dataset and IKEA's websites were used to assess the material composition of the furniture items (IKEA, 2021a). The number of sales per PAs was retrieved from Ingka (2021a). Data on customer travel was retrieved from Ingka (Ingka, 2021b). Data specific to aspects of IKEA's second-hand store in ReTuna was retrieved from IKEA Second-hand store (2021). IKEA's climate footprint data was retrieved from IKEA's sustainability report for the business year 2021 (IKEA, 2021d). Further information on the specific data used is found in the following life cycle inventory section.

3.2. Life cycle inventory and data collection – potential climate savings of second-hand trade

The methodology to estimate the climate impact avoided by selling second-hand furniture was built on previous research addressing similar problems (Castellani et al., 2015, Fortuna and Diyamandoglu, 2017, Privett, 2018). The climate impact possibly avoided by selling second-hand furniture was compared to the additional impact of selling second-hand furniture by constructing an LCA model in Excel (Microsoft Corporation, 2018). The following section will describe and motivate the data collected and used to construct the life cycle inventory (LCI) of the LCA Excel model. The LCA model was built based the current and potential future versions of IKEA's second-hand business model. IKEA ReTuna was used as a representative for IKEA's second-hand trade. The LCA model was built based on state-of-the-art research on how to evaluate potential climate benefits of reuse. The LCA model contains sensitive data and will therefore not be published. The life stages of the system were divided into two main parts PAE and additional impacts as seen in Figure 2.

There is a wide variety of products that IKEA sells from various materials. Products that were assumed to be not desirable second-hand and products that are considered consumables were disregarded as well as PA contributing to less than 0.01% of the revenue. This was done because it was found unlikely these products will ever be sold in IKEA's second-hand stores. This was decided based on discussions with IKEA's representatives. About 14% of items sold were disregarded mostly because they were considered consumables or assumed too not be desirable second-hand. So, 86% of the 1,000,000 furniture items were assumed to be sold in second-hand IKEA stores. About 0.8% were missing EVs. The total weight of the disregarded items was found to be 273 tonnes which was about 2% of the total weight of the 1,000,000 items. So, despite disregarding about 14% of sold items it was still found representative enough for selling 1,000,000 items second-hand.

3.2.1. Potential avoided emissions (PAE)

The most important assumptions for this project, was that second-hand item purchases replace purchases of new items to some extent and that items are saved from final disposal. The PAE of second-hand sales was found to be cradle-to-gate climate impacts of the furniture new and EOL impacts as mentioned previously. So, the cradle-to-gate climate impacts of IKEA's furniture needed to be evaluated. The cradle-to-gate impacts were estimated by first estimating the *full life cycle emissions* (FLCE) and then subtracting the emissions from the life stages not avoided by second-hand trade. The FLCE of IKEA's furniture items were estimated by using EVs, represented in kg CO_2e per kg product, suitable for IKEA's 208 PAs. Secondary data was used for the EVs. EVs for furniture items were retrieved from a report published by The Mistra foundation, or The Swedish Foundation for Strategic Environmental Research, (hereinafter the *Mistra report*). The Mistra foundation analyzed the LC impacts of 218 consumption items common in Swedish households. They used The Energy Analysis Program (EAP) built on the input-output method. The items were of a wide range of categories, one of which was furnishings. The furnishings category had EVs for 21 different furniture item subcategories. Five additional subcategories, from other item categories than furnishings, were found to be useful for this project. So, in total 26 EVs were used for IKEA's 208 PA (Carlsson-Kanyama et al., 2019).

The environmental impacts considered in the Mistra report were climate impact, land use, and water use. The climate impact was used for this project and was expressed by EVs in kg CO_2e emissions per kg product and kg CO_2e emissions per SEK cost. The EVs per kg product was mostly used in this project since it can be uncertain to use monetary units (Isacs et al., 2016). The EVs from the Mistra report included cradle-to-grave climate impacts associated with raw material extraction, manufacturing, transport from manufacturer to consumer, domestic usage, and waste processing. Impacts of infrastructure needed for manufacturing were included as well as cradle-to-grave impacts of packaging, suitable for each item category. The combination of mass balances and financial balances was used to estimate the total environmental impacts. The Mistra report used LCA studies on items representative of each product sub-category to produce EVs for each of their product type. The product type EVs used from the Mistra report, the details about the analyzed item, and its material composition are found in *Appendix A: Emission Values in the Mistra report* (Carlsson-Kanyama et al., 2019).

IKEA's sales data, described in section 3.1.3., was used to estimate the FLCE of the weight of a suitable variety of 1,000,000 items. The top 10 items sold were analyzed as well as information on the material composition of those items, available on IKEA's websites (IKEA of Sweden, 2022b, IKEA, 2021a). To be able to match IKEA's 208 PA with the 26 EVs from the Mistra report a hierarchy of matching was developed. EVs were matched with the PAs after the following hierarchy (a more detailed description of assumptions made for matching EVs with the PAs is found in *Appendix A2*).

(1) Based on item types. For example, the Mistra EV for "Wardrobes, chest of drawers, and bookcases" was matched with the PA "Bookcases".
(2) Based on the material composition of the items in the PA since the main environmental intensive hotspots of furniture are in the production and supply of materials (Cooper et al., 2021). Item types analyzed in the Mistra report were matched with PAs of similar material composition (IKEA, 2021a).
(3) Set based on averages of several product types from the Mistra report. The average was calculated based on the material composition of the items in the PA. The average was only used if the item category consisted of items made from materials that were not like any product type in the Mistra report.

The sales data had information on the percentage of sales from each PA sold in conventional IKEA stores (Ingka, 2021a). That was used to assume how many of the 1,000,000 items could be sold in second-hand stores from each PA. This is a hypothetical scenario, that sales in conventional stores and second-hand stores would be similar. This was assumed since IKEA's goal is to become fully circular which means all new items sold should be reused if possible. The weight of the top 10 products in each PA was used to calculate the average weight (IKEA of Sweden, 2022b). The weight was missing for some of the PAs and in those cases, the weight of the top sold item was retrieved from IKEA's website (IKEA, 2021a).

Equation (1) was used to estimate the first LC cradle-to-grave emissions for the weight of 1,000,000 items or the FLCE of the functional unit (n_{items}*w). The data used to estimate the FLCE, the data sources, and calculated values are displayed in Table 1.

$$FLCE\ [kg\ CO2e] = \sum S_{IKEA} * n_{items} * w * EV_{items} \ (1)$$

Where:

S_{IKEA}: Share of items sold in each Product Area [%]

n_{items}: number of items sold [items]

w: average weight of items in each Product Area [kg/item]

EV_{item}: Emission values [kg CO_2e/kg]

Table 1: Data table for assessing full life cycle emissions of the weight of 1,000,000 IKEA items.

Variable	Source	Value
S_{IKEA}	(Ingka, 2021a)	Various for each PA (not published)
n_{items}	Set	1,000,000 items
w	Calculated from IKEA of Sweden (2022b)	14.5 kg
EV_{items}	(Carlsson-Kanyama et al., 2019)	Various, see Table 14 in Appendix A1

Since the EVs from the Mistra report included cradle-to-grave emissions of consumption items the calculated FLCE cannot fully be considered as avoided emissions. Therefore, to calculate the PAE, emissions from life-stages not avoided by second-hand sales needed to be subtracted from the estimated FLCE. *Figure 3* indicates the difference between life stages included in the estimated FLCE and life stages that are assumed to be avoided by selling second-hand. In *Figure 3* the life stages that cannot be avoided by second-hand sales, but are included in the estimated FLCE, are marked in red. The EOL impacts, assumed to be avoided by reusing the products, was included in the FLCE (Carlsson-Kanyama et al., 2019). Considering the EOL impacts to be avoided is common in studies analyzing the environmental benefits of reuse (Fortuna and Diyamandoglu, 2017).

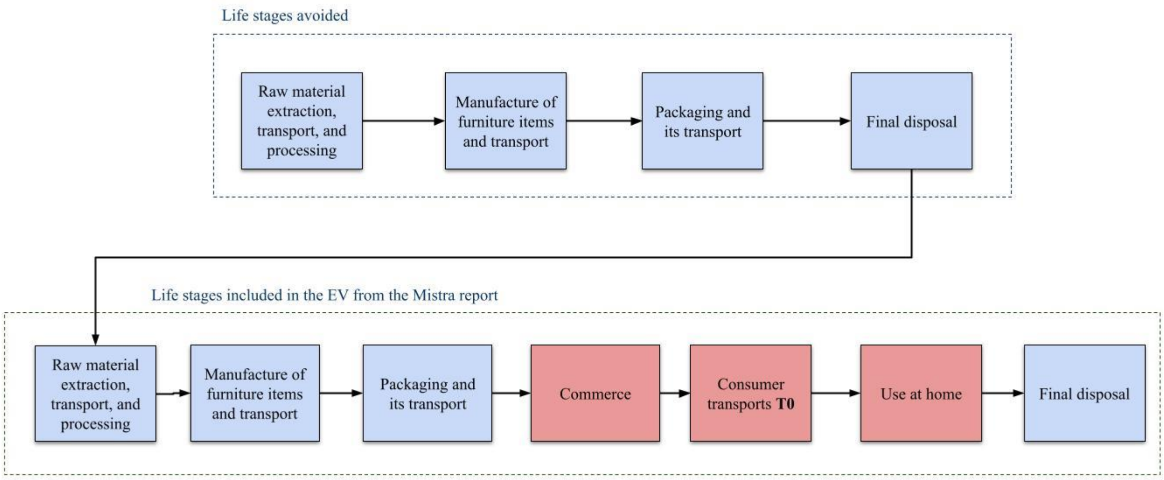

Figure 3: Potential avoided emissions versus life stages included in the emission values from the Mistra report.

Based on previous research and data available the PAE were estimated with equation (2). Estimating emissions from *commerce*, *T0*, and *Product use at home* is further described in the following sub-sections.

$$PAE\ [kg\ CO_2e] = FLCE - PUE - Commerce - T0\ (2)$$

Where:

PUE: Emissions from products use at home, see section 3.2.1.1. [kg CO_2e]

Commerce: Emissions from retail services of conventional stores, see section 3.2.1.2. [kg CO_2e]

T0: Transport emissions of customers of conventional stores, see section 3.2.1.3. [kg CO_2e]

3.2.1.1. Emissions from products use at home

Product use emissions (PUE) can be significant. In 2016 emissions from products use at home were about 23% of IKEA's carbon footprint. Although, it had been reduced to 17% by 2021 (IKEA, 2021d). Because of limited data available, the PUE were disregarded. A brief approximation was conducted to assess the possible emissions associated with use at home and how it might affect these results. The average CO_2e emissions per product was estimated by dividing the overall emissions from *Product use at home*, reported in IKEA's 2021 sustainability report, to the number of items sold in the same period. That value was then multiplied by 1,000,000 to have an idea of the potential PUE. This was not found suitable to rely heavily on in the model, since IKEA's footprint in the sustainability report was not estimated with the same method as was used in this project. The method used in IKEA's sustainability report was not clear nor transparent so it was uncertain to use the information provided there (IKEA, 2021d). The value of PUE in equation (2) was set to either zero or the estimated PUE described here.

3.2.1.2. Emissions from the commerce of conventional IKEA stores.

As mentioned in section 3.1.2 IKEA's commerce, or as called *Retail and other operations* in the sustainability report, contributed to less than 2% of IKEA's CO_2e emissions in 2021 (IKEA, 2021d). Emissions stemming from commerce have been found to be neglectable compared to other emission sources of second-hand trade (Castellani et al., 2015). Therefore, for simplifications, emissions from the commerce were disregarded in estimating the PAE and, *Commerce* in equation (2) was set to zero.

3.2.1.3. Transports of customers of conventional IKEA stores (T0)

The Mistra EVs included emissions from customers' transport from store to home (T0). Although, the transports of customers of conventional stores cannot be avoided by second-hand trade. So, emissions from T0 needed to be estimated and subtracted from the estimated FLCE to calculate the PAE. As discussed in section 2.2.3 transportation emissions are dependent on the mode of transportation, transportation distances, and the number of trips. Number of trips were calculated by dividing the number of items (1,000,000) to the number of items bought per trip. So, T0 emissions were calculated with equation (4).

$$T0 = \sum S_{mode.i} * EV_{mode.i} * 2d_{0.j} * n_{items} / n_{items.bought.n} \text{ (3)}$$

Where:

$S_{mode.i}$: Share of customers in each transportation mode (i: passenger cars, bus, or train) [%]

$EV_{mode.i}$: Emission value for the transportation modes [kg CO_2e/km]

$d_{0.i}$: Distance traveled from customers' home to IKEA stores (j: car or non-car) [km]

$n_{items.bought.n}$: New items bought in conventional stores per trip [items]

The data on $S_{mode.i}$ was received from IKEA global conventional stores. The modes included in the data were bus, car/van, IKEA Shuttle bus, motorcycle/scooter, taxi, train, and other. The same data collection had information on average distances travelled by car or other transportation modes to and from stores. Distance for T0 was defined as $d_{0.car}$ (distance by car) and $d_{0.non}$ (distance by non-car) (Ingka, 2021b). Sinha et al. (2019) developed a transportation model to assess the difference in emissions from different transportation modes. The model was suitable for Swedish conditions and was used to set EVs for the different transportation modes. The model was used by assuming traveling distances of 1 km for each of the transportation modes with the average number of passengers in the vehicles. Sinha et al. (2019) model included passenger car, bus, train, walking, and biking. Sinha et al. (2019) EVs were set for the share of IKEA's consumers in the following way.

- Passenger cars – for the share of customers travelling in car/van and taxi.
- Bus – for the share of customers travelling in bus and IKEA Shuttle bus.
- Train – for the share of customers travelling in train, motorcycle/scooter, and other.

The number of items bought per customer per trip, or $n_{items.bought}$ was provided in IKEA's sales data. The discussed information and sources are displayed in Table 2.

Table 2: Data table used to assess emissions from the transport customers of conventional store.

Variable	Source	Value
$S_{mode.1}$ (passenger car)	(Ingka, 2021b)	83.0%
$S_{mode.2}$ (bus)	(Ingka, 2021b)	11.0%
$S_{mode.3}$ (train)	(Ingka, 2021b)	7.00%
$d_{0.car}$	(Ingka, 2021b)	12.5 km
$d_{0.non\text{-}car}$	(Ingka, 2021b)	16.0 km
$EV_{mode.1}$ (passenger car)	(Sinha et al., 2019)	0.240 kg CO_2e/km
$EV_{mode.2}$ (bus)	(Sinha et al., 2019)	0.212 kg CO_2e/km
$EV_{mode.3}$ (train)	(Sinha et al., 2019)	0.017 kg CO_2e/km
$n_{items.bougt}$	(Ingka, 2021a)	9.40 items

3.2.2. Replacement rate (RR)

As discussed in section **Erreur ! Source du renvoi introuvable.** research on *RRs* of furniture is currently lacking. RRs are dependent on several aspects such as the product type, the individual purchasing, or the economic system. For the scope of this project, Privett (2018) definition of RR was found suitable to reformulate for reuse. According to their definition, RRs are dependent on two variables, life extention period (*LEP*) and the probability of replacement (*Pb*). The LEP is a portion of the expected durability of the second-hand item to the expected durability of the same item new. The Pb is the porpability that the second-hand purchase is replacing a new item purchase, see equation (4) (Privett, 2018).

$$RR = LE * Pb \quad (4)$$

Where:

LEP: life extension period = $\frac{Durability\ of\ a\ second-hand\ item\ [years]}{Durability\ of\ the\ same\ item\ new\ [years]}$

Pb: the probability that the second-hand purchase is replacing a new purchase (0-1)

Research on the difference in the durability of second-hand and new furniture is highly lacking and no quantitative data was found suitable for the LEP of second-hand IKEA furniture (Privett, 2018). To respond to the data limitations an alternative method was used. RRs were set based on literature analysis. Research that has previously estimated RRs for items like those IKEA sells was used. To convey that different product types have different RRs it would have been optimal to have different RRs suitable for each of IKEA's 21 HFBs (Castellani et al., 2015). Data suitable for each was not found. Average of the identified RRs was used for the cases where none of the identified RRs were suitable for the specific HFB. The RRs identified, their sources, and the suitable HFBs are presented in Table 2 along with arguments on why the specific HFB and RR were matched together.

Table 3: Setting RR for the 21 different furniture categories of IKEA (HFBs).

What kind of item was analyzed and where	RR_{HFB}	Matched with *HFB* and why	Reference
Other textiles such as toys, bags, mixed other textile products, scarfs, hats, and shoes. Conducted in Angola	77.0%	*09 – Children's IKEA* That HFB includes a lot of mixed textile products and textile toys. The value set for Angola was used since its economy was the closest to the Swedish economy	(Nørup et al., 2019)
Mostly electronics, household appliances, and clothing. Conducted in the UK. Analyzed repair but not reuse	88.0%	*10 – Lightning and Home electronics* *50 – Home electronics* *70 – Home appliances* The study included several home electronics and home appliances in a western European economic system	(Privett, 2018)
Household textiles such as potholders, dishtowels, rags, wipers, facecloths, tablecloths, towels, curtains, and linens. Conducted in Angola	67.0%	*11 – Bed and Bath textiles* *12 – Home textile* *13 – Rugs* All are considered household textiles. The value set for Angola was used	(Nørup et al., 2019)
Furniture accessories such as drinking glasses. Conducted in Italy	84.0%	*14 – Cooking* *15 – Eating* Those HFBs include furniture accessories like drinking glasses. A study	(Castellani et al., 2015)

		was conducted on a western European economic system.	
Furniture. Conducted in Italy	35.0%	*16 – Decorations* Low value for furniture was used since IKEA's own experience was that second-hand purchases from this HFB are additional buys but not replacing new items to be bought (Haltia and Johansson, 2021)	(Castellani et al., 2015)
Average of all identified RR suitable to use for IKEA's product types	68.9%	*01 – Living room – seating* *02 – Living room – storing* *03 – Workspace* *04 – Bedroom* *05 – Beds and Mattresses* *06 – Bathroom* *07 – Kitchen* *08 – Dining* *17 – Outdoor and secondary storage* *18 – Home organizations* No other identified RRs was found suitable for the specific HFBs	(Castellani et al., 2015, Nørup et al., 2019, Thomas, 2011, Privett, 2018)

The replacement rate used for the analyzed system was defined by the sum of all multiplies of the share of items sold per PA and the identified RR for the specific HFB, see equation (4).

$$RR_{system} = \sum S_{IKEA} * RR_{HFB} \ (5)$$

Where:

RR_{system}: Replacement rate of the system [%]

RR_{HFB}: Replacement rates set for each HFB (see Table 3) [%]

Only a portion of the PAE can be considered as avoided emissions because not all second-hand purchases replace the purchase of a new product (Castellani et al., 2015, Nørup et al., 2019, Farrant et al., 2010). The PAE was multiplied with the $RR_{sysstem}$ to calculate, what is here defined as, *Avoided emissions*, see equation (6).

$$Avoided\ emissions\ [kg\ CO_2e] = RR_{system} * PAE \ (6)$$

3.2.3. Additional emissions (emissions of second-hand trade)

As discussed in section 2.2.3 second-hand trade is not free from emissions. There are additional transports and repair interventions for the analyzed second-hand trade. The following section will present the method used to assess the emissions of IKEA ReTuna, the representative case for second-hand trade. This has been defined as additional emissions for the analyzed system.

3.2.3.1. Cleaning and repairs

IKEA ReTuna does not have a significant intervention when it comes to repairs. Refurbishments are not performed due to legal and compliance reasons (Haltia and Sinclair, 2022b). The repairs performed in ReTuna mainly consist of cleaning the furniture and improving their visual aesthetics. Sometimes spare parts are replaced with IKEA's own replacement parts (IKEA, n.d.b, IKEA, 2021b, IKEA, 2021c). To estimate emissions from cleaning and repair, an EV from the Mistra report was used. That EV was in monetary units despite the possibility of its uncertainty (Isacs et al., 2016). Using a monetary unit was found to be able to convey the significance of the repair conducted since low cost should express a low level of repairs and reverse. The EV was for *Repair of furniture, furnishings, and floor coverings* and was found suitable to use for IKEA's repairs. It was additionally coherent with other emission data used in this project (Carlsson-Kanyama et al., 2019). Emissions from repairs were calculated with equation (7).

$$Emissions\ from\ repair\ [kg\ CO2e] = EV_{repairs} * Cost_{kg} * W_{1\ million}\ (7)$$

Where:

$EV_{repairs}$: EV for furniture repair from Carlsson-Kanyama et al. (2019) [kg CO2e/SEK cost]

$Cost_{kg}$: Cost of repairs per kg product [SEK/kg]

$W_{1\ million}$: Weight of the 1,000,000 items (functional unit) [kg]

To calculate the cost of repair per kg product the total cost of repairs for the analyzed period was retrieved from IKEA ReTuna along with the total weight of items sold. The cost per kg was calculated with the following equation (8).

$$Cost_{kg} = \frac{Cost_{total.repairs}}{W_{ReTuna}}\ (8)$$

Where:

$Cost_{total.rapairs}$: Total cost of repairs [SEK]

W_{ReTuna}: Weight of items sold in ReTuna [kg/item]

The total weight of items sold in ReTuna was calculated with the share of sales of each HFB sold in ReTuna, the total number of items sold in the analyzed period, and the average weight of items in each HFB. The total weight of items sold in IKEA ReTuna was calculated with equation (9).

$$W_{ReTuna} = n_{ReTuna}(\sum S_{ReTuna} * w)\ (9)$$

Where:

$n_{ReTunas}$: Total number of items sold in ReTuna for the analyzed period [items]

S_{ReTuna}: Share of sales of each HFB sold in ReTuna [%]

Data required to estimate the *Emissions from repair*, and calculated variables are displayed in Table 4.

Table 4: Data table used to calculate emissions from repair

Variable	Source	Value
$EV_{repairs}$	(Carlsson-Kanyama et al., 2019)	0.0122 kg CO_2e/SEK
$Cost_{total.repairs}$	(IKEA Second-hand store, 2021)	Confidential
n_{ReTuna}	(IKEA Second-hand store, 2021)	Confidential
S_{ReTuna}	(IKEA Second-hand store, 2021)	Various

3.2.3.2. *Second-hand transports*

Second-hand trade usually causes increased transportation but how significant it is, is dependent on the specific case of the second-hand platform. Transportation emissions can be the dominating factor in emissions from second-hand trade (Fortuna and Diyamandoglu, 2017). So, accounting for the emissions of the transportation of the second-hand trade was an important part of estimating the additional emissions. As discussed in section 2.2.3 emissions of transportation are highly dependent on the mode of transportation and transportation distances. (Fortuna and Diyamandoglu, 2017, Castellani et al., 2015, Böckin et al., 2020). The increased transportations for IKEA ReTuna are both transportations from donations and the transportations of the customers to and from the second-hand store.

There were four main types of donation paths for the analyzed case. One of the paths (T1) was the transportation to and from Stadsmissionen drop-off points. Stadsmissionen is a societal organization that has several projects on social care. One of the projects involves selling second-hand items such as furniture where they collaborate with IKEA (Stockholms Stadsmission, n.d.). There was a Stadsmissionen drop-off point in Stockholm where IKEA could pick up their own furniture and transport to ReTuna. T1 involved two different segments of transportation. The first segment was when the first owner transports their donated furniture to the drop-off point (T1A) and the second segment was when IKEA picked up the furniture and transported it to ReTuna (T1B).

The second donation path (T2) was where the first owner transports their furniture from their homes directly to ReTuna. The last donation path, or T3, was the transportation of rescued furniture that IKEA did not sell in their conventional store in Vesterås, Sweden. That furniture was transported from Vesterås to Eskilstuna in IKEA's freight vehicles. IKEA did have other drop-off points but donations from those drop-off points were, according to the data, less than 2% of donations. Those donations were therefore disregarded for this analysis (IKEA Second-hand store, 2021). The transportation of the customers to the store from their homes was called T4. In Figure 4 the transportations related to IKEA's second-hand trade are displayed visually.

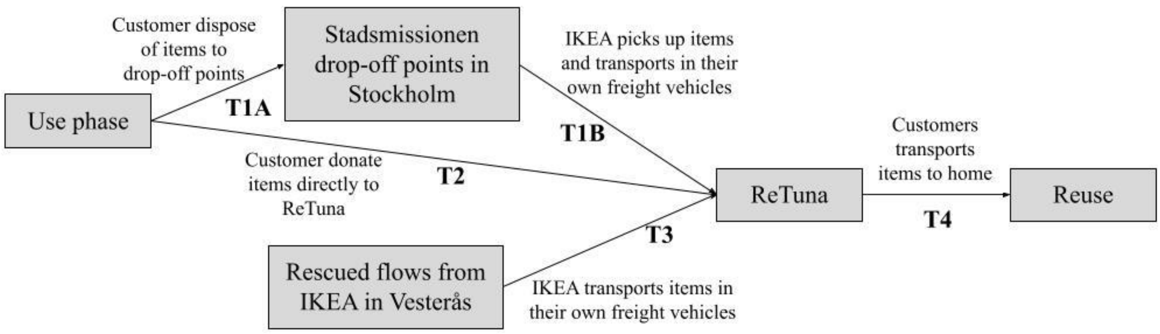

Figure 4: Second-hand trade related transportation for IKEA, ReTuna.

Emissions from T1A and T1B were first assessed to be able to assess the emissions from the donations related to the Stadsmissionen drop-off point (T1). Emissions from T1A was assessed similarly to emissions from T0, with equation (10). Based on discussion with IKEA's advisors it was assumed that almost all donations would be by passenger cars. So, the EV for passenger cars from Sinha et al. (2019) was used, or $EV_{mode.1}$ defined in section 3.2.1.3. Distance was multiplied with two to represent travel front and back.

$$T1A = EV_{mode.1} * 2d_{1A} * n_{items} * n_{items.donated.1A} \quad (10)$$

Where:

d_{1A}: Average distance for Stockholmers to Stadsmissionen drop-off point [km]

$n_{items.donated.1A}$: Average number of items donated per trip for T1A [items]

Assumptions had to be made for d_{1A} and $n_{items.donated.1A}$.

- d_{1A} was measured with the measure distance function in Google Maps (2022) from Stadsmissionen drop-off point (Strömsätragränd 18, 127 35 Skärholmen) to center of Stockholm (T-Centralen).
- $n_{items.donated.1A}$ was estimated based on discussions with IKEA's advisors.

The following Table 5, displays the variables needed to estimate emissions from T1A and assumed values.

Table 5: Data table of variables and their values used to assess emissions of donation path segment T1A.

Variable	Source	Value
d_{1A}	Measure distance function (Google Maps, 2022)	8.08 km
$n_{items.donated.1A}$	(Haltia and Sinclair, 2022a)	2.00 items

For T1B IKEA used larger freight vehicles to transport from Stadsmissionen drop-off points to ReTuna. IKEA's freight vehicles use the biofuel *hydrogenated vegetable oil* (HVO) (Haltia and Sinclair, 2022a). Sinha et al. (2019) model was therefore not found suitable to use for those transportations. EV for freight transportation were extracted from the LCI database Ecoinvent3. Environmental effects of transportation in Ecoinvent3 consider the travel forth and back but depend on the sizes of the vehicles used (Wernet et al., 2016). IKEA's vehicles used for the donation transports are distribution freight trucks that can carry 18 EU pallets (Haltia and Sinclair, 2022a). According to Sussex Transport such vehicles would weigh between 26 to 44 tonnes (Sussex Transport, 2019). EV for heavy freight vehicles of 16-32 tonnes was extracted from Ecoinvent3 or the data on *Transport, freight, lorry, 16-32 metric ton, EURO3 RER| transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U* (Wernet et al., 2016). According to Biofuel Express, a leading distributor of fossil-free fuels, HVO emit on average 90% less CO_2e emissions than diesel fuels (Nilsson, 2022). The Ecoinvent3 data was therefore adapted so that the emissions from the fuel would be 10% of the emissions caused by diesel fuel ($EV_{freightheavy.HVO}$). Emissions from other life stages of the transports was not changed from the Ecoinvent3 data. Emissions for other types of trucks were extracted from Ecoinvent3 for a sensitivity analysis. This is explained and the results presented in Appendix B. Equation (11) was used to assess the emissions for T1B.

$$T1B = EV_{freightheavy.HVO} * d_{1B} * n_{items} * w \quad (11)$$

Where:

d_{1b}: Distance from Stadsmissionen drop-off point to ReTuna [km]

$EV_{mediumfreight.HVO}$: EVs for freight vehicles of 16-32 tonnes using HVO fuel [kg CO_2e/ton-km]

The distance, d_{1B}, was measured with measure distance function in Google Maps (2022) from Stadsmissionen drop-off point to ReTuna in Eskilstuna. The following Table 6, displays the data needed to estimate emissions from T1B and assumed values.

Table 6: Data table of variables and their values used to assess emissions from donation path segment T1B.

Variable	Source	Value
d_{1B}	Measure distance function (Google Maps, 2022)	85.2 km
$EV_{freightheavy.HVO}$	Adapted from Ecoinvent3 (Wernet et al., 2016)	0.147 kg CO_2e/ton-km

The emissions from the donation path T2 were estimated with the same method as emissions from T1A. Again, most donations are by passenger cars, so, $EV_{mode.1}$ was used. Emissions from T2 were estimated with equation (12).

$$T2 = EV_{mode.1} * 2d_2 * n_{items} * n_{items.donated.2} \ (12)$$

Where:

d_2: Average distance from Eskilstunas homes to ReTuna [km]

$n_{items.donated.2}$: Average number of items donated per trip for T2 [items]

Assumptions had to be made for d_2 and $n_{items.donated.2}$.

- d_2 was measured with the measure distance function in Google Maps (2022) from the center of Eskilstuna to ReTuna since most of the donations from individuals come from the inhabitants of Eskilstuna (IKEA Second-hand store, 2021).
- $n_{items.donated.2}$ was set from a previous analysis IKEA conducted in ReTuna (IKEA Second-hand store, 2021).

The emissions from the transportation of the rescued furniture from Vasterås (T3) were estimated with the same method as the emissions from T1B, or with equation (13). The EV for $EV_{freightheavy.HVO}$ was again used but other EVs were used for a sensitivity analysis, presented in Appendix B.

$$T3 = EV_{freightheavy.HVO} * d_3 * n_{items} * w \ (13)$$

Where:

d_3: Distance from IKEA Vasterås to ReTuna [km]

The following Table 7, summarizes the data needed to estimate emissions for T2 and T3 and assumed values.

Table 7: Data table of variables and their values used to assess emissions from donation paths T2 and T3.

Variable	Source	Value
d_2	Measure distance function (Google Maps, 2022)	3.35 km
$n_{items.\ donated.2}$	Set based on IKEA Second-hand store (2021)	2.00 items
d_3	Measure distance function (Google Maps, 2022)	12.2 km

The overall emissions from the transportation of donations ($T_{donations}$) of the 1,000,000 items were estimated with equation (14).

$$T_{donations} = S_{donation.1} * T1 + S_{donation.2} * T2 + S_{donation.3} * T3 \ (14)$$

Where:

$S_{donation.1}$: Share of donations by T1[%]

$S_{donation.2}$: Share of donations by T2[%]

$S_{donation.3}$: Share of donations by T3[%]

IKEA ReTuna had data on the number of items donated per donation path which was used to calculate the share of donations per donation path, the share is presented in the following Table 8 (IKEA Second-hand store, 2021).

Table 8: Data table of the share of donations per donation path.

Variable	Source	Value
$S_{donation.1}$	Calculated from IKEA Second-hand store (2021)	6%

$S_{donation.2}$	Calculated from IKEA Second-hand store (2021)	67%
$S_{donation.3}$	Calculated from IKEA Second-hand store (2021)	27%

The emissions for the transportations of customers of the second-hand store (T4) were estimated similarly to the emissions from T0. The share of transportation modes was set according to conventional stores since the end-goal is for second-hand stores to potentially be located within conventional IKEA stores (Haltia and Sinclair, 2022a). The EVs for the transportation modes from Sinha et al. (2019) were used for T4 as was done for T0. T4 was calculated with equation (15).

$$T4 = \sum S_{mode.i} * EV_{mode.i} * 2d_4 * n_{items} / n_{items.bought.sh} \quad (15)$$

Where:

d_4: Distance travelled from customers home to second-hand [km]

$n_{items.bought.sh}$: Items bought second-hand per trip [items]

Assumptions had to be made for d_4. d_4 was measured with the measure distance function in Google Maps (2022) both from the ReTuna store to center of Eskilstuna and from the Stockholm IKEA conventional store (Ekgårdsvägen 2, 141 75 Kungens Kurva) to centre of Stockholm (T-Centralen). The average of those two distances was used. This was because second-hand stores could either be like the ReTuna one or as second-hand outlets in conventional IKEA stores. The ReTuna was used as a representative of such cases and the Stockholm IKEA store was used a representative of second-hand outlets in conventional stores (Haltia and Sinclair, 2022a). The number of second-hand items bought per trip was from IKEA ReTuna's sales data (IKEA Second-hand store, 2021). The data assumed and set to estimate the emissions from T4 is summarized in Table 9.

Table 9: Data table of variables and their values used to assess emissions from customer transport.

Variable	Source	Value
d_4	Measure distance function in Google Maps (2022)	7.32 km
$n_{items.bought.sh}$	(IKEA Second-hand store, 2021)	3 items

3.2.4. Comparison of avoided emissions and additional emissions, "climate savings"

After the avoided emissions and additional emissions had been estimated, they were compared. This was to estimate the potential "climate savings" of second-hand trade. The *Potential "climate savings"* (PCS) of second-hand trade was calculated with equation (15).

$$PCS\ [kg\ CO_2e] = Avoided\ emissions - \ Emissions\ from\ repair - T_{donations} - T4 \quad (15)$$

As discussed, the emissions from the use phase were not subtracted from the Avoided emissions but cannot be considered a part of the avoided emissions. Therefore, the PCS was also calculated by subtracting the use emissions to see how that would affect the results, see equation (16).

$$PCS_{subtracting\ use} [kg\ CO_2e] = Avoided\ emissions - Products\ use\ at\ home - Emissions\ from\ repair - T_{donations} - T4 \quad (16)$$

The share of the PCS of the FLCE was calculated with equation (17). The share of the PCS of the Avoided emissions was calculated both without subtracting the PUE, with equation (18), and subtracting the PUE, with equation (19).

$$Savings_{FLCE}\ [\%] = \frac{PCS}{FLCE} * 100 \quad (17)$$

$$Savings_{Avoided\ emissions}\ [\%] = \frac{PCS}{Avoided\ emissions} * 100\ (18)$$

$$Savings_{Avoided\ emission.use}\ [\%] = \frac{PCS_{subtracting\ use}}{Avoided\ emissions - Product\ use\ at\ home} * 100\ (19)$$

Both the estimated FLCE and the RR are highly uncertain because of assumptions made. The estimated FLCE were compared to IKEA's value chain emissions reported in their sustainability report. The total number of sold items in the analyzed period was input into the model and the results were compared to the furniture value chain emissions reported in the sustainability report. The furniture value chain emissions in IKEA's sustainability report were 26.5-million-tonnes CO_2e emissions and the FLCE were about 38-million-tonnes CO_2e (IKEA, 2021d). So, the FLCE estimated in this thesis project were about 30% higher than reported in IKEA's sustainability report. Therefore, a sensitivity analysis was constructed to analyze how other estimation of the FLCE would affect the potential avoided climate impact and the estimated *PCS* and $Savings_{Avoided\ emissions}$. Three new estimations for FLCE were analyzed which are further described in Table 10. The sensitivity analysis was performed for RR_{system} from 10% to 100%.

Table 10: Assumptions made for the sensitivity analysis of potential "climate savings" and its share of full life cycle emissions

Assumption	Description
Underestimated life cycle emissions	Assumed that the furniture value chain emissions, or the FLCE, were lower than IKEA reported in their sustainability report. FLCE were assumed to be 23-million-tonnes CO_2e.
Life cycle emissions reported in the sustainability report	Assumed that the furniture value chain emissions, or the FLCE, were as IKEA reported in their sustainability report. FLCE were assumed to be 26.5-million-tonnes CO_2e.
Full life cycle emissions (FLCE)	Assumed that the furniture value chain emissions, or the FLCE, were as estimated in section 4.1.1 of this report.
Overestimated life cycle emissions	Assumed that the furniture value chain emissions, or FLCE, were higher than was estimated in section 4.1.1 of this report.

3.3. Required share of second-hand sales for IKEA to reach and go beyond their climate commitments

The LCA Excel model was built to be able to estimate what the share of second-hand sales would need to be for IKEA to reach and go beyond its goal of a 15% decrease in value chain emissions (IKEA, 2021d). To simplify that estimation, it was assumed that second-hand trade would be the only climate mitigation action of IKEA. As mentioned in section 2.1 IKEA aims to reduce its overall value chain emissions by 15% by 2030 from the 2016 baseline year. IKEA's goal of emission reduction was defined as *Goals*. In 2016 their overall value chain emissions were 27.72 million tonnes of CO_2e which means their goal was to reduce that to 23.56 million tonnes of CO_2e by 2030 (IKEA, 2021d).

As mentioned, IKEA does not only produce furniture but is also involved in other activities such as producing food. From the sustainability report and discussions with IKEA's representatives, the emissions caused only by the full life cycle of furniture were calculated. According to discussions with IKEA's representatives, the emissions from the phases food ingredients and other, in the sustainability report, was said to be from other sources than the life cycle of furniture (Haltia and Sinclair, 2022a). The footprint of the phases related to the life cycle of furniture was therefore said to be 26.48 million tonnes of CO_2e. The remaining emissions were then 1.24 million tonnes of CO_2e (IKEA, 2021d).

A hypothetical scenario was created to fulfill the second objective. In the hypothetical scenario, second-hand trade would be the only climate mitigation measure of IKEA. IKEA has other climate mitigation measures (IKEA, 2021d). For the hypothetical scenario there would only be four sources of emissions: new furniture trade, second-hand furniture trade, food ingredients, and other. Let's call share of second-hand sales $Share_{second\text{-}hand}$ and the share of new item sales $Share_{new}$, see equation (20).

$$Share_{new} = 1 - Share_{second\text{-}hand} \quad (20)$$

The share of the PCS from the full life cycle emissions has been defined as $Savings_{FLCE}$ [%]. Second-hand trade still has emissions as defined in equation (21).

$$100\% - Savings_{FLCE} \text{ of emissions of the full life cycle of furniture} \quad (21)$$

This information was used to construct in the following model for the hypothetical scenario, see equation (22). The model is built on conservation of mass.

$$27.72 * (1 - Goals) = 1.24 + 26.48 * Share_{new} + 26.48 * Share_{second-hand} * Savings_{FLCE} \quad (22)$$

Or:

$$27.72 * (1 - Goals) = 1.24 + 26.48 * (1 - Share_{second-hand}) + 26.48 * Share_{second-hand} * Savings_{FLCE}$$

From the method described in section 3.2, $Savings_{FLCE}$ can be estimated and the results are presented in section 4.1.4. The current *Goal* is 15% or 0.15. These values can be input to equation (22) to solve for $Share_{second\text{-}hand}$ to estimate what the share of second-hand sales would need to be for IKEA to reach its climate commitment goals. To estimate what the share of second-hand sales would need to be for IKEA to go beyond the 15% decrease in value chain emissions the *Goals* variable was increased from the current 15% to desired values.

3.4. Analysis for improvements in IKEA's second-hand trade and scenario building

To identify improvements in second-hand trade the LCA Excel model was analyzed. Realistic improvements were suggested based on the knowledge and understanding of the second-hand case gained from analyzing sales data and discussions with IKEA's representatives (IKEA, 2021d, ReTuna, n.d., IKEA of Sweden, 2022b, Haltia and Sinclair, 2022a, IKEA Second-hand store, 2021). The $Savings_{Avoided\ emissions}$ was dependent on the PCS and the Avoided emissions, see equation (18). The Avoided emissions were dependent on the RR and the PCS, see equation (6). Those factors were identified to be prominent for improvements (IKEA Second-hand store, 2021, Haltia and Sinclair, 2022a). The model was analyzed based on how the emission savings were estimated to identify how IKEA could improve the climate savings of their second-hand trade. The main factors where improvements could be made were identified from the results presented in section 4.1. The main factors were maximizing PAE and RR and minimizing the additional emissions.

Measures to maximize the PAE were identified from analyzing the Excel model. Measures to maximize the RR were identified from a literature review on social influence. Measures to minimize the additional emissions were explored by identifying improvements in the life stage of second-hand trade that caused emissions. Two improvements were identified for the cleaning and repair, six for donations transport, and two for customer travel. The identified improvements for the additional emissions were used to create seven scenarios that had a mix of improvements, see Figure 5. This section will further describe how the improvements were identified and explored.

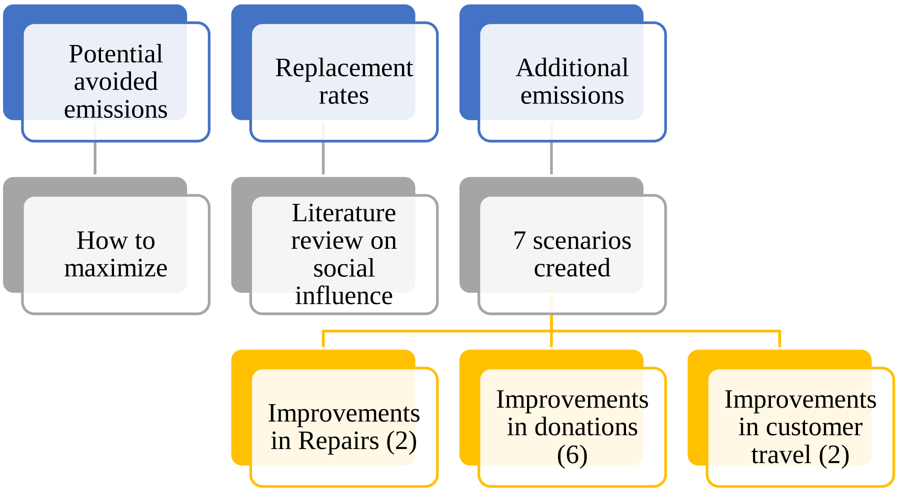

Figure 5: How improvements for climate savings of second-hand trade were identified.

3.4.1. Analyzing improvements in the avoided emissions

Avoided emissions are dependent on PAE and RR, see equation (2). The estimation on the FLCE, emissions from T0, and PUE were analyzed in the Excel model to identify improvements in the PAE. As seen from equations (4), (5), (6), and (18), the replacement rate variable (RR and RR_{system}) affected the avoided emissions highly. This was identified to be a variable that IKEA ReTuna could affect to maximize the emission savings. Maximizing the RRs could have significant effects on the avoided emissions (Fortuna and Diyamandoglu, 2017, Castellani et al., 2015). Improvements for the RR_{system} were identified by reviewing literature on replacement rates of furniture. The LCA Excel model was used to analyze what effects increased/decreased RRs could have on the emission savings.

3.4.2. Analyzing improvements for additional emissions

The factor that IKEA ReTuna has the most control over are the additional emissions or the emissions from their second-hand trade. As seen in equation (14) the additional emissions depend on the Emissions from repair, emissions from $T_{donations}$, and emissions from T4. IKEA could affect those emissions to maximize the emission savings. Improvements for the additional emissions were identified by analyzing the emissions estimation in the LCA Excel model from cleaning and repairs, donation transports ($T_{donations}$), and second-hand customer transport (T4). Only improvements that were found realistic for IKEA's case were analyzed (IKEA Second-hand store, 2021, Haltia and Sinclair, 2022a).

3.4.2.1. Improvements in emissions from cleaning and repair

The method used to estimate emissions from cleaning and repairing was based on the economic cost spent by IKEA on it, as seen in equation (7). Therefore, the main improvement that could be suggested was related to controlling the cost spent on cleaning and repair. The period that was analyzed for this project was from November 2020 to October 2021 (Carlsson-Kanyama et al., 2019, IKEA Second-hand store, 2021). IKEA ReTuna opened on November 2nd, 2020 and has already performed improvements since then. According to sales data, the cost of repairs has already decreased by 30%. So, the emissions from repair has already decreased according to the method used to estimate emissions from repairs (IKEA Second-hand store, 2021). Discussions with IKEA indicated that it was realistic that the cost could be reduced further. Although, costs are unstable, and the could still increase (Isacs et al., 2016). Therefore, the effect on the emissions from repairs was analyzed for increased costs and reduced costs.

3.4.2.2. Normalizing donations transportation

Emissions from donations varied significantly depending on the donation path although that was also caused by different share of donations by donation paths and difference in distance travelled. To further understand which donation path was preferable on a climate perspective the emissions caused by the donation paths were normalized so each donation path would transport 33% of the donated items. The total distance travelled by T1 was 101 km, while T2 was 7.7 km, and T3 was 24 km. To fully understand the hierarchy of donation paths on a climate perspective the emissions of donations were also normalized for the total distance travelled. For the normalization it was assumed that all donations' paths would be in total 10 km. For T1 it was assumed that T1A would be 3 km and T1B would be 7 km since it was found likely that the drop-off point would be located closer to homes while the distance from the drop-off point to a second-hand store was likely to be longer.

3.4.2.3. Building donation and customer travel scenarios

Donation path T3 was not found feasible to increase since it was debatable if the items transported from the IKEA store in Vesterås could be considered second-hand (Haltia and Sinclair, 2022a). Based on the results presented in section 4.3.3, a hypothetical scenario for the donation transportation was suggested. The hypothetical scenario relied on drop-off points. To analyze the emissions of that scenario distances were assumed. It was assumed that drop-off points could be on average in 3 km distances from households and the drop-off points could be on average in 15 km distances from second-hand stores/ outlets. It was assumed that all donations would be from such a donation path. This scenario was named *Donation scenario 1*. It could be difficult to keep drop-off points in a 3 km distance from all homes. So, the effects the distance from home to drop-off points had on the emissions of the Hypothetical donation scenario was analyzed by changing the 3 km value to desired distances.

Other suggestions for climate improvements in the donations were identified, summarized in Table 11. As seen in equations (11) and (13), emissions from the donations could be decreased by changing the vehicles used for transportation paths T1B and T3. Therefore *Donation scenario 2* was suggested (Iritani et al., 2015). As seen in equations (10) and (12), another possibility was to increase the share of donators in public transportation for donation paths T1A and T2. Therefore *Donation scenario 3*, *4* and *5* were suggested (Sinha et al., 2019). Although, it was not found realistic to assume a high share of donators in public transport since it was unlikely that large furniture would be donated by public transport. Another aspect that could affect the donation emissions for transportation paths T1A and T2 was the number of items donated per trip, see equations (10) and (12). Therefore *Donation scenario 6* was suggested (IKEA Second-hand store, 2021). For the Donation scenario 6 the same number of items donated per trip was assumed for T1A and T2. The five additional donation scenarios are summarized in Table 11.

Table 11: Five additional improved donation scenarios on a climate perspective.

Donation scenario	Description	Details
Donation scenario 2	Improved vehicles for donation paths T1B and T3	EV for estimating the transportation emissions from T1B and T3 for train freight vehicles was used, or $EV_{freightheavy.HVO}$ = 0.0566 kg CO_2e/ton-km
Donation scenario 3	Improved travel modes (1) for donators via donation paths T1A and T2	Assumed that 75% of donations would be by passenger cars, 15% by bus, and 10% by train
Donation scenario 4	Improved travel modes (2) for donators via donation paths T1A and T2	Assumed that 50% of donations would be by passenger cars, 30% by bus, and 20% by train

Donation scenario 5	Improved travel modes (3) for donators via donation paths T1A and T2	Assumed that 25% of donations would be by passenger cars, 50% by bus, and 25% by train
Donation scenario 6	Improved number of items donated per trip via donation modes T1A and T2	Assumed that 4 items would be donated per trip for both T1A and T2

Analyzing the improvements for the second-hand customer travel was simpler since there was only one transportation path, T4. The main variables that IKEA could affect in equation (15) were the share of customers per transportation mode, the number of items bought per trip, and the distance for customers to store. Two analyses were performed on the impact of improvements in the transportation of second-hand customers. First, the impact on the emissions was analyzed when the number of items purchased per trip was increased. Next the impact on the emissions was analyzed when the share of customers per transportation mode was changed. Three scenarios were created for the different shares of customers per transportation mode, they are summarized in Table 12. The shares were assumed with the average share of transportation modes in Sweden according to Statista (2020). Emissions were analyzed for 1-10 items purchased per trip since the average number of items purchased per trip was around nine for conventional stores and three for the second-hand store. A sensitivity analysis was conducted to analyze how distance from home to store affected the emissions from T4 for the scenarios presented in Table 12. The distance analyzed was from 5 to 50 km from home to store.

Table 12: Descriptions of the improvement scenarios in the transportation modes of customers and donators of IKEA second-hand.

Customer transportation mode scenarios	Details
100% in passenger cars	100% of customers travel to store by passenger cars and none by public transports
Assumed for the current state	83% of customers travel to the store by passenger cars, 11% by bus, and 7% by train
50% in passenger cars	50% of customers travel to the store by passenger cars, 33% by bus, and 17% by train
100% in public transport	None of the customers travel to the store by passenger cars, 67% by bus, and 33% by train

Table 12 was also used to analyze improvements in donation transports. The emissions from the suggested donation and customer travel improvements were estimated with the LCA excel model with the same methods as used to estimate emissions from second-hand transportation, described in section 3.2.3. This was to analyze the decrease in emissions that could be obtained from the improvements. The *Data table* in the *What-if analysis* function in Excel was used for sensitivity analysis on several aspects of donations and customer travel (Microsoft Corporation, 2018).

3.4.3. Building improvement scenarios

Based on the method described in the previous section, results presented in section 4.3.3, and discussions with IKEA's representatives, a few improvements were chosen to be included in the scenario analysis. The chosen improvements were those found to be both realistic and have desirable effects on the additional emissions. The impact of improved RR was analyzed in the scenario analysis. The chosen improvements are summarized in the following bullet-point list.

- Repairs – cost of repairs has already decreased by 30%.
- Repairs – cost of repairs reduced further or by 60%.
- Donations – all donations by drop-off points (hypothetical donation scenario 1).

- Donations – more donations by public transport (donation scenario 5).
- Donations – four items donated per trip (donation scenario 6).
- Customer travel – 50% travel by passenger cars and five items purchased per trip.
- Customer travel – 5 km distance from home to store and five items purchased per trip.

As seen in the bullet-point list, there were two proposed improvements in the repair services, three proposed improvements in donations, and two proposed improvements in the customer transport. Seven improvement scenarios were created each with a collection of the chosen improvements. One improvement in repair, one improvement in donation and one improvement in customer travel. The scenarios created and analyzed are described in Table 13.

Table 13: The seven scenarios created for improvements.

Scenarios	Description
Scenario 1	The cost of repairs has already decreased by 30%, all donations would be from donation path T1, 50% in passenger cars, and five items purchased per trip.
Scenario 2	The cost of repairs has already decreased by 30%, All donations would be from donation path T1, 5 km distance from home to store, five items purchased per trip.
Scenario 3	The cost of repairs per product has already decreased by 30%, more donations would be by public transport, 50% in passenger cars, five items purchased per trip.
Scenario 4	The cost of repairs per product has already decreased by 30%, more donations would be by public transport, 5 km distance from home to store. five items purchased per trip.
Scenario 5	The cost of repairs per product has already decreased by 30%, four items donated per trip (T1A and T2), 50% in passenger cars, five items purchased per trip.
Scenario 6	The cost of repairs per product has already decreased by 30%, four items donated per trip (T1A and T2), 5 km distance home to store, five items purchased per trip.
Scenario 7	The cost of repairs decreased further (60%), four items donated per trip (T1A and T2), 5 km distance from home to store, five items purchased per trip.

The LCA model was used to estimate the decrease in emissions for the improved scenarios. The scenario that resulted in the lowest level of emissions was proposed to implement for IKEA second-hand. The model was additionally used to calculate the required share of second-hand sales for IKEA to reach their climate commitments if they would implement the improvement scenarios of their second-hand trade.

4. Results and analysis - life cycle impact assessment and interpretation

The following section will present the results of this study. In section 4.1, the results of the LCA conducted to fulfill this study’s first objective will be presented. In section 4.2, the results of the calculations conducted in the LCA model to fulfill this study’s second objective will be presented. In section 4.3, the results of the improvement analysis and the scenario building conducted to fulfill this study's third and final objective will be presented.

4.1. Potential "climate savings" of IKEA's second-hand trade

In this section, the results of the LCA performed in the Excel model is be presented. There were three main factors in the analyzed case, the PAE of second-hand trade, RRs of second-hand sales, and the Additional emissions of second-hand trade.

4.1.1. Potential avoided emissions

In Figure 6 the estimated FLCE, the PUE, and the emissions from T0 transport for selling 1,000,000 new items is displayed. The PAE are presented both without subtracting the PUE and by subtracting the PUE, see Figure 6.

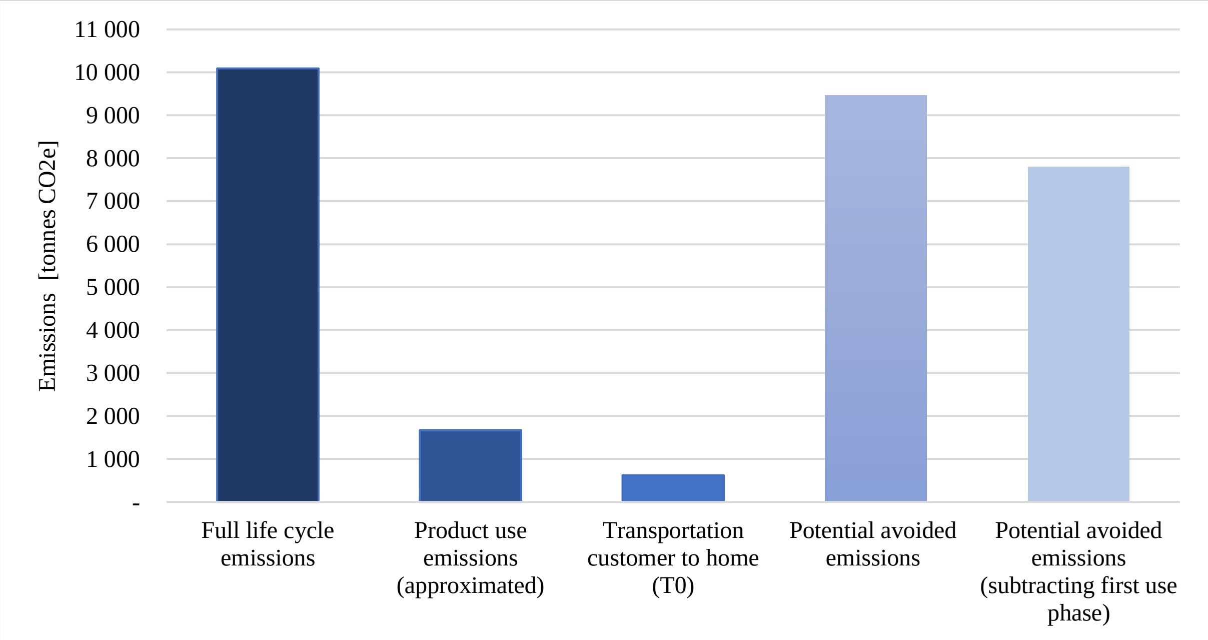

Figure 6: Full life cycle emissions of 1,000,000 new furniture, emissions from theirs use and transportation to home, and the calculated potential avoided emissions.

As seen in Figure 6 the estimated FLCE of 1,000,000 IKEA furniture items was found to be around 10,100 tonnes of CO2e, the PUE were approximately 1,670 tonnes, and the emissions from T0 were around 621 tonnes. The PAE were found to be around 9,470 tonnes of CO2e but about 7,8000 tonnes if the PUE were also subtracted from the PAE.

4.1.2. Replacement rates

IKEA sells its second-hand products at approximately 50% of the original price of the products (Haltia and Johansson, 2021). So, according to the analytical model developed by Thomas (2011), discussed in section 2.2.2, the RR of the ReTuna store might therefore be around 50%. Although, passive durable products, such as the majority of IKEA's products, have more potential for life extension and likely higher RRs (Böckin et al., 2020). According to calculations, the RR_{system} was found to be 68.9%. That RR was used to estimate the Avoided emissions by selling 1,000,000 second-hand items instead and the results are displayed in Figure 7. On the left side is the estimation of Avoided emissions not subtracting the PUE and on the right side is the estimation of the Avoided emissions subtracting the PUE from the PAE.

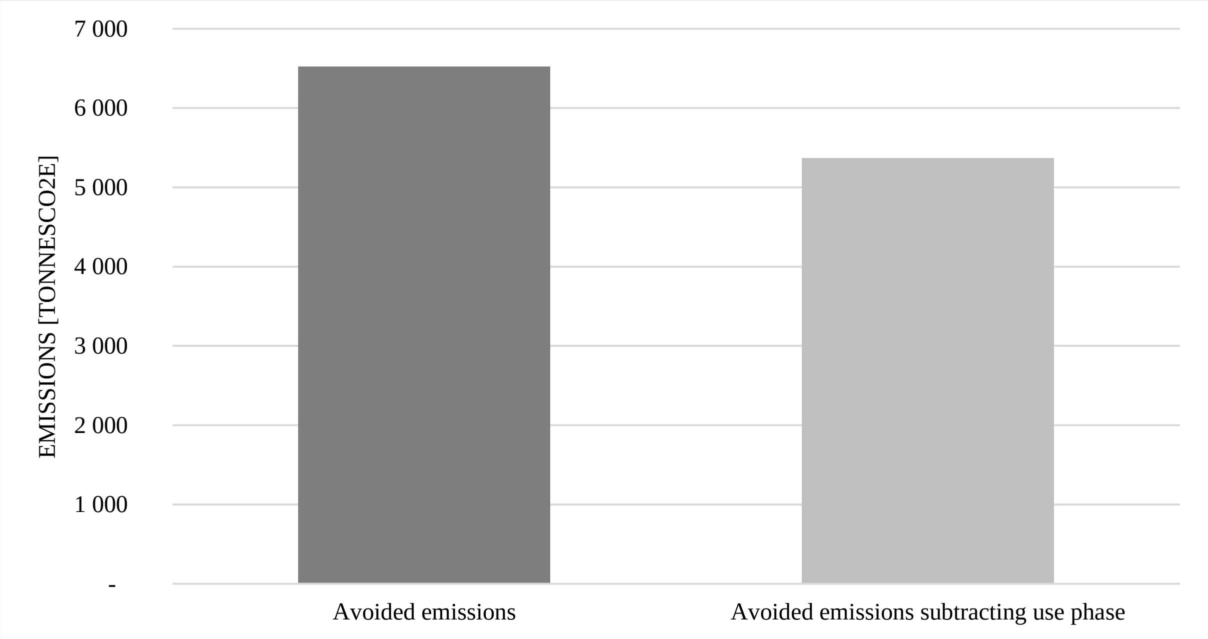

Figure 7: Estimation of the avoided emissions by selling 1,000,000 second-hand items.

As seen in Figure 7 the Avoided emissions were estimated to be about 6,520 tonnes of CO_2e. The estimated Avoided emissions were about 5,370 tonnes if the PUE were subtracted from the PAE.

4.1.3. Additional emissions – emissions from IKEA's second-hand trade

The following section will present the results from the assessment of emissions from IKEA's ReTuna second-hand trade, or the Additional emissions. The Additional emissions were estimated to be about 2,3300-tonnes CO_2e for selling 1,000,000 second-hand items. There were two main actions causing The Additional emissions, emissions from additional transports and emissions from cleaning and repairing the furniture. There were both upstream transports, or transports of donations ($T_{donations}$), and downstream transports, or the transports of customers from ReTuna to homes (T4). The estimated Additional emissions are presented in Figure 8. In Figure 8 emissions are presented in tonnes of CO_2e and with the share of each life stage of the total Additional emissions.

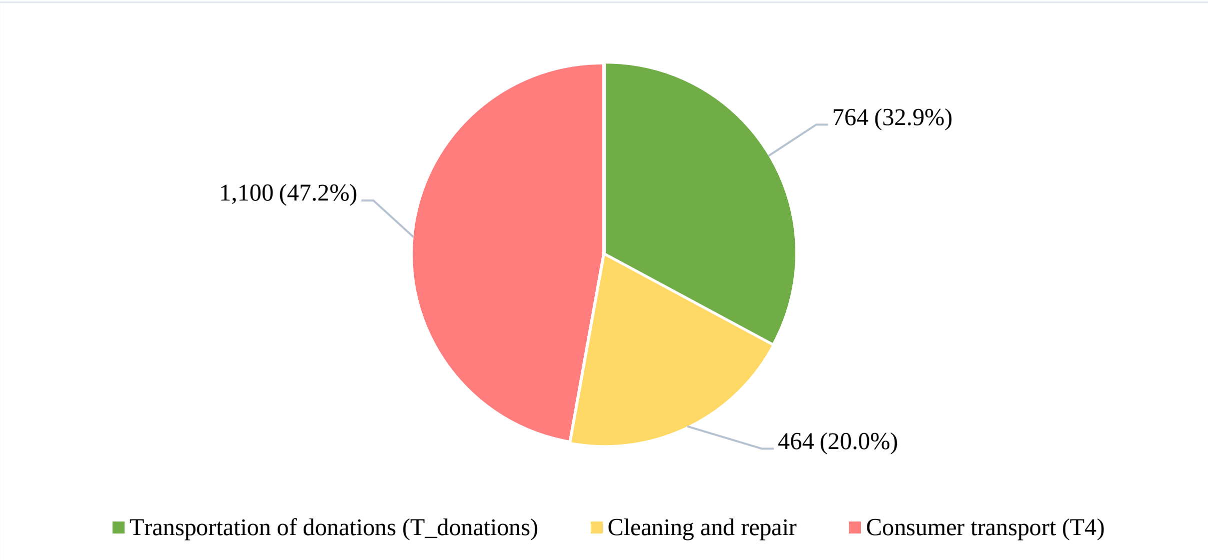

Figure 8: Estimated Additional emissions caused by selling 1,000,000 second-hand items (emissions from each life stage in tonne CO_2e emissions and its share of the total Additional emissions).

As seen in Figure 8 the emissions from transportation are higher than emissions from the cleaning and repair. The emissions from the transportation of donating and buying 1,000,000 second-hand items in ReTuna are estimated to be in total 1,860 tonnes or about 80.0% of the Additional emissions of this second-hand trade. The emissions from donations transportation ($T_{donations}$) were estimated to be 764 tonnes or 32.9% of the total Additional emissions. The emissions from the second-hand customer travel (T4) were estimated to be around 1,100 tonnes or about 47.2% of the estimated Additional emissions. The emissions from cleaning and repair were found to be 464 tonnes CO_2e or 20.0% of the Additional emissions.

As mentioned, IKEA did not have significant interference when it came to cleaning and repairs hence the Emissions from repair were not found to be significant. Emissions from T4 are higher than the emissions from $T_{donations}$ but were still found to be quite significant. Since there are three different paths of donations (T1, T2, T3) to the ReTuna store and donations were found to be responsible for significant amount of the Additional emissions, it was found meaningful to compare the emissions from each donation path, see Figure 9.

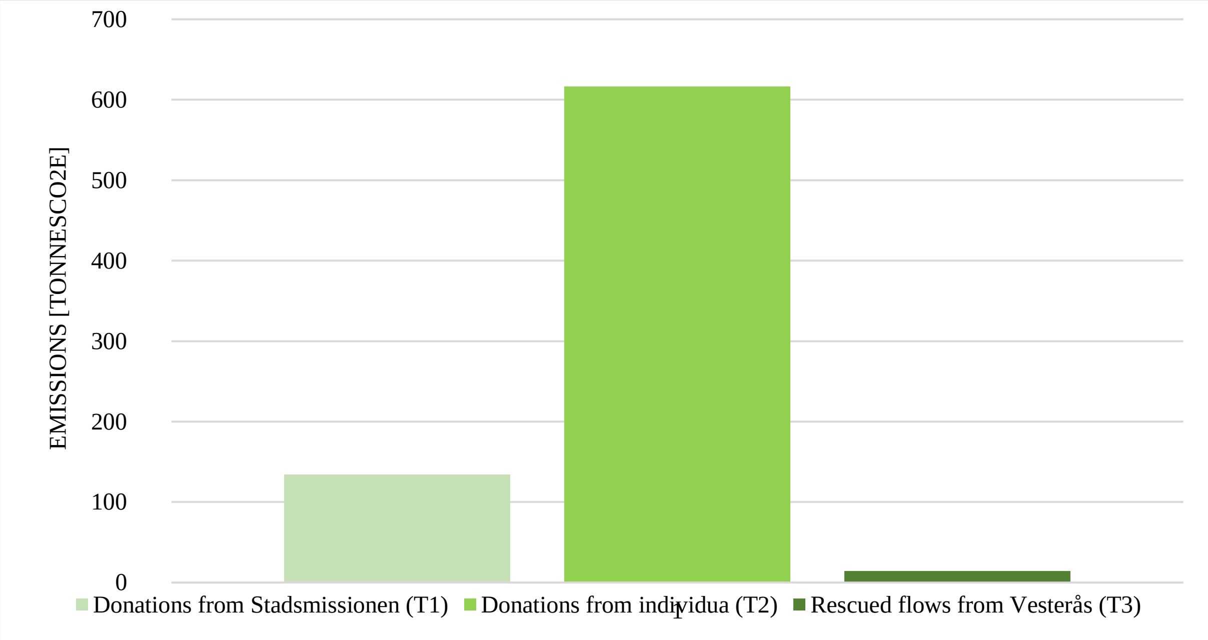

Figure 9: Estimation of the emissions caused by donating 1,000,000 second-hand items to ReTuna per donation path.

As seen in Figure 9 emissions from donations by T1 were over 134 tonnes, emissions from donations by T2 were over 616 tonnes, and emissions from donations by T3 were about 14.1 tonnes. The main source of emissions from donations was from the donation path T2 where individuals donate directly to ReTuna although most of the donations come by that donation path.

4.1.4. Comparison of avoided emissions and additional emissions (savings)

The PCS of IKEA's second-hand trade was estimated, and the results are presented in Figure 10. This is the result of the first objective of this study and was for the current case of IKEA's second-hand trade. In Figure 10 the estimation of emissions is presented for selling and buying 1,000,000 IKEA furniture new or second-hand. The emissions are marked to be related to the second-life cycle of the products, related to the first life cycle, or saved emissions. The orange column is related to the second life cycle and displays the Additional emissions. The blue columns are related to the first life cycle and display the estimated FLCE, the PAE, and the Avoided emissions considering RR. The PUE were not subtracted from the values in the blue columns. The two yellow columns display the estimated PCS resulting from second-hand trade. The PCS is first presented without subtracting the PUE and displays the percentage of “climate impact savings” (Savings$_{FLCE}$, and Savings$_{Avoided\ emissions}$). The PCS is then presented when PUE were subtracted from PAE and the percentage of “climate impact savings” is marked (Savings$_{Avoided\ emissions.use}$). The emission savings are presented with negative values to represent those emissions were “saved”.

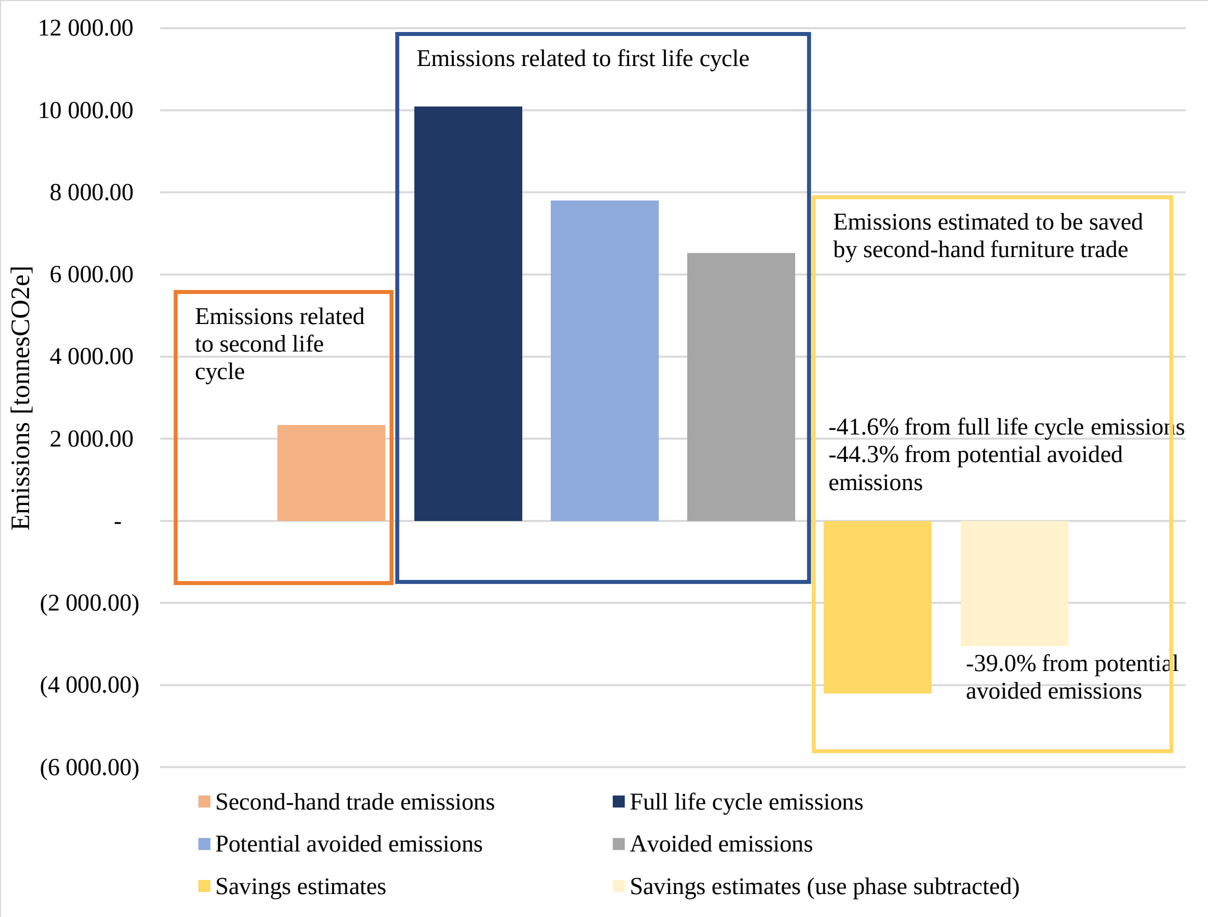

Figure 10: The results of the comparison of avoided emissions and additional emissions of IKEA's second-hand trade and the estimated climate impact savings.

According to estimates the CO_2e emissions saved by selling 1,000,000 second-hand furniture could be around 4,200 tonnes, but 3,040 tonnes if the PUE were subtracted from the PAE, see Figure 10. According to the estimation on the PCS, IKEA's second-hand trade can reduce emissions by 41.6% than was estimated to be the FLCE. Second-hand trade has 39.1% to 44.3% lower emissions than was estimated to be the PAE, depending on if the PUE are subtracted from the PAE or not. A sensitivity analysis, described in section 3.2.4, was performed both on the PCS and the Savings$_{FLCE}$, see Figure 11. In Figure 11 negative values for the PCS represent emissions saved, and positive values represent emissions emitted. For the savings, it is reversed.

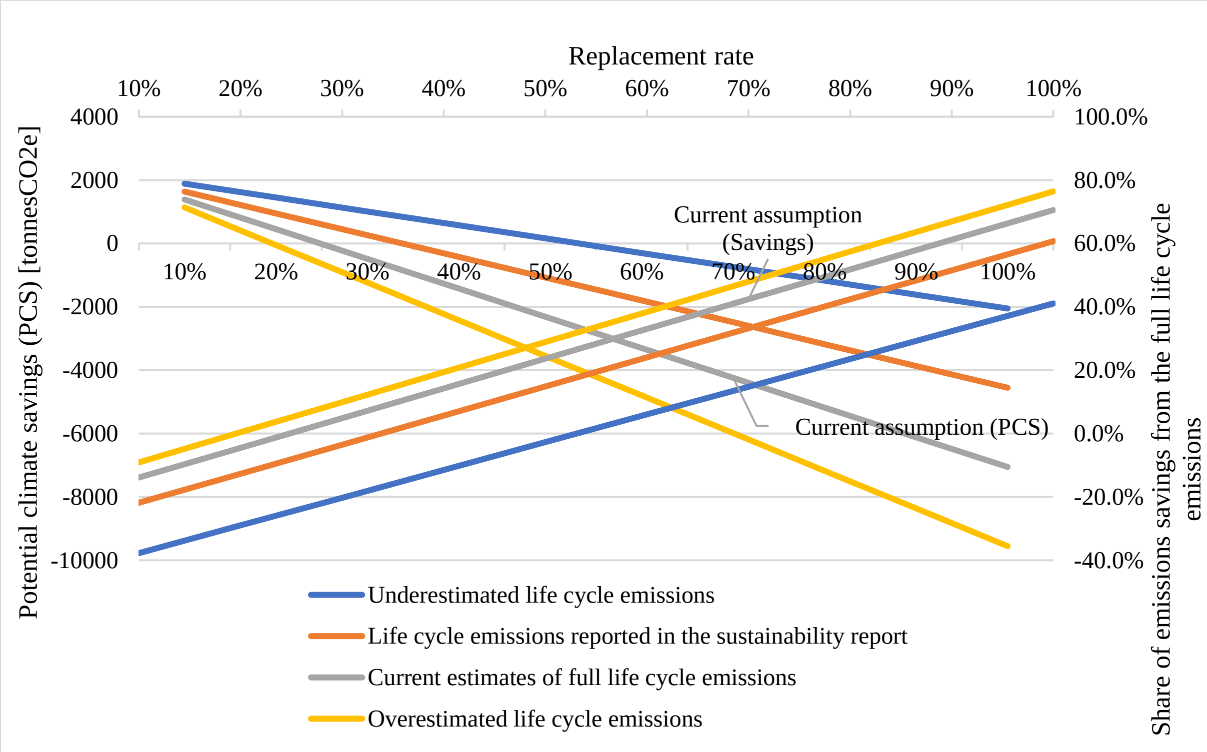

Figure 11: Sensitivity analysis on the estimated potential climate savings based on assumptions of full life cycle emissions and replacement rate.

As seen in Figure 11 both the estimated FLCE and RR_{system} have significant effects on the estimated PCS although the RR_{system} was more effective. For the current estimates of the FLCE, the PCS ranges from 1,390-tonnes CO_2e emitted to 7,050-tonnes saved for RR_{system} from 10% to 100%. For the current estimates of the RR_{system} the emissions range from 740-tonnes CO_2e to 7,740-tonnes saved for the four analyzed estimations of FLCE. As seen in Figure 11, both the estimated FLCE and RR_{system} have significant effects on the estimated $Savings_{Avoided\ emissions}$ although the RR_{system} was more effective. For the current estimates of the FLCE, the $Savings_{Avoided\ emissions}$ ranges from 13.9% of PAE emitted to 70.5% of PAE saved for RR_{system} from 10% to 100%. For the current estimates of the RR_{system} the $Savings_{Avoided\ emissions}$ ranges from 14.8% to 51.6% of PAE saved for the four analyzed estimations of FLCE. As seen in Figure 11, by using the current estimate of FLCE, emissions of second-hand trade exceed the emissions avoided for RRs lower than 25%. By using the footprint reported in IKEA's sustainability report, emissions of second-hand trade exceed the emissions avoided for RRs lower than 35%. So, for all RR above 25% to 35% emissions are saved by the current state of IKEA's second-hand trade.

4.2. Required share of second-hand sales for IKEA to reach and go beyond their goals

For the current state of Goals = 15% and $Savings_{FLCE}$ = 41.6%, the share of second-hand sales would need to be 37.8% for IKEA to reach their climate commitments according to the LCA model built. It was assumed that second-hand sales would be IKEA's only climate mitigation measure. The required share of second-hand sales for IKEA to go beyond the goal of a 15% decrease in value chain emissions is displayed in Figure 12. Decreases in value chain emissions from 15% to 100% were analyzed.

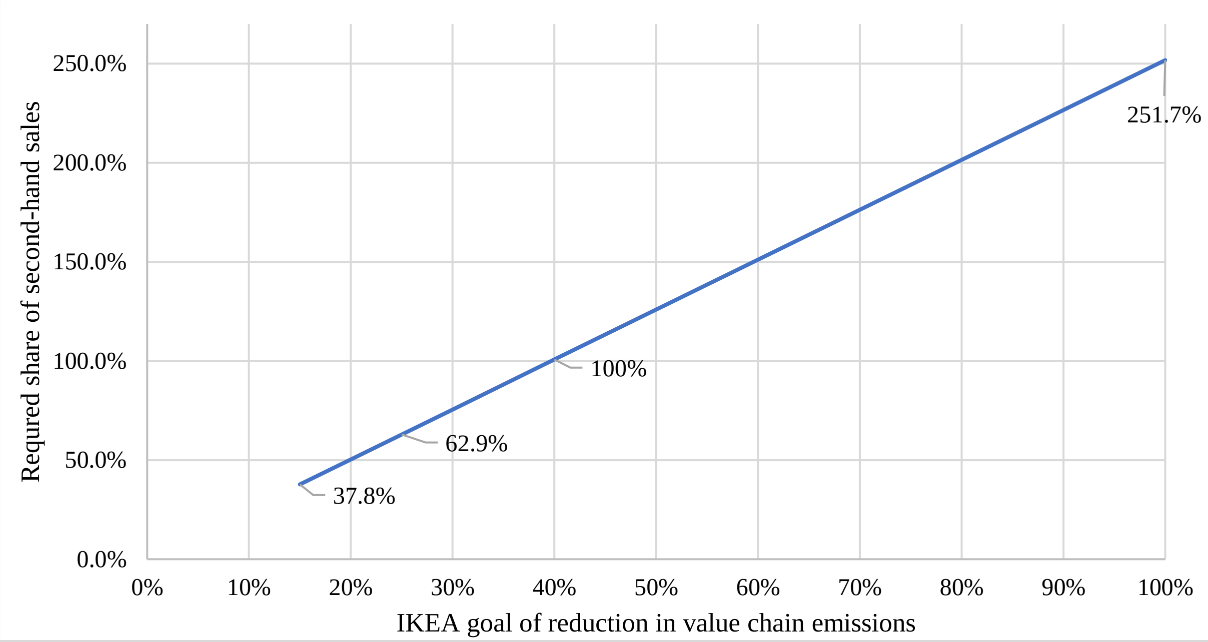

Figure 12: The required share of second-hand sales based on IKEA's goals of value chain emission reduction.

As seen in Figure 12 if IKEA goes beyond its goal of a 15% reduction in value chain emissions the required share of second-hand sales increases. If the goal is set to be a 25% reduction the required share of second-hand sales would need to be 62.9%. If IKEA only sold second-hand items, the value chain emissions could decrease by about 39.8%. So, according to the results of this project and the current state of second-hand trade, second-hand sales could at best reduce emissions by around 39.8%. To fully reduce their overall value chain emissions, by only using second-hand sales as a climate mitigation measure, the share of second-hand sales would need to be 252% according to the model, which is not in relation to reality.

4.3. Analysis for improvements in the second-hand trade

The LCA model was used to estimate the emissions of the improved scenarios of second-hand trade. Three main aspects were identified for having the potential for improvements: the PAE, the RR, and the Additional emissions. The following section will describe the results of the improvement analysis.

4.3.1. Improvements in the potential avoided emissions

To estimate the PAE of second-hand trade a method, described in section 3.2, was used that relied on a hypothetical scenario. The hypothetical scenario assumed that IKEA second-hand would sell a similar range of products as in conventional stores since IKEA aims at becoming fully circular. That requires them to reuse everything that can be reused and recycle or repurpose the rest (IKEA, 2021d). Although, selling this range of products does not necessarily result in the optimal case of avoided climate impact. The PAE were dependent on the variety of products sold in the second-hand store. As seen from equations (1), (2), and (18) selling a higher share of carbon-intensive products could result in higher levels of PAE and possibly a higher avoided climate impact. For example, selling one second-hand IKEA sofa could result in the PAE of 67.2 kg CO_2e but selling one second-hand duvet cover could result in the PAE of 8.33 kg CO_2e. The main potential improvement identified to maximize the PAE was changing the variety of items sold. Selling more items with higher EVs would result in higher PAE and possibly higher PCS. The emissions were also dependent on the weight of the items so selling heavier items would result in higher PAE and possibly higher PCS.

The range of products sold per product category (S_{IKEA}) was identified the only variable related to the PAE that IKEA second-hand could affect. Emissions from T0 could be indirectly influenced by conventional IKEA stores e.g., by having charging stations for electric vehicles in their parking lots (Haltia and Sinclair, 2022a). Although, the emissions from T0 and the PUE cannot be controlled by IKEA second-hand since those variables are dependent on new furniture trade but not second-hand trade. The only improvement suggested for the PAE is to sell more items that cause more emissions in their first life cycle e.g., heavier items.

4.3.2. Improvements in replacement rates

RR is an important variable in analyzing the environmental benefits of a reuse but is complicated to influence since it depends on several aspects of the market in question and the preferred outcome. The preferred outcome refers for example to if the goal is to maximize emission savings or maximize the social benefits. For cases with especially low RRs, reuse might not be environmentally beneficial (Sandin et al., 2019, Thomas, 2003, Thomas, 2011, Fortuna and Diyamandoglu, 2017, Castellani et al., 2015, Nørup et al., 2019). As indicated in equation (4), RRs are dependent on the LEP and the probability that the second-hand purchase replaces a new item purchase (Pb). The LEP is the proportion of the durability of the second-hand item to the durability of the same item new. So, the longer the LEP the higher the RR (Privett, 2018). Increasing the Pb would also increase RRs. Measures to maximize RRs were identified from previous research, see section 2.2.2. The results of the effects on the PCS of increased RR will be presented in this section.

It is difficult to know the exact effects of actions on the RRs because of the complicated relationship RR has with aspects such as the economy, demographics, price of products, and durability (Sandin et al., 2019). Although, if RRs would be increased by some means it would affect the emission saved. The results of the analysis of increased/decreased RR are displayed in Figure 13 where negative values represent emissions emitted to the atmosphere and positive values represent emissions saved. The state of the current case is marked with red dots in Figure 13.

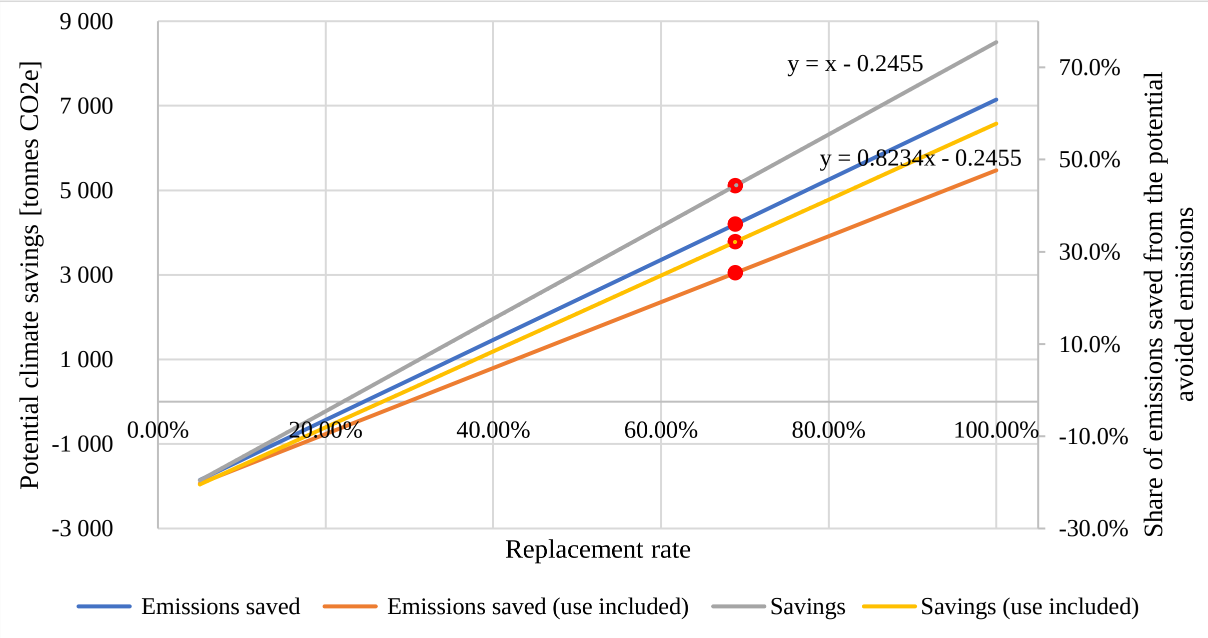

Figure 13: The effect of changed replacement rates on avoided emissions and the potential climate savings.

As seen in Figure 13, if RRs are ≤ 24.6% the second-hand trade will result in emissions emitted. If the RRs = 0% 2,330 tonnes of CO_2e would be emitted from the second-hand trade. For emissions saved and savings (use included) second-hand trade could result in emission savings for all RRs above 29.8% according to this analysis. For emissions saved and savings (use included) second-hand trade could result in emission savings for all RRs above 24.6% according to this analysis. If the RRs are increased to 80% by any means, the $Savings_{avoided\ emissions}$ could be about 55.4% or about 5,250 tonnes. If the RRs are increased to 100%, so assuming all purchases replaced a new item purchase, the emissions saved are from 57.8% to 74.4%, or 5,470 to 7,140 tonnes, depending on if the PUE are subtracted from the PAE or not.

4.3.3. Improvements in additional emissions

In this section, improvements in IKEA's second-hand trade will be explored and analyzed. How IKEA can minimize the additional emissions of the second-hand trade was explored. The results of the improvement analysis in the cleaning and repairs is first presented and then the results of the improvement analysis in the transportations of donations and consumer transport.

4.3.3.1. Cleaning and repairing

The Emissions from repairs were estimated by using the cost spent by IKEA on repairs. IKEA has improved its repair services by reducing the cost of repairs from the analyzed period (IKEA Second-hand store, 2021, Haltia and Sinclair, 2022a). Therefore, the potential for improvements in the repair stage was not found to be high. How Emissions from repairs was affected by increased and reduced costs was analyzed and the results are displayed in Figure 14. The costs will not be presented.

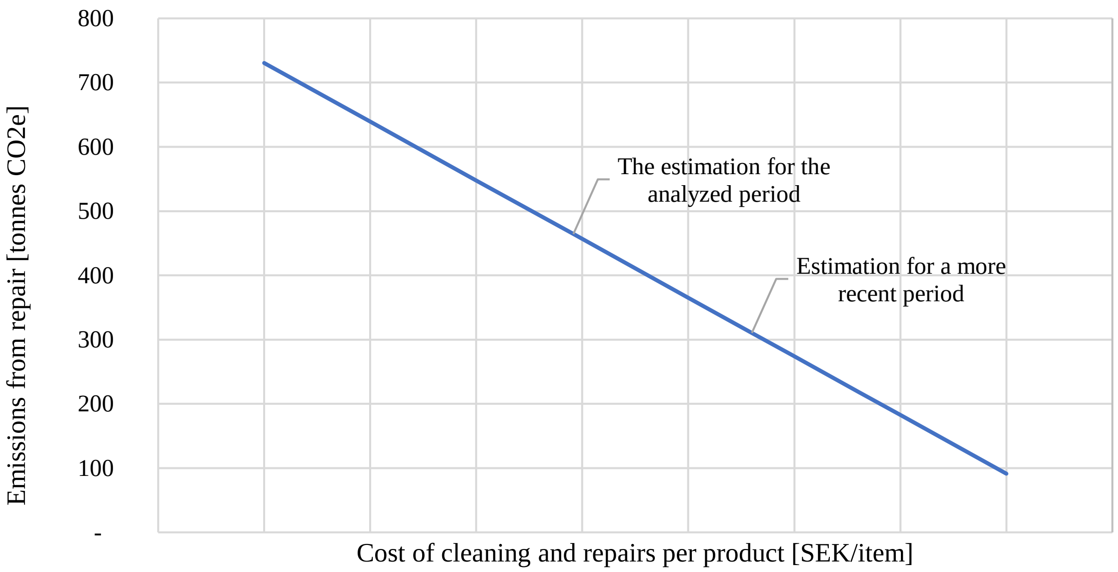

Figure 14: Analysis of emissions from repairs based on increased and decreased costs of repairs.

As seen in Figure 14, the cost of repairs and emissions from repairs had a lineal relationship. If the cost of repairs was doubled the emissions from repairs were also doubled according to the method used to estimate the Emissions from repair. The improvement suggested for repairs was to reduce cost of repairs. IKEA had already decreased the cost of repairs by 30% and the Emissions from repairs might have already decreased. According to the model the emissions had decreased from 464 tonnes CO_2e to 310 tonnes for repairing 1,000,000 second-hand items. If IKEA manages to decrease the cost of repairs even further or by 60%, the emissions from repairs could be decreased to approximately 183 tons. If the costs of repairs increase by 60%, the emissions from repair were estimated to be 731 tonnes.

4.3.3.2. Transports of donations and customer transports

Emissions from transportation caused 80% of the additional emissions caused by second-hand trade. This indicates that improvements in the transportation could have significant effects on the additional emissions and the PCS. In this section, improvements will be identified and their effects on the PCS will be analyzed. First improvements for the donation transport will be discussed and thereafter improvements for the customers' travel. Emissions from the transportation of donations will decrease with decreased travel distances but to simplify this analysis, the change in emissions with changed travel distances was not analyzed for the donation transportation except for Donation scenario 1.

Emissions from the transport of donations

As seen in Figure 9 the emissions from donations vary significantly depending on the donation path although each had different characteristics. To understand what donation path was preferable from a climate perspective the results were normalized both based on the share of donations from each donation path and distance traveled and the results are presented in Figure 15.

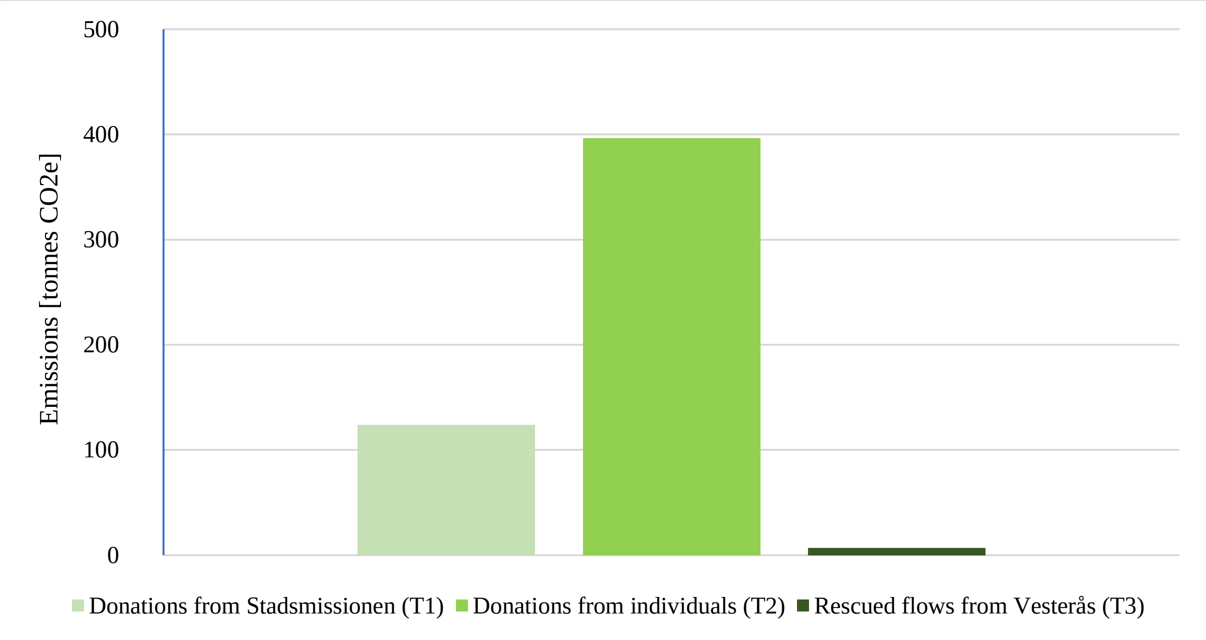

Figure 15: Estimations of the emissions caused by donating 1,000,000 second-hand items to ReTuna normalized for the share of donations per path and distances traveled.

As seen in Figure 15, for a normalized share of donations and distance traveled, donation path T2 results in the highest level of emissions, followed by donation path T1, and the donation path T3 had the lowest level of emissions, see Figure 15. This indicated that from a climate perspective donation path T3 was the most beneficial and donation path T2 was the least beneficial. Donation path T3 was not found feasible to focus on, since those items are from a recovery store and are not considered second-hand but rather saved first-hand items (Haltia and Sinclair, 2022a). A hypothetical scenario was created by assuming that all donations would be by donation path like T1 with assumed distances. The hypothetical scenario or *Donation scenario 1* was to have several drop-off points. The drop-off points could be at a certain average distance from households where the first user can discard their used furniture. IKEA could then pick up items and deliver them to their second-hand outlets or stores. This would reduce the travel distances traveled in passenger cars, which causes high level of emissions, and increases the more optimal transportation, where IKEA's freight HVO vehicles are used that have larger quantities of furniture per trip. The results of the emissions caused by the Donation scenario 1 are presented and compared to the current emissions of donations in Figure 16.

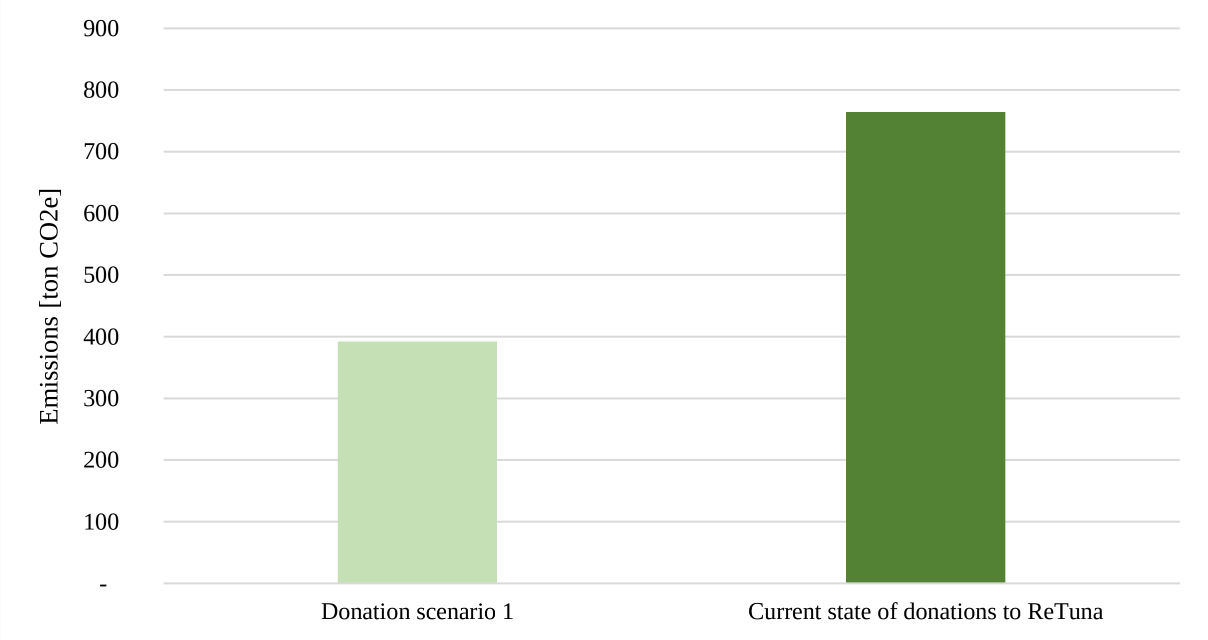

Figure 16: Emissions from the donations of Donation scenario 1 (left) and the current state (right).

As seen in Figure 16, Donation scenario 1 could reduce the emissions from donating of 1,000,000 items from 764 tonnes to 392 tonnes. This was highly dependent on the transportation distances set. The effects of the assumed distances were analyzed, and the results are presented in Figure 17.

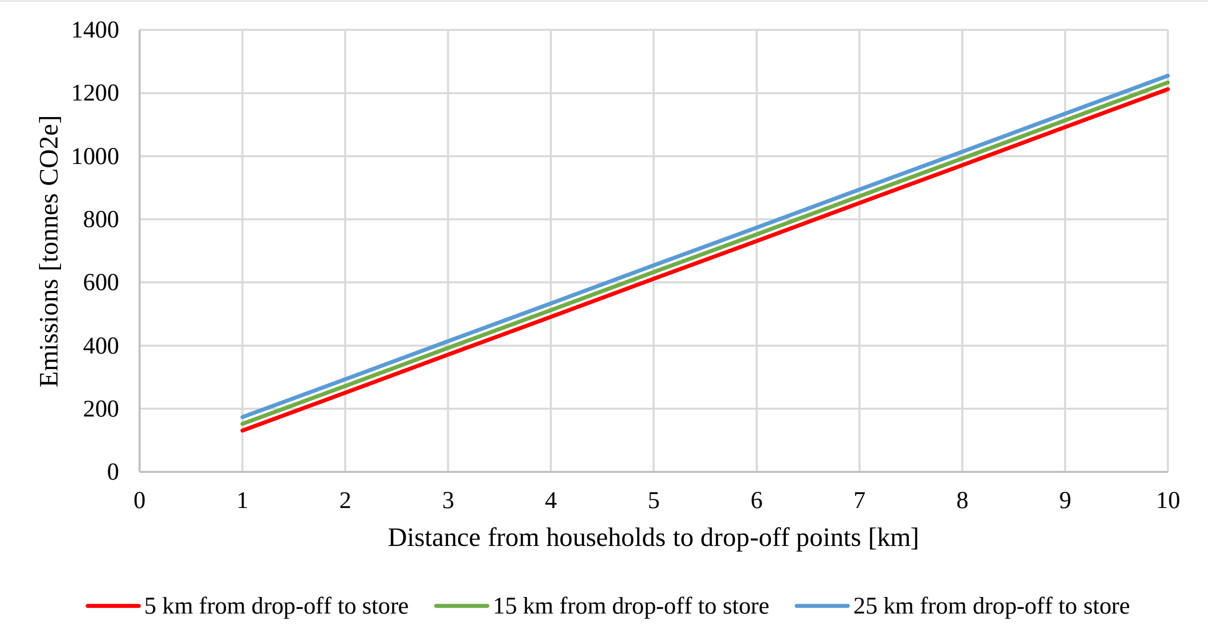

Figure 17: Emissions from several scenarios of the Donation scenario 1.

As seen in Figure 17 the transportation distances assumed for the Donation scenario 1 had significant effects on the emissions caused by donations. The distance from the drop-off points to homes had more effects than the distance from the drop-off points to the store.

Five more improved donation scenario were created, their emissions were estimated, and the results are presented in Figure 18. In Figure 18 the current emissions from donations, estimated in section 4.1.3, and emissions from Donation scenario 1 are also presented, for comparison. Each column is marked with the percentage of decrease in emissions from the current state of the donations.

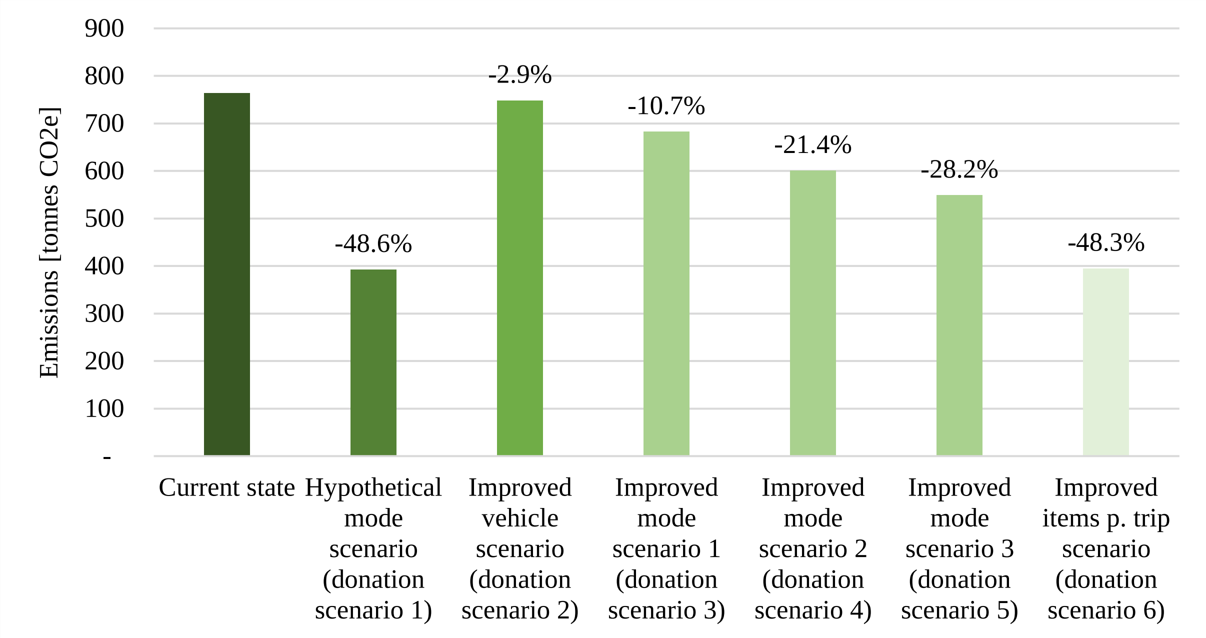

Figure 18: Total emissions of transportation of donations for the current state and the six proposed improved donation scenarios.

As seen in Figure 18 the Donation scenario 1 performed best on a climate perspective. Changing the vehicle used for transportation of donations, or Donation scenario 2, had the least effects on the emissions from donations ($T_{donations}$) even though the vehicle used had significantly lower emissions than the vehicle currently used. The Donation scenario 3 to 5 caused from 10.7% to 28.2% decrease in $T_{donations}$. Donation scenario 3 to 5 assumed the share of donation in passenger cars from 75% to 25%, see Table 12 for further detail. Increasing the number of items donated per trip had significant effects on the $T_{donations}$, or Donation scenario 6. Emissions from Donation scenario 6 was further analyzed based on the number of items donated per trip and the results are presented in Figure 19.

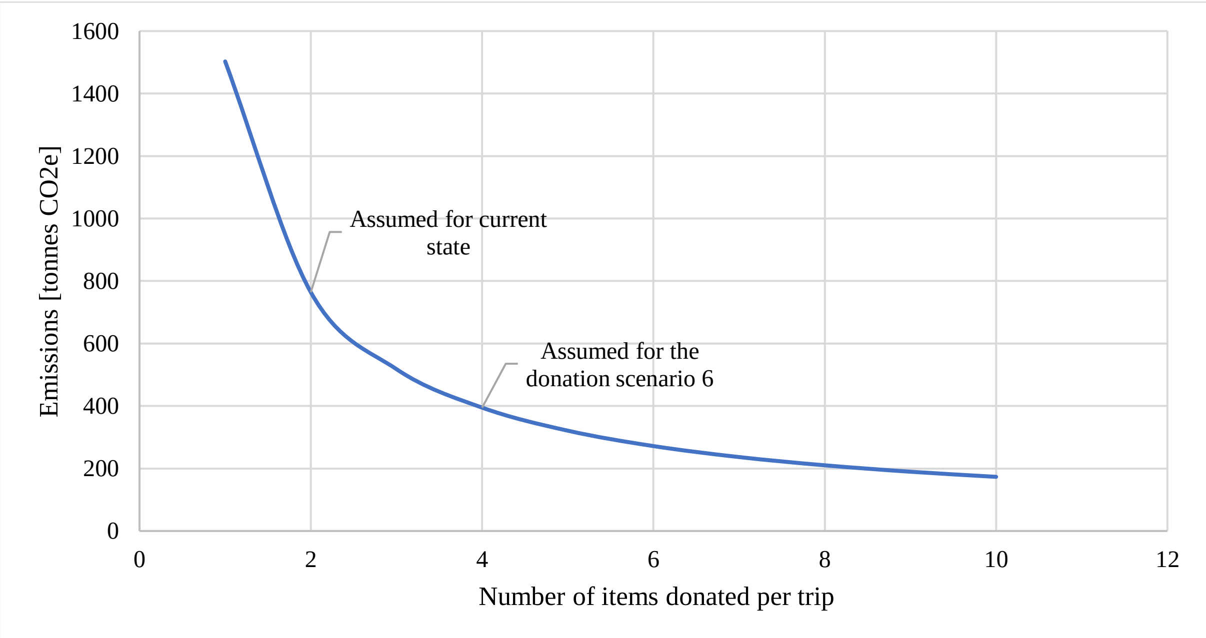

Figure 19: The effects of the number of items donated per trip for donation paths T1A and T2 on the overall emissions from donations (further analysis on Donation scenario 6).

As seen in Figure 19 the number of items donated per trip had significant effects on the emissions of donations. The emissions from donations can be reduced from about 764 tonnes to 173 tonnes if the number of items donated per trip for T1A and T2 was increased from 2 to 10 items.

Emissions from transportations of customers to home

The emissions from customer transport (T4) were the most emission-intensive life stage of IKEA's second-hand store in ReTuna and were estimated to be around 1,100 tonnes CO_2e. A sensitivity analysis was performed to analyze the impact on the emissions from T4 when the number of items purchased per trip and the share of customers in public transport were increased and the results are presented in Figure 20. Four scenarios of customers per transportation modes were analyzed, described in Table 12.

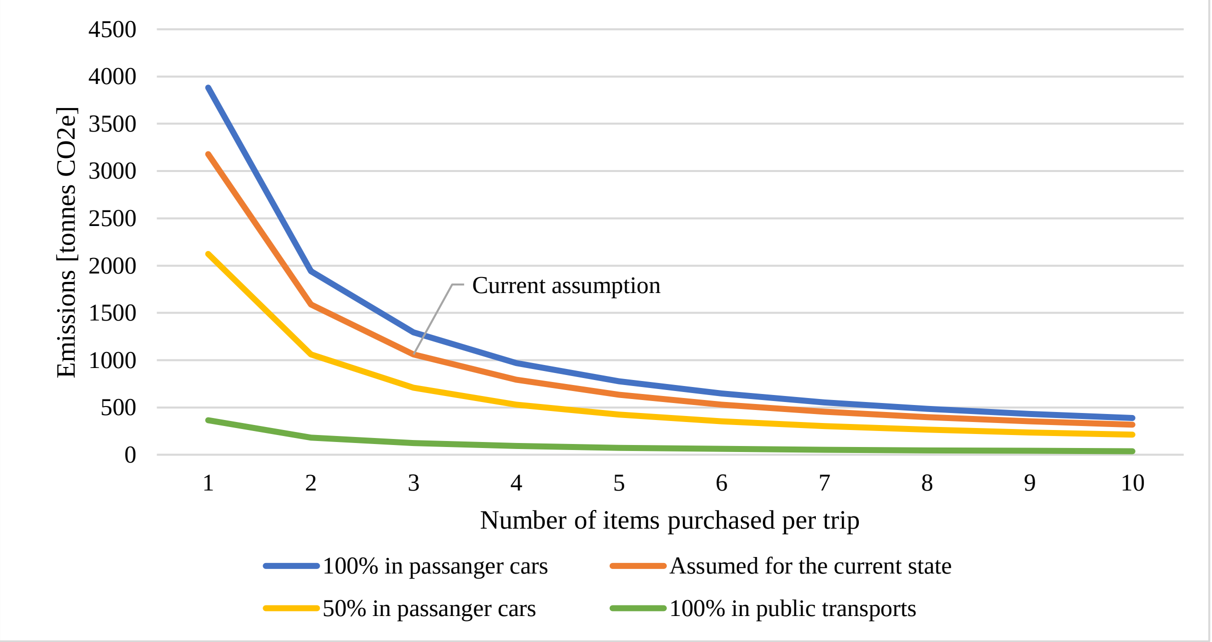

Figure 20: Sensitivity analysis on the emissions for the scenarios of the second-hand customer transportation mode and the number of items purchased per trip.

As seen in Figure 20 the emissions from second-hand customer travel are influenced both by the share of customers per transportation mode and by the number of items purchased per trip. For the current case of the share of customers per transportation mode, the emissions varied from 3,180-tonnes CO_2e to 318 tonnes for the number of items bought per trip from 1 to 10. For the current case of items bought per trip (3 items), the emissions varied from 1,290 tonnes CO_2e to 122 tonnes for the scenarios from 100% in passenger cars to 100% in public transport.

Lastly, a sensitivity analysis was conducted on the effects the number of items purchased per trip and the distance from store to customer homes had on the T4 emissions. The results are presented in Figure 21.

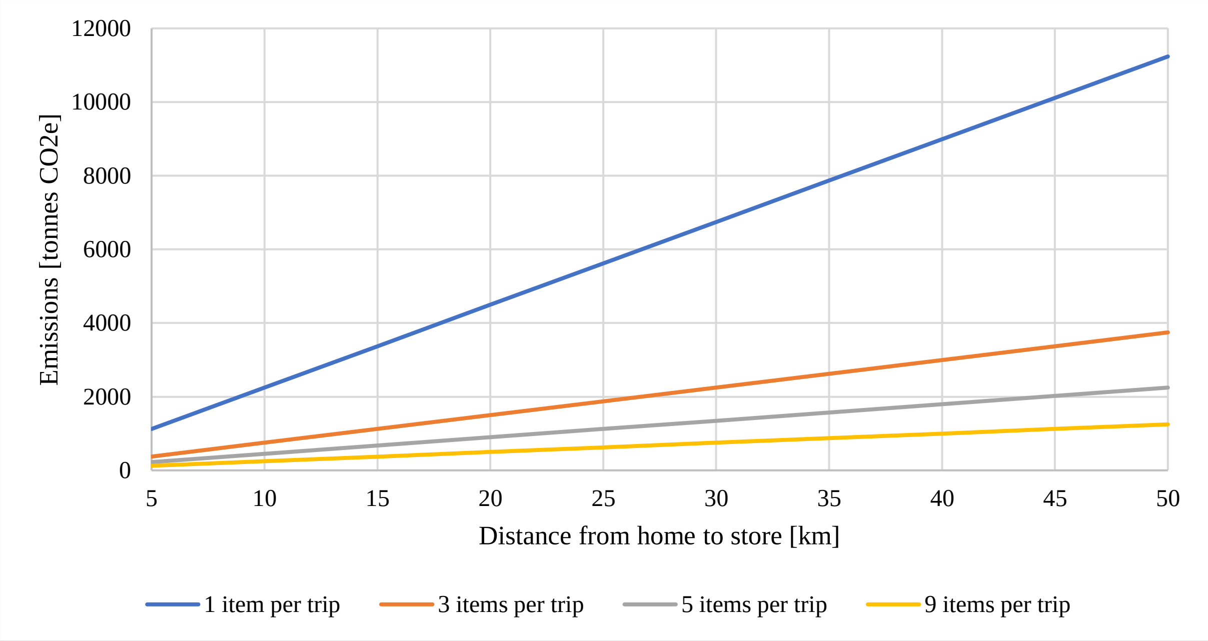

Figure 21: Changes in customer transportation emissions based on how many items are purchased per trip and the distance from home to store.

As seen in Figure 21 the analysis again revealed that the number of items purchased per trip and the distance traveled both had effects on the emissions from T4. For the current state of items bought per trip (3 items), the emissions varied from 330-tonnes CO_2e to 3,330-tonnes. For the current state of the average travel distance assumed (14.6 km) the emissions from T4 varied from 3,370-tonnes CO_2e to 375 tonnes for items purchased per trip from one to nine. So, the distance traveled, and items bought per trip showed similar effects on the emissions from T4.

4.3.4. Scenario analysis

The PCS and $Savings_{FLCE}$ for the six improvement scenarios were analyzed and compared to the current state. The results of the analysis on the changes in the PCS are displayed in Figure 22. Thereafter, the results of the analysis on the changes in share of climate impact saved from the FLCE ($Savings_{FLCE}$) are displayed in Figure 23. In Figure 22 and Figure 23 negative values represent emissions emitted and positive values represent emissions avoided. The seven scenarios were described in Table 13.

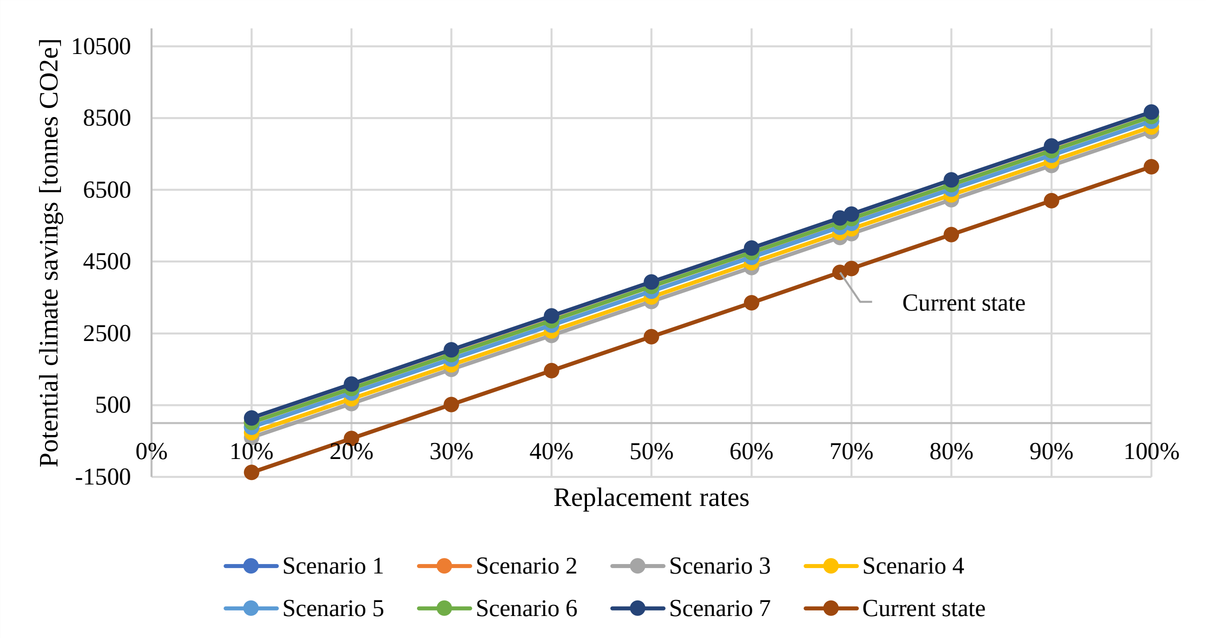

Figure 22: Potential climate savings for the current state and the seven improvement scenarios of second-hand trade.

As seen in Figure 22 the scenarios of improvements in second-hand trade have effects on the *PCS*. Scenario 7 results in the highest PCS or the highest level of GHG emissions mitigated and Scenario 3 resulted in the lowest PCS. For the estimated RR_{system} the improved scenarios resulted in PCS from 5,170 to 5,830-tonnes CO_2e while the PCS for the current system was 4,200-tonnes CO_2e. For the current state of the additional emissions the PCS ranged from 1,380-tonnes CO_2e are emitted to 7,140-tonnes are saved for RR_{system} from 10% to 100%.

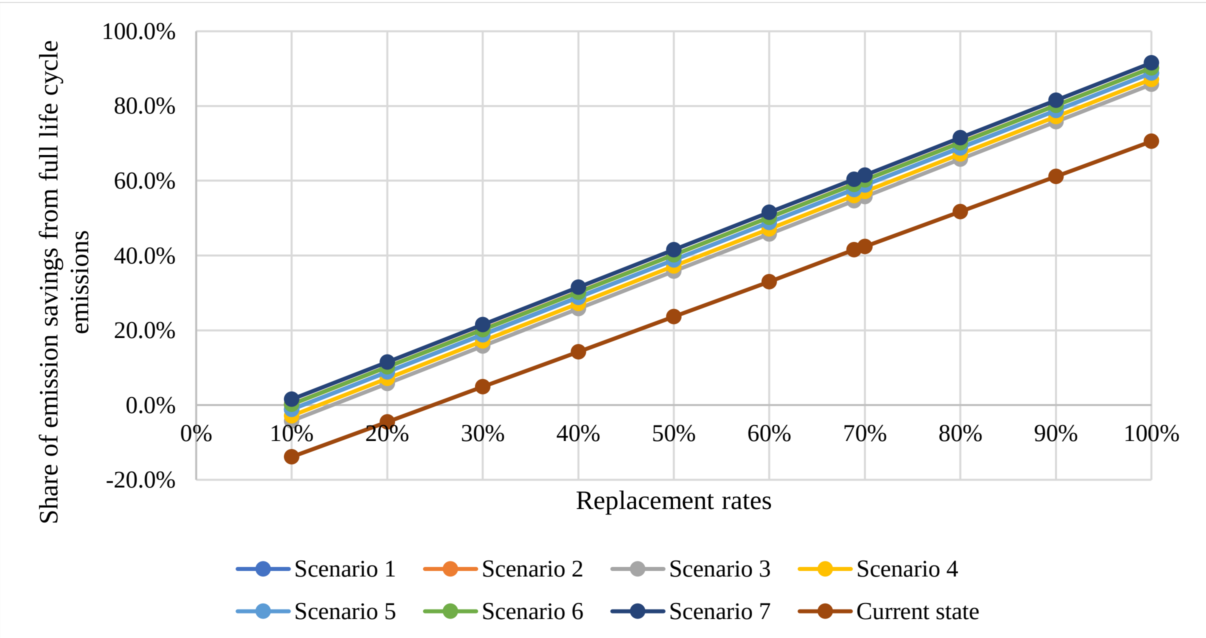

Figure 23: Share of emission savings from full life cycle emissions for the current state and seven improvement scenarios of second-hand trade.

As seen by comparing Figure 22 and Figure 23 the effects of the scenarios on the $Savings_{FLCE}$ was found to be similar to the effects of the scenarios on the PCS. As seen in Figure 23 the scenarios of improvements in the second-hand trade had effects on the $Savings_{FLCE}$. Although the changes in the

RR_{system} had more effects. For the estimated RR_{system} the improved scenarios resulted in $Savings_{FLCE}$ from 54.6% to 60.4% while the $Savings_{FLCE}$ for the current state was estimated to be 41.6%. For the current state of additional emissions, the $Sacings_{FLCE}$ ranges from 13.9% of the FLCE emitted to 70.5% of the FLCE saved.

The required share of second-hand sales for IKEA to reach their goal of a 15% decrease in value chain emissions for improved scenarios was analyzed for three scenarios of the estimated FLCE, described in Table 10, and the results are presented in Figure 24.

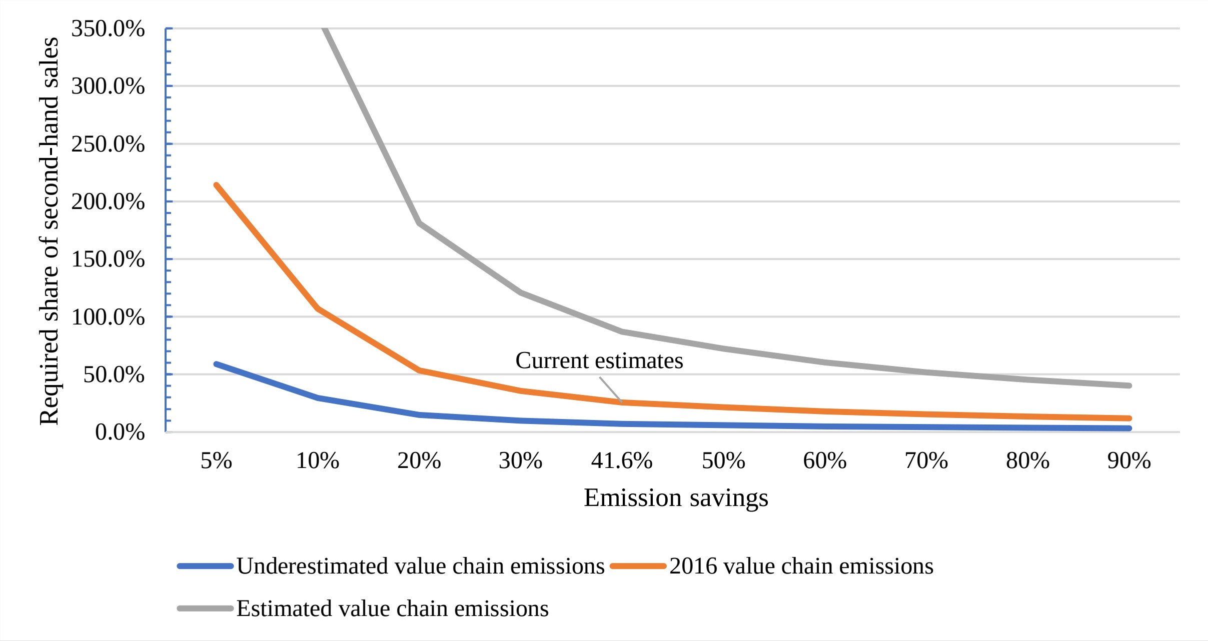

Figure 24: Required share of second-hand sales for IKEA to reach their 2030 commitments for improved emission savings.

From analysis of the savings, it was found realistic that the second-hand trade could be improved to reach up to 80% climate impact saved from FLCE. To reach that the additional emissions need to be minimized and the RRs need to be maximized. So, as seen in Figure 24 if the $Savings_{FLCE}$ would be improved to 80% the required share of second-hand sales for IKEA to reach their 2030 climate commitments would need be about 19.6%, assuming second-hand trade would be IKEA's only climate mitigation measure.

5. Discussion

The following section will discuss the results of this thesis project and the assumptions made to estimate the "climate savings" of second-hand trade. Measures to improve confidence in assumptions made for this analysis will be suggested. Circularity solutions' contributions to the decarbonization of companies will be discussed concerning IKEA's reuse scheme and their climate commitments. How furniture companies can develop future second-hand trade to increase the PCS will be discussed. Realistic measures to increase the climate impact saved for IKEAs second-hand trade will be suggested. This section will compare the results of this study to other similar studies and suggest future studies on this topic.

5.1. The life cycle inventory – "climate savings"

In this section the assumptions made to estimate the "climate savings" of second-hand trade will be discussed and how they affect the results of the first objective of this study. There were three main variables influencing the "climate savings", the PAE, RRs, and Additional emissions of second-hand trade.

5.1.1. Potential avoided emissions (PAE)

The PAE were dependent on the estimated FLCE, emissions of T0, approximated PUE, and emissions from commerce. As mentioned in section 3.2, about 14% of 1,000,000 items assumed to be sold second-hand were disregarded when estimating the FLCE. Although, this was found to be only 2% of the weight of the 1,000,000 items. Indicating that the defined system was well represented in the estimation of the FLCE. It was unlikely that several of the 208 IKEA product types would ever be sold second-hand. Customers of second-hand furniture are less likely to buy reused soft items such as mattress covers or sheets. It was also found unlikely that customers would buy cleaning utilities such as toilet brushes or mops (Edbring et al., 2016). The items' considered consumables are items that are used up, usually in the first life stage, such as candles, napkins, and light bulbs. Those items could be sold second-hand if the first owner bought and never used them and such consumption behavior is common in the throwaway society (Castellani et al., 2015). Although, for simplification and the definition of second-hand products' those items were disregarded in the LCA model. Had those products been included in the model, the estimated FLCE, PAE, and "climate savings" could have been higher.

The items disregarded in estimating the FLCE were not completely coherent with the items IKEA does not accept in their Buyback & Resell service. There were several items included in estimating the FLCE that IKEA does not accept and buy back, for example, outdoor furniture. IKEA's Buyback service is admirable for contributing to circularity and rewarding customers that help them do so. Although, to achieve full circularity more is still needed. For IKEA to become fully circular by 2030, it would be optimal to reuse all types of furniture in an acceptable state. IKEA will therefore have to sell similar items in their second-hand stores as they do in conventional stores, except for special cases where reuse is not possible. It is not clear how IKEA intends to achieve full circularity while not accepting several types of furniture in their buyback services (Nikas et al., 2022, IKEA, 2021d, IKEA, n.d.e).

When matching the 26 EVs from the Mistra report and IKEA's 208 PAs several problems were encountered. Matching a few EVs with so many furniture types required several approximation assumptions. The Mistra report was lacking in some product types, for example, no values were for ceramic products such as bathroom sinks, items made from hard plastics, nor fridges and freezers. Ceramic products were disregarded. For plastic items, EV for Other non-durable small household articles were used. That EV was retrieved from an LCA conducted on plastic bags (Carlsson-Kanyama et al., 2019). That EV was used for plastic IKEA items since it was the best available option. The life cycle of plastic bags, which can be considered consumables, and plastic IKEA items might be quite different and their emissions too. This assumption was therefore uncertain. For fridges and freezers, the EV for dishwashers, from the Mistra report, was used. Dishwashers and fridges and freezers have quite different characteristics and material compositions, so this assumption was also found uncertain. Several IKEA PAs were not like any of the product types in the Mistra Report and approximation was often used or an average value of several product types. The reason for only using EV from the Mistra report was to be consistent with data sources and the method used to retrieve EVs. To be able to do that a significant approximation was needed to estimate the FLCE of the 1,000,000 items. So, the FLCE had significant uncertainty. If the LCA model would be developed further, it is recommended that IKEA uses more specific EVs for each of its PAs.

The estimation of FLCE was uncertain. So, the FLCE were compared to the value chain emissions of IKEA, as reported in their sustainability report. The estimated FLCE were found to be significantly higher than the footprint reported in the sustainability report (IKEA, 2021d). This indicates that the method used to estimate FLCE might result in too high emissions. Although, IKEA's sustainability report was not found to be transparent enough on aspects such as what was included when estimating their value chain emissions and how they did so. Therefore, it was difficult to identify the exact reason for the difference between the two footprints. This was analyzed in a sensitivity analysis presented in section 4.1.3 discussed later in this section.

The PAE were estimated both by including the approximated PUE and without it. The PUE were approximated based on IKEA's sustainability report. This was because of the scope of the project and the data available. This approximation was mainly used to get the idea on how the result might change if PUE would be included. Using average emissions for product use for the furniture sold by IKEA was questionable. Some furniture items have almost no emissions in the use stage (e.g., a sofa) while other products, especially those using electricity, cause a lot of emissions in the use stage (e.g., lighting appliances) (Böckin et al., 2020). The emissions for commerce were additionally disregarded similarly to other studies addressing the same problem since they tend to be neglectable (Castellani et al., 2015). This might also affect the results.

The estimated emissions from T0 were found to be 6.16% of the estimated FLCE. In IKEA’s sustainability report *Customers' travel and home deliveries* were found to be 5.88% the carbon footprint of IKEA’s furniture (IKEA, 2021d). This can be considered within the error of margin and the difference might be explained by the fact that home deliveries were not considered in this project. A sensitivity analysis was performed on the emissions from T0, see Figure 25 in Appendix B, which revealed that the emissions were more sensitive to changes in the travel distances than the share of customers per transportation mode. So, it is important to try to minimize the distance for customers to the stores. The emissions from T0 were significantly lower than the emissions from T4 although both had shared characteristics. This difference was mainly because the customers of conventional stores buy many items per trip, or 9.4 items. Which was significantly higher than for the second-hand store, which was 3 items per trip. It was not certain that IKEA could influence their customers to buy more items per trip and it might rather cause overconsumption. This indicates that circularity and climate mitigation does not always go hand-in-hand.

The emissions from EOL of the furniture were disregarded because that was found to be common for studies on the climate impact of reuse. Although scientifically it is not sound to assume the EOL to be avoided since the product will eventually end up in final disposal, possibly after several reuse cycles. Reuse is merely an internal step for products before reaching EOL (Fortuna and Diyamandoglu, 2017). This assumption affects the results severely but had to be made because of the scope of the project and limited data. Since emissions from EOL, Product use at home, and commerce were disregarded the only emission source subtracted from FLCE to archive PAE was T0. This resulted in the FLCE to be quite close to the estimated PAE. PAE (without subtracting PUE) was found to be 9,470 tonnes CO_2e while PAE subtracting the PUE was found to be 7,800 tonnes CO_2e or almost 20% lower. This indicates that including the emissions from the use stage will affect the "climate savings" result of this project which might be lower. In the future development of the LCA model, the PUE and emissions from commerce should be included. Accounting for those stages should be straightforward if suitable data is available.

5.1.2. Replacement rates

The RR was a highly important and highly uncertain variable required to estimate potential "climate savings" of second-hand trade. Several studies had researched RRs of various systems, most of which did so with behavior analysis. Several studies had researched RRs for clothing, but few studied RRs for furniture. Research had identified varied RRs in the ranges from 10% to 90% depending on aspects such as the product type, location of analysis, and the specific research methodology (Castellani et al., 2015, Privett, 2018).

A suitable method for identifying RR is identifying the LEP of the product and performing behavioral analysis on the probability that the customer's purchase is replacing a new product to be purchased (Fortuna and Diyamandoglu, 2017, Privett, 2018, Nørup et al., 2019). The results will vary for different locations of analysis so finding a RR for IKEA's second-hand trade worldwide might not be feasible (Nørup et al., 2019). To improve the estimation of "climate savings" it was found optimal that IKEA, or companies dealing with similar problems, perform behavioral analysis on their second-hand customers in a specific location. Performing a behavioral analysis in several locations could indicate the difference in the RRs between different locations. That was not feasible for this project because of the scope (Nørup et al., 2019, Fortuna and Diyamandoglu, 2017).

The RR identified for the system of this project was found to be 68.9%. This value was higher than was identified to be the average value for product types like IKEA's, which was 66.8%. The RR value for the system was found to be even higher than the average value of all identified RRs, which was 54.0% (included RRs of clothing items, cell phones, and books). Although, after conducting significant research on RRs, it was found likely in relation to reality since passive durable products, not using electricity, have been identified to have higher RRs (Böckin et al., 2020, Kaddoura et al., 2019).

5.1.3. Additional emissions – emissions from IKEA's second-hand trade

The additional emissions were estimated to be around 2,330-tonnes CO_2e. Out of the 2,330-tonnes, the emissions from $T_{donations}$ were about 764 tons, the Emissions from repair about 464 tons, and the emissions from T4 about 1,100 tons. T4 was the most emission intensive life stage of the analyzed second-hand trade. Emissions from T4 was likely high because it was assumed that most consumers buy few products per trip. This was found to be in relation to reality. The second-hand consumer transport was likely causing a significant portion of the additional emissions of second-hand trade and improvements in the consumer transport would highly affect second-hand trade's potential as a carbon sink.

The Emissions from repairs were calculated from the cost of repairs. Using monetary value to estimate emissions can be uncertain as mentioned in section 3.1.1 (Isacs et al., 2016). The estimated Emissions for repairs are therefore uncertain. To further understand the Emissions from repairs a more detailed method could be used such as an LCA on the repairs in ReTuna. It would be interesting to compare results from such analysis and the results of this thesis project to gain understanding on how using a monetary value to estimate emissions is performing. A sensitivity analysis was performed on the estimated Emissions from repairs, see Figure 26 in Appendix B. The sensitivity analysis revealed that the estimation was sensitive both to changes in the cost of repairs and the average weight of the products repaired. Although, the emissions were more sensitive to changes in the costs.

The emissions from $T_{donations}$ varied significantly depending on the donation path. The donation path T2 resulted in the highest level of emissions, followed by T1, and donation path T3 resulted in the lowest level of emissions. This was mostly caused by the fact that most of the donations, or 67%, came from T2. Even though 27% of the donations came by T3 while 6% of the donations came by T1, the emissions of T1 exceeded emissions from T3. This was caused by the fact that there were two segments of transportation for T1, T1A, and T1B. One of the stages, T1A, consisted of the transportation of individuals in passenger cars with relatively few items per trip causing a high level of emissions. The difference was also caused by the difference in travel distances. T1B consisted of travels from Stockholm to Eskilstuna which was about 80 km. Other distances were shorter. The emissions from donations were further analyzed for improvements because of their significant contribution to the additional emission. That will be discussed in section 5.3.

5.1.4. Comparison of avoided emissions and additional emissions ("savings")

According to estimates, IKEA's second-hand trade had 41.6% lower emissions than was estimated to be the FLCE of 1,000,000 new furniture. Second-hand trade had 44.3% less emissions than was estimated to be the PAE. If the PUE were subtracted from the PAE, second-hand trade had 39.0% lower emissions than the PAE. So, subtracting the use stage from the PAE resulted in 5.30% lower savings even though the use stage caused about 17.8% of IKEAs furniture footprint reported in the sustainability report (IKEA, 2021d). This was likely because the RR_{system} was multiplied by the PAE after subtracting the PUE. Additionally, the PUE were approximated from IKEA's sustainability report and the FLCE estimated in this project were higher than was reported in the sustainability report (IKEA, 2021d). Including the use emissions will likely affect the savings.

The sensitivity analysis performed on the PCS and the $Savings_{FLCE}$ revealed that the RR_{system} has more effects on the results than the estimated FLCE. The RR had significant effects on the results and finding measures to maximize RRs of second-hand trade could result in significantly higher emissions "savings". By using the same FLCE as was reported in IKEA's sustainability report and the RR_{system} = 68.9% the PCS could be around 2,490 tonnes CO_2e emissions saved instead of 4,200 tonnes CO_2 emissions saved. The $Savings_{FLCE}$ could be around 33.2% instead of 44.3%. Using other estimates on FLCE results in lower emission savings, but emissions are still saved but not emitted. For all RR above 25% to 35% (depending on the FLCE used) second-hand trade would result in emissions savings according to the analysis of this project. Most of the studies, identified in section 2.2.2., reported furniture items to have higher RRs than 35%, so IKEA's second-hand trade already most likely results in emissions to be saved.

5.2. Required share of second-hand sales for IKEA to reach and go beyond their goals

The share of second-hand sales would need to be around 37.8% for IKEA to reach its goal of a 15% decrease in value chain emissions according to the analysis of this project. If the share of second-hand sales would be increased to 50% IKEA could decrease its value chain emissions over 20.0%. If IKEA would only sell second-hand the value chain emissions could be reduced by 39.8%. The hypothetical scenario created to answer these studies' second objective, that second-hand sales would be IKEA's only climate mitigation measure, was obviously not in relation to reality. IKEA had already taken several climate mitigations measures such as energy transition and making use of different waste types, as discussed in section 2.1.1.

Reuse has been identified for its potential to decarbonize various industries by several researchers (Nikas et al., 2022, Mercader-Moyano and Esquivias, 2020, Bataille et al., 2018). These results confirmed that and indicated the great potential reuse has in acting as a carbon sink. These results were dependent on the current case of IKEA's second-hand store in ReTuna, and improvements could reveal even greater potential to decarbonize IKEA's actions with reuse. Although, as the results also indicated reuse still has emissions and can therefore only do so much. This project indicated that for the current case of IKEA second-hand reuse could at maximum reduce IKEA's value chain emissions by around 40%. So, the company requires other climate mitigation measures to reach carbon neutrality.

IKEA's sustainability report indicated that IKEA's carbon footprint in 2016 was about 27.7 million tonnes of CO_2e. By 2030 they aim to reduce it to 23.6 million tonnes. IKEA's forests absorbed about 5.3 million tonnes of CO_2e emissions in 2021. This means that they still need to reduce their footprint or absorb emissions of 18.3 million tonnes to reach carbon neutrality. It was not found clear how IKEA aims to become carbon neutral but still only reduce its value chain emissions by 15% (IKEA, 2021d). IKEA's second-hand trade obviously contributes to circularity and will be one of the most important actions taken for IKEA to reach full circularity. Reuse also reduces the burdens of waste and resource consumption of packaging since IKEA's second-hand store in ReTuna does not repackage the items (Fortuna and Diyamandoglu, 2017, Böckin et al., 2020, Castellani et al., 2015, Farrant et al., 2010, IKEA, 2021b). The results of this study indicate that reuse additionally has the potential to contribute to climate neutrality, although can only reduce emissions by about 40% for the current state, so cannot act alone.

5.3. Improvements suggested for IKEA ReTuna

This section will summarize the possible improvements to second-hand furniture trade. There were mainly three aspects identified for improvements: (1) maximizing PAE, (2) maximizing RRs, and (3) minimizing the additional emissions. The following sections will present suggested improvements in each of those aspects for IKEA's second-hand trade.

As suggested in section 4.1.1, PAE can be increased by selling more heavy items with high EVs which could potentially result higher emission savings, although that is not certain. Selling heavier items could result in increases in transport emissions for T1 and T3 according to the LCA model since emissions were dependent on the weight of the transported items. The effects of selling more emission-intensive and heavy items on the emission savings should be further analyzed. Previous studies have highlighted that for certain product groups reuse is not environmentally beneficial e.g., because of the effects in the use phase for product consuming energy. For products where energy efficiency has been improved significantly a new product is more environmentally beneficial than reusing (Böckin et al., 2020, Wiprächtiger et al., 2022). This should be taken into consideration when choosing what IKEA products to sell second-hand.

5.3.1. Improvements in RRs

To maximize RR, IKEA should focus on selling durable items whose life span has room to be extended. IKEA should design the products they produce for reuse by making sure the products are durable and suitable for a life extension. The probability that the second-hand purchase is replacing a new purchase is not as simple for IKEA to influence. That was found to be affected by aspects such as the demographics, purchasing power of individuals, their shopping habits, and their reuse behaviors (Nørup et al., 2019, Thomas, 2003, Thomas, 2011). It has been reported that countries with higher purchasing power had higher RRs. So, to achieve higher RRs, it would be better to implement second-hand trade in countries with higher purchasing power (Nørup et al., 2019). Although, the social benefits of reuse are higher in countries with lower purchasing power.

IKEA could affect shopping habits and reuse behaviors of certain demographics by controlling price of the second-hand items. The RRs have been shown to be related to the second-hand-to-new price ratio (Thomas, 2011). This indicates that if second-hand items were sold at prices closer to the prices of the items new, the RRs would approach 100%. This indicates that IKEA should not price their items too low. Although, if the items are too expensive the social benefits of reuse might be lost (Geyer et al., 2016, Landeta-Manzano et al., 2017). So, finding a good balance is required. The price second-hand is currently driven down because of societal views on reused items. If consumers could be ensured that the quality of their second-hand purchase was high the price could be set higher which could result in higher RRs (Thomas, 2003). IKEA could affect the shopping habits and reuse behaviors of their environmentally conscious consumers by emphasizing the environmental benefits of reuse for example through marketing which could contribute to higher RRs (Skonberg and Thorbecke, 2022). Targeting older consumers could also result in higher RRs (Edbring et al., 2016).

IKEA could use information provided in this thesis report and take actions based on the location of the second-hand trade, its economy, consumers, and the preferred outcome of the actions. It was found to be difficult to know the exact effects of such actions because of the complicated relationship between RRs, demographics, economy, life extension, and such. This has been studied but research is still lacking, especially for furniture items. The RR was a highly important variable when it came to "emission savings" of second-hand trade. All actions taken to improve RR will have significant effects on the environmental benefits of reused furniture. According to the model, for optimal RRs the FLCE can be reduced by 77% by second-hand trade.

5.3.2. Improvements in the second-hand activities

The activities causing emissions in IKEA's second-hand trade were cleaning and repairs, donation transportation, and customer transportation. Measures to minimize those emissions will affect the PCS of second-hand trade. The main improvement suggested for the cleaning and repairs was to reduce the cost of repairs. Although, IKEA employed workers through a societal organization to perform the repairs and was therefore contributing to the society in Eskilstuna. Reducing the cost of repairs might affect those societal benefits. Although, IKEA could reduce costs in other aspects such as the cost of physical resources used to clean and repair their furniture and the societal benefits might be maintained (Haltia, 2022).

The emissions from $T_{donations}$ showed to vary significantly between donation paths because of the different characteristics. To understand what donation path was preferable on a climate perspective the results were normalized both by share of donations per donation path and the total distance traveled. The normalized result showed that donation path T3 had the lowest level of emissions, followed by donation path T1, and donation path T2 had the highest level of emissions. This was caused by the fact that donations paths T1 and T2 involved donations via passenger cars with relatively few furniture donated per trip. Passenger cars caused the highest level of emissions out of the analyzed vehicles and the number of trips was important. The donations T1B and T3 were transported in larger vehicles with more furniture on each trip, or more optimized transportation. IKEA had control over those vehicles and what type of fuel was used. IKEA used the HVO biofuel based on information provided by IKEA representatives (Haltia and Sinclair, 2022a). Although, different methodologies were used to estimate the emissions for T1B and T3 versus T1A and T2. Sinha et al. (2019) EVs were used for T2 and T1A but EVs from Ecoinvent3 were used T1B and T3. This might influence the difference in emissions.

The rescued flowed from Vasterås (T3) are not considered second-hand, but rather items saved in their first life cycle. Although, if the items would not be saved by the ReTuna store they would be recycled or sent to the final disposal. Although, it was not found realistic to increase the share of furniture from T3. Increasing the share of the transportation path T1 was found more realistic for future cases of IKEA's second-hand trade. Therefore, Donation scenario 1 was created where all donations would be by T1 with assumed distances. The distances from home to the drop-off point were analyzed and the results indicated that the distance would have significant effects on the emissions. Emissions for this hypothetical scenario can be as low as 131 tonnes and as high as 1,260 tonnes for donating 1,000,000 items for the home-to-drop-off-points distances from 1 to 10 km and distance from drop-off point to stores from 5 to 25 km. Distance from drop-off point to store had less effects because those are by larger vehicles with less emissions per ton-km.

The donation scenarios resulted in emissions in descending order: Donation scenario 2, Donation scenario 3, Donation scenario 4, Donation scenario 5, Donation scenario 6, and Donation scenario 1. So, Donation scenarios 1 and 6 had the highest potential to reduce emissions or about 48.6% to 48.3% reduction respectively. Donation scenarios 3 to 5 caused emissions reduction from 10.7% to 28.2% whereas donation scenario 5 showed the best performance. Although, it cannot be considered realistic to assume that 75% of donators travel via public transport to donate furniture items. It was additionally questionable to assume that 50% of donators travel via public transport as was assumed for Donation scenario 4 where emissions from donations were found to decrease by 21.4%. Donation scenario 3 was more realistic and might be the actual case for ReTuna since the share of donators per transportation mode was not certain but was assumed to be similar as is in regular stores. Donation scenario 3 caused a 10.7% decrease in emissions from donations. Changing the vehicle used as was done for Donation scenario 2 had minimal effects or only a 2.9% reduction in emissions despite significantly lower emissions per ton-km.

The number of items donated per trip had significant effects as Donation scenario 6 revealed. Although, it was questionable if IKEA could affect the number of items donated per trip. It was not found likely that customers would donate many IKEA items per trip to a drop-off point or ReTuna. Each customer has limited amounts of IKEA furniture and it was unlikely that they have the availability to donate several IKEA furniture at the same time, unless for special circumstances. IKEA could though be aware of the significant effect number of items donated per trip had on the emissions when trying maximize the climate impact "savings" of their second-hand trade. The number of items donated per trip was important to the emissions of the transportation of donations.

Donation scenario 1 was suggested to be the most realistic and most effective measure to reduce emissions of donations. Finding measures to maximize the number of items donated per trip will also be influential but there was doubt that IKEA could control that. It will also be important if donation scenario 1 was implemented, to minimize the distance traveled especially for the transportation segment from the home of the donator to the drop-off point. Using less emission-intensive fuel will have some effects although they will be minimal. If possible, it would be beneficial to influence, or even help, donators to donate via public transport.

For the second-hand customer transport, there was only one transportation mode, T4. The variables that affected the emissions from T4 were identified to be the share of customers per transportation mode, the number of items bought per trip, and the distance for customers to store. The number of items bought per trip had more effects on emissions than the share of customers per transportation mode. It was not found realistic to assume that 100% of the customers of furniture store would travel by public transport although, this might be realistic for some future scenarios of IKEA's second-hand trade. Even though the number of items had more effects on the T4 emissions the share of customers per transportation mode also had significant effects. If 100% of the customers travel by passenger cars the emissions from T4 can range from 3,880 tonnes to 380 tonnes for items purchased per trip ranging from 1 to 10. If 100% of the passengers travel by public transport the emissions from T4 can range from 365 tonnes to 36.5 tonnes depending on items purchased per trip ranging from 1 to 10.

If one item would be purchased per trip the T4 emissions ranged from 1,120 to 11,200 tonnes for 5 to 50 km. If nine items would be purchased per trip the T4 emissions ranged from 124 tonnes to 1,240 tonnes for 5 to 50 km. The distance traveled and the number of items bought per trip showed to have similar effects on the T4 emissions. Although, by going from 1 item purchased per trip to 3 items purchased per trip the emissions, assuming a 15 km travel distance, range from 3,370 to 1,120-tonnes CO_2e. Although, it was not certain that influencing consumers to buy more items per trip would contribute to sustainability. That might rather contribute to overconsumption even though second-hand items are being consumed. This indicates again that circularity and climate mitigation do not always go hand in hand. Some actions to maximize emissions savings might not be beneficial from a circularity perspective. For future cases of IKEA's second-hand trade, it was suggested that the stores should be within a certain distance from most of their consumers and consumers should not be influenced to travel long distances just to consume second-hand items. Inspiring consumers to travel by public transport would reduce the additional emissions of IKEA's second-hand trade.

5.3.3. Scenario analysis

The improved scenarios all resulted in a higher level of PCS, see Figure 23. Scenario 7 performed best, and Scenario 3 performed worst concerning the PCS. Although the changes in the RR_{system} had far more effects on the PCS. So, by improving IKEA's second-hand trade with the suggested scenarios emissions saved by second-hand trade could be increased from 4,200-tonnes CO_2e up to 5,720-tonnes CO_2e for the current estimates of RR_{system}. As seen in Figure 23 the scenarios of improvements in the second-hand trade had effects on the $Savings_{FLCE}$. By improving IKEA’s second-hand trade by the suggested scenario's, $Savings_{FLCE}$ could be increased from 41.6% up to 60.4%. Scenario 7 showed the highest $Savings_{FLCE}$ and Scenario 3 showed the lowest $Savings_{FLCE}$ out of the suggested scenarios. This was also the case for PCS. Although the changes in the RR_{system} had more effects. According to this analysis Scenario 7 was suggested to perform best concerning climate savings. Although the Donation scenario 6 might be difficult to achieve for IKEA. Improvement scenario 2 was found to perform well regarding climate savings and was found to be realistic to implement. That scenario would also allow IKEA to maintain the societal benefits from its repair services. Therefore, Improvement scenario 2 was suggested to be implemented for IKEA's second-hand trade to improve climate performance.

Finding measures to control the RR will also have significant effects as has already been suggested. RR has been reported to be up to 90% for furniture items. By improving both second-hand activities and RRs the emission savings could be improved by up to 80% according to the analysis conducted in this thesis project. To reach about 80% of savings both the second-hand trade emissions and the RR needs to be improved simultaneously. If the savings can be improved up to 80%, second-hand sales would need to be around 20% of sales for IKEA to reduce their value chain emissions by 15% assuming second-hand sales would be the only climate mitigation measure. This indicates reuse's great potential to act as a carbon sink to contribute to the decarbonization of companies.

5.4. Relating to the results of similar studies

Wiprächtiger et al. (2022) performed a study on the environmental impact comparison of waste prevention strategies, such as reuse. The study was found highly relevant to compare to the results of this project. The study concluded that the reuse of products was not necessarily an environmentally favorable strategy. For clothing, consumer behavior leads to increased consumption of clothes overall. Furniture was found to have higher replacement potential than clothing. Although, for furniture rebound effects were found to be a major negative drawback and could reverse the results. The study concluded, similarly to this study, that transports were highly important regarding the environmental effects of circularity solutions for furniture. Reusing furniture showed good potential in reducing the environmental effects of furniture. Take back schemes of furniture showed to reduce impacts by 70%. (Wiprächtiger et al., 2022). A study conducted by the Swedish Society for Nature Conservation concluded that by choosing to buy second-hand furniture instead of new the climate impact can be decreased by 85-92%. That was significantly higher than was estimated in this study. The reason was mainly that in the study of the Swedish Society for Nature Conservation social influence such as RRs were not considered nor was the donation transportation. Their method was built on LCA and a comparison of the embodied waste versus product total waste to indicate the resource consumption of the product (Lexén et al., 2021).

Farrant et al. (2010) concluded that reusing clothing decreased the global warming potential by about 14%. Sandin et al. (2019) estimated that if clothing lifespan was twice as long the climate impact decreased by 49%. Repair cafés showed to reduce GHG emissions by 88% (Privett, 2018). Global warming potential was reduced by about 45-72% by prolonging the lifetime of passive durable products such as furniture (Kaddoura et al., 2019). So, reusing has shown various performances in decarbonizing, and it seems to be highly dependent on the specific case and the location of the analysis. The results of this study seem to be within ranges previously estimated by studies addressing similar issues. The results of this study seem to be in the lower ranges of what has been assessed for passive durable products such as furniture. This might be because reuse enterprises, such as IKEA have been known for yielding the highest level of climate impact out of reuse platforms (Fortuna and Diyamandoglu, 2017). It could also indicate that the results of this study overestimate the impact of IKEA's second-hand trade or the effects of the RRs. Castellani et al. (2015) concluded that for a second-hand store, selling clothing and furniture, the GHG emissions saved were about 160 tonnes CO_2e a year. By inputting the same number of items into the LCA Excel model as they used, the GHG saved would be around 130 tonnes

CO_2e a year. Indicating again that possibly the additional emissions were slightly over accounted for in the LCA Excel model.

5.5. Limitations and future work

As has been discussed in this section the results are highly dependent on the assumption that second-hand purchases replace purchases of new items to some extent. This is not the case for all second-hand sales, some second-hand sales are additional purchases resulting in emissions emitted and no emissions saved. Also, assuming the items to be saved from final disposal is not exactly scientifically sound. Second-hand items will, in the end, end up in final disposal so it is not right to consider the final disposal emissions to be avoided altogether. The second-hand items will eventually end up in final disposal or at least recycling. Although, since previous studies on the climate benefits of reuse did consider the final disposal emissions to be avoided such was assumed for this thesis project. Comparing recycling, incineration, landfilling, and reuses performance from a climate perspective would be interesting to analyze in future studies. Several studies have addressed the issue, but improved understanding is still required especially for furniture. A recent study by Wiprächtiger et al. (2022) addressed this issue. Addressing the number of potential reuse cycles furniture has would additionally be interesting to analyze.

The estimated FLCE was a highly uncertain variable since 208 furniture item categories were matched with 26 EV of consumption items, this could easily be improved even using the Excel model constructed for this project. This study was highly dependent on assumptions made for the data that was not available. This study would benefit from being improved with more sound assumptions as has been mentioned throughout this section. As introduced in the background section of this report it was not scientifically sound to talk about emission savings, but it was possible to compare emissions avoided and additional emissions. Because of the scope of this project and the intended audience a decision was made to define the difference between the two as "climate savings". As mentioned, the study did not analyze numerically the effects from rebound effects which have though been found to highly affect the environmental impacts of second-hand furniture. The effects of rebound effects have been analyzed in previous studies.

There is currently a huge scientific gap in understanding RRs and further research is required. Science also needs to further understand the LEP of furniture products (Privett, 2018). Although, IKEA is currently researching the LEP of their products and it will be interesting to relate that to the results of this project (Haltia and Sinclair, 2022a).

6. Conclusion

An LCA Excel model was built to estimate the climate savings of selling second-hand furniture. The characteristics of IKEA's second-hand store in ReTuna were used as a representative case for second-hand trade. The results showed that for the current state of the store the estimated climate "savings" was around 41% to 46% compared to the full life cycle emissions or emissions avoided. This was caused by avoiding the production of new items and avoiding the end-of-life impacts by reusing the items instead of discarding them to final disposal. For the analyzed case of second-hand trade emissions are most likely saved. Reuse is ranked high in the WMH because it promotes resource efficiency and minimize waste generation and it also contributes to climate mitigation.

If second-hand trade would be the only climate mitigation measure of IKEA, the share of second-hand sales would need to be around 37.8% for IKEA to reach its goal of a 15% decrease in its value chain emissions. The results indicated that reuse could significantly contribute to climate commitments of companies, although it cannot be the only mitigation measure to reach carbon neutrality.

The transports of customers and donations were the most emission-heavy life stages of second-hand trade for the analyzed case. Although, the replacement rates had the most effect on the climate impact savings of second-hand trade. Finding measures to maximize replacement rates will have significant effects on reuse's potential to decarbonize companies. Scenarios of improvements in the second-hand trade were analyzed. When suggesting improvements, it was also important to consider what was found realistic to implement for the case of IKEA. The conclusion was that Improvement scenario 2 was suggested. Improvement scenario 2 involved donations by drop-off points within a 3 km distance from households where a certain amount of furniture is picked up by IKEA's freight vehicles that used HVO fuel and driven to IKEA second-hand. The drop-off points were on average within 15 km distance from IKEA second-hand. The cost of repairs was kept such as the current state so the societal benefits were not lost. The stores were within a 5 km distance from customers and customers purchased five items per trip. It was found to be beneficial if consumers were encouraged/helped to travel by public transport. Although, precautions are highlighted that influencing customers to buy more might not contribute to more sustainable consumption. If improvements would be made both in the second-hand activities and replacement rates the climate savings could be up to 80% and the required share of second-hand sales would need to be 20% for IKEA to reach its goal of a 15% decrease in value chain emissions.

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Appendices

Appendix A: Emission values

The EVs used for IKEA's products and how and why EVs were matched with specific PA is explained in this Appendix.

6.1.1. Appendix A1: Emission values for IKEA's products

The following section will present EVs used for IKEA's 208 furniture item categories that were archived from Carlsson-Kanyama et al. (2019). Further information on the data, the item analyzed by the Mistra foundation, and its material composition is described in further detail in the *Emission values* tab in the LCA Excel model. The EVs are displayed in Table 14.

Table 14: Emission value data used for assessing the potential avoided emissions (retrieved from Carlsson-Kanyama et al. (2019))

Category	EV [kg CO2e/kg item]
Furnishings	
Sofas	1.38
Chairs	2.27
Beds	3.69
Wardrobes, chest of drawers, and bookcases	0.286
Garden furniture	7.47
Pots, vases	2.19
Carpets and rugs	14.5
Sheets and pillowcases	6.61
Blankets, pillows, and bedspreads	18.7
Dishwashers	3.62
Clothes and washing machines	4.06
Panels, hobs, spit roasters, ovens, combined cookers, and microwave ovens	3.27
Vacuum cleaners	7.06
Cups and mugs	2.41
Bowl	2.97
Kitchen utensils and articles	3.31
Glassware, tableware, cutlery, and household utensils	13.8
Major tools and equipment	2.61
Small tools and miscellaneous accessories	3.50
Other non-durable small household articles	5.99
Recreation, sport, and culture	
Toys and hobby items	32.0
Travel goods	22.0
Products for pet	16.1
Information and processing equipment	77.3
Equipment for the recreation, recording, and reproduction of sound	7.83

How these EVs were matched with the 208 PAs is explained in detail in the next section.

6.1.2. Appendix A2: Furniture item categories and assumptions made for emission values

A brief description of the 208 furniture item categories (PAs) and the assumptions made to match EVs from the Mistra reports can be found in the attached pdf document *Appendix A-Furniture item categories and assumptions for EVs* (IKEA of Sweden, 2022a).

Appendix B: Sensitivity analysis

6.1.3. Appendix B1: Vehicles used for donation transport

The vehicles used for donation transport was not certain so, a sensitivity analysis was conducted. Based on the number of furniture transported each trip, assumptions were made on the kind of vehicles that might be used for those transports. The number of furniture transported on each trip was discussed with IKEA (Haltia and Sinclair, 2022a). Data was exported for commercial vehicles, medium freight vehicles weighing 3.5-7.5 tons, and freight vehicles weighing 16-32 tons. The exact transportation data exported from Ecoinvent3 are listed in the following list. As mentioned, the emissions were adapted so that emissions from fuels were decreased by 90% (Wernet et al., 2016, Nilsson, 2022). More detail about the exact values are found in Table 16.

- **Commercial vehicles:** Transport, freight, light commercial vehicle Europe without Switzerland | processing | cut-off, U
- **Medium freight:** Transport, freight, lorry 3.5-7.5 metric ton, euro3 RER| market for transport, freight, lorry 3.5-7.5 metric ton, EURO3 | Cut-off, U
- **Heavy freight:** Transport, freight, lorry, 16-32 metric ton, EURO3 RER| transport, freight, lorry 16-32 metric ton, EURO3 | Cut-off, U
- **Train freight:** Transport, freight train (Europe without Switzerland)| diesel | Cut-off, U

Table 15: Emission values of different vehicles for donation transportation emissions.

Variable	Source (Wernet et al., 2016)	Emissions [kg CO_2e/ton-km]
$EV_{commercial.diesel}$	Ecoinvent3	1.90
$EV_{commercial.HVO}$	Adapted from Ecoinvent3	1.63
$EV_{freightmedium.diesel}$	Ecoinvent3	0.509
$EV_{freightmedium.HVO}$	Adapted from Ecoinvent3	0.457
$EV_{freightheavy.diesel}$	Ecoinvent3	0.164
$EV_{freightheavy.HVO}$	Adapted from Ecoinvent3	0.147
$EV_{freighttrain}$	Ecoinvent3	0.566

6.1.4. Appendix B2: Customer transport (T0) and repair emissions

A sensitivity analysis was performed on the emissions from transportation of customers of conventional IKEA stores since data was not available and variables had to be assumed. The results of that sensitivity analysis are presented in Figure 25.

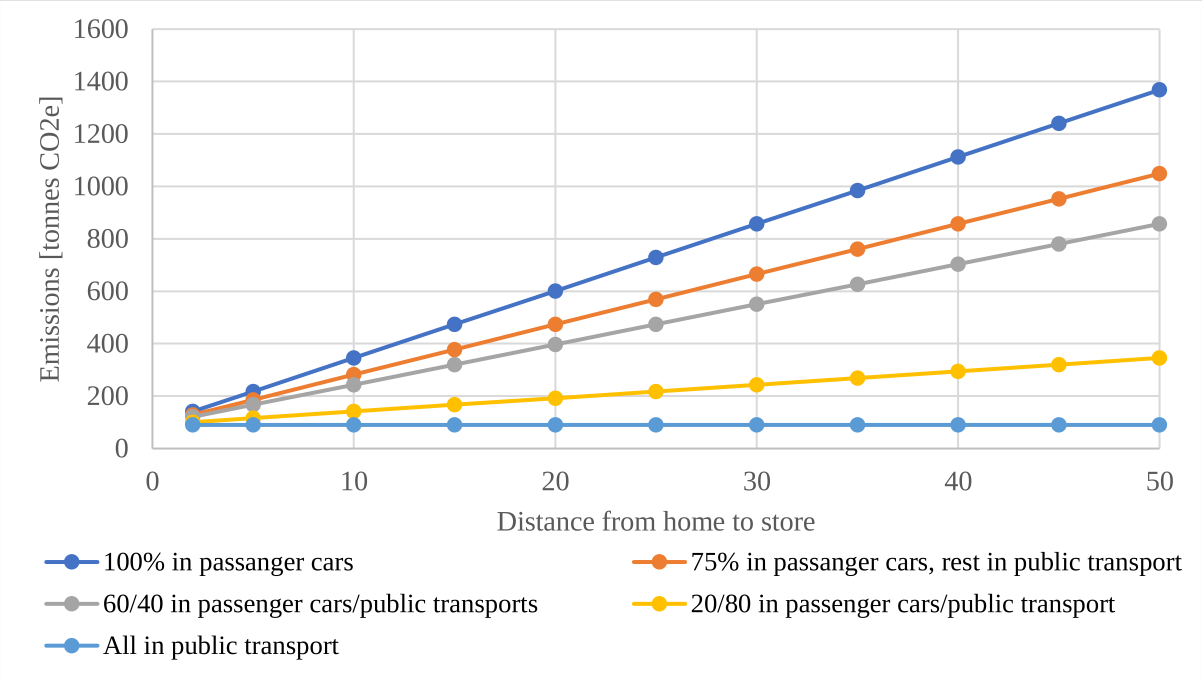

Figure 25: Sensitivity analysis for the emissions from the customer of conventional store transportation.

A sensitivity analysis was performed on the emissions from cleaning and repair conducted in ReTuna since monetary EV was used which can be uncertain. The results of that sensitivity analysis are presented in Figure 26. Since the cost and weight was considered sensitive data their values are not displayed in Figure 26.

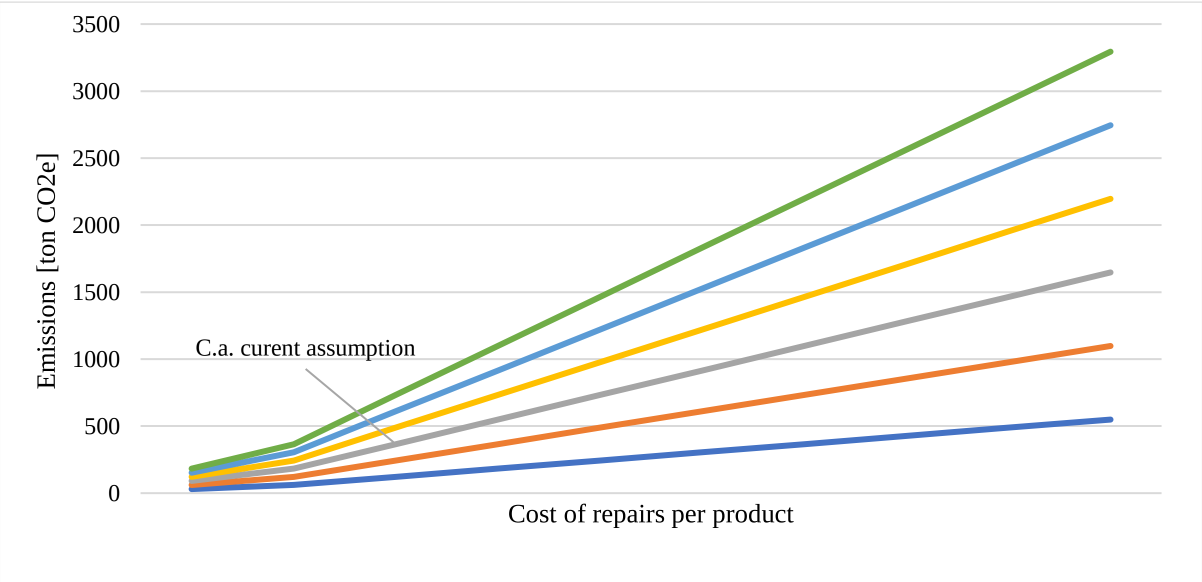

Figure 26: Sensitivity analysis on emissions from cleaning and repair based on different average weight of items and cost of repairs per product.

As seen in Figure 26 the sensitivity analysis revealed that the emissions varied from 91.5 to 1,650-tonnes CO_2e for the current average weight of items and cost of repairs per product increasing. The emission varied from 122-tonnes to 732-tonnes CO_2e for the current state of cost per repair and average weight per item increasing.

TRITA-ABE-MBT 22431