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Sharing services and environmental impacts: An assessment of selected services in the Hammarby Sjöstad region of Stockholm

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Summary

As the unsustainable consumption of goods and services continues to increase globally, collaborative consumption, sharing services and the sharing economy have been identified and promoted as an important step in transforming current business models toward more sustainable practices. However, the environmental implications of sharing services are not always transparent and are often assumed to create large environmental benefits.

This study aims to review the environmental performance, and potential, of different sharing services available in the Hammarby Sjöstad area of Stockholm. These include 1) the sharing platform provided by Hygglo.se, 2) package drop-off and pick-up services offered by QLocx and 3) sharing of cargo bikes. Life cycle assessment (LCA) is used to identify the impacts and benefits of the sharing services, taking into account both current and future consumption patterns, product lifetime and use, potential replacements of conventional products and services, impacts from digital infrastructure and the implications these may have. Furthermore, the study outlines an approach to identify methodological considerations for assessing these systems using LCA and addressing the sensitivity of these choices.

The results suggest that there is a significant potential for the sharing services reviewed to reduce environmental impacts. The Hygglo.se platform in particular offers large potential to reduce production impacts for new product purchases and reduce impacts even further if product purchases are avoided through the availability of the sharing service. The QLocx system can significantly reduce impacts from logistics services and transportation by reducing delivery attempts and providing increased availability for delivery and pick-up services. Finally, by replacing conventional modes of transportation, for e.g. shopping trips, the cargo bike sharing similarly can reduce impacts significantly, offering a low-carbon transportation method. The results also examine potential synergies of the services, i.e. combining QLocx services for product sharing through Hygglo.se. As such the impacts from the sharing products are further reduced. However, and as the discussion outlines, the results are dependent upon a number of assumptions and are sensitive to choices made, e.g. to transportation methods and the number of uses. The study thus outlines many of the potentially sensitive methodological choices and outlines improvements for reviewing the impacts of sharing services in the future.

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1 Introduction

As the unsustainable consumption of goods and services continues to increase globally, collaborative consumption, sharing services and the sharing economy have been identified and promoted as an important step in transforming current business models toward more sustainable practices (Zamani et al, 2017; Belk, 2014; Norden, 2017; Piscicelli et al, 2014). In recent years sharing services are becoming increasingly available to the public, through a number of initiatives, e.g., sharing services, boards, physical events, etc.); with cities being important grounds for testing and realizing the potential (Cohen and Munoz, 2015). With these services often being promoted as more environmentally friend option to traditional consumption methods, it is becoming ever more important to review the implications of sharing services. However, the environmental implications of sharing services are not always transparent and are often assumed to create large environmental benefits. Despite this, there is a limited availability of studies reviewing the environmental potential of sharing systems (Zamani et al, 2017).

This study aims to review the environmental performance, and potential, of different sharing services available in the Hammarby Sjöstad area of Stockholm. Life cycle assessment (LCA) is used to identify the impacts and benefits of the sharing services, taking into account both current and future consumption patterns, product lifetime and use, potential replacements of conventional products and services, and the implications these may have. Therefore, an assessment approach is outlined for reviewing the environmental performance of sharing services. Furthermore, the study also aims to identify methodological considerations for assessing these systems and addressing the sensitivity of these choices.

2 Methodology

In order to capture environmental impacts and benefits of sharing services, the method life cycle assessment (LCA) was employed. Three sharing services were analyzed: 1) Hygglo, 2) Qlocx and 3) cargo-bike sharing in residential buildings; see short descriptions of the services in the subsequent text before reviewing more specific methodology applied in each service. Data for current consumption patterns and future scenarios have been developed in collaboration with IVL, KTH, ElectricityStockholm and Evothings Labs. The data is used to create a baseline and scenarios for comparisons. These have then been used to review the potential of the three sharing services. The data and insights are supplemented by estimates, assumptions and information from a broader literature for reviewing environmental performance of shared resources (e.g. industrial symbiosis) and sharing economy services (such as product services systems (PSS)).

Sharing services may take on a number of different forms to allow for the sharing of products and services between businesses, users, providers, etc. Figure 1provides a review of different forms of sharing services and the flow of materials/products before they reach the end-of-life (EOL) phase. The traditional (or baseline) approach is a linear system where a user purchases a product and discards it once it has reached the EOL. Sharing of products may also be possible through collaborative models, where persons can share products amongst one another, in so-called person to person or peer to peer (P2P) forms. This can be done informally or facilitated by digital platforms (e.g. Hygglo.se). Other typical methods include, e.g. sharing libraries, where products purchased by a business and are rented by users in business to consumer (B2C) or business to business (B2B) approaches. For a more thorough description of different forms, definitions, reviews (and controversies) related to different sharing services, platforms and approaches in, e.g. (Acquier et al., 2017; Frenken and Schor, 2017; Munoz and Cohen, 2017). In the context of this report, the entity owning or sharing/lending the product is hereafter referred to as the "provider" and the entity renting/borrowing the product is referred to as the "user" of the product/service.

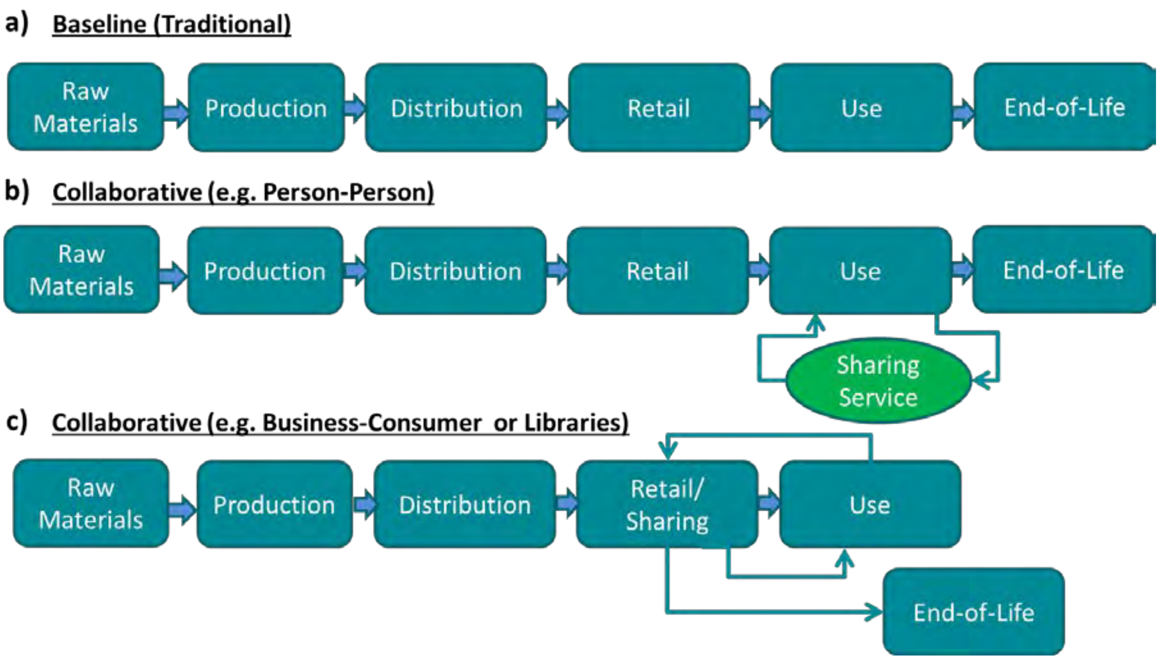

Figure 1: Different forms of sharing/collaborative consumption compared to a baseline. These are represented by a) a traditional consumption model, b) collaborative consumption where products are shared between a provider and user, and c) sharing through e.g. sharing libraries.

2.1 Reviewing Environmental Impacts

2.1.1 Overarching Methodology

The first step of the assessment was to identify the methodological considerations that must be outlined in order to transparently, and thoroughly, assess the environmental performance of the sharing service(s). The impacts of the sharing services, were conducted from a cradle-to-gate perspective. Figure 2 depicts the impacts for a product being shared from cradle-to-grave. However, in this study the end-of-life phase is not accounted for, as the products are assumed to still be in use after the period of assessment, i.e. one year. In each subsection below, further details about the assumptions and methods used for the assessment are outlined; the complexity of which varies for the different sharing services.

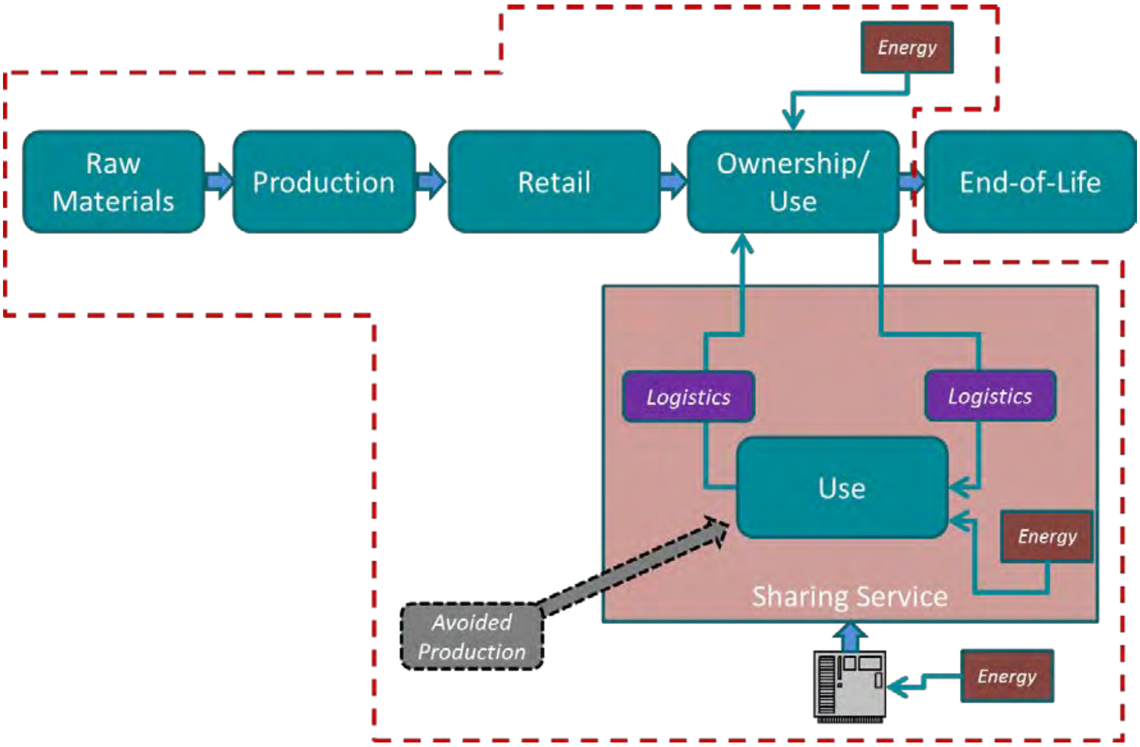

Figure 2: Review of impacts associated with sharing services reviewed in this study. The dashed line represents the system boundaries of the LCA.

The impacts associated with the sharing of the products can be associated with different phases of the life cycle, from the extraction of raw materials to use of the product and final disposal. The impacts for the product/service include the raw materials and production impacts. Thereafter, the product is made available directly or through retail operations to the owner. Throughout this process, there are energy and transportation impacts which must be accounted for (not depicted in Figure 3). Unlike the linear consumption and use of products, sharing alters[1] the use phase of the product by making the product available to be used by multiple users[2]. In Figure 1 this is depicted as "loops" between the use and retail phases, and can include a sharing service platform. A more

[1] In this context, the term "alter" was used as the overall lifetime of the product may be reduced, but the service life of the product may increase.

[2] In Product Service System approaches, the production may also be altered for extending the life of the product, and include increased maintenance; however, this is not reviewed in the context of this report.

thorough review of the sharing service platform is further illustrated in Figure 2, which requires additional infrastructure, logistics, etc.

For this report, the impacts from sharing services can be outlined using a general approach; which is elaborated further in each section. Equation 1 below outlines the overall impact of the sharing service (I_S), taking into account the impacts from the production of the product (I_P) and retail (I_R), the use of the product,(I_U) the sharing infrastructure (I_{SI}) and the credits for potential replacement of products (I_{RP}).

$$\textit{Equation 1:} \quad I_S = I_P + I_R + I_U + I_L + I_{SI} - I_{RP}$$

The impact from the products (I_P) includes the impact of the raw materials, production process and all associated energy and transportation needed to produce the final product for retail. Retail impacts (I_R) can also be accounted for and can include all transportation of the products to the point of sale. The impacts from the use of the product (I_U) varies between the different products and sharing services assessed; which can include inputs of e.g. energy and other materials (e.g. for skis, it was assumed that wax was needed). Only the impacts for the use of the product by the user of the shared product were reviewed; no impacts from the use of the product by the provider are included as they are outside the scope of this study. Impacts from the logistics (I_L) include the transportation of the product from the provider to the user, and back again. This is conducted by reviewing the transportation distance, mode of transport, and impacts per distance. Impacts from the sharing infrastructure (I_{SI}) include e.g. the impacts from the digital sharing platform (webpage, data traffic, use of mobile phone or computer to search and rent/lend the product(s) and data storage) or any traditional infrastructure needed for sharing (e.g. small garages and locking mechanisms needed). Finally, as sharing a product has the potential to replace the purchase of conventional products, impacts from the replaced products (I_{RP}) can also be included where relevant.

2.1.2 Life Cycle Inventory Data for Products and Other Processes

In all cases, life cycle inventory (LCI) data was developed within the study or taken from LCI databases. A major limitation of LCA studies such as this, encompassing a wide array of products, processes and systems is that data may not be available in commercial databases. However, when available, datasets from the LCI database Ecoinvent v 3.3 were employed. Data for several of the products were also available in Environmental Product Declarations (EPD).

When datasets were not available, impacts were estimated using insights from previous work; see Blocket (2014). Using this method, material composition for the products are reviewed and impacts associated with these materials, along with a production factor, are included to provide a screening of the associated impacts with that product; see, e.g. Table 1 for an example. In order to gauge the soundness of these values, data for similar products or systems were used for comparison; see Appendix for a listing of the impacts used for products reviewed in this study.

Table 1: Example of the ad-hoc LCA calculations for products

Material	Amount (kg)	Impact (kg CO_2-eq/ kg material)	Result (kg CO_2-eq)
Plastic (Unspecified)	2	2.9	5.8
Steel (Stainless)	0.5	4.6	2.3
Polyethylene	1	4.5	4.5
Production Factor	(1.3)		(12.6*1.3)
	Impact for Product		*16.4 kg CO_2-eq/pc*

The life cycle impact assessment method (CML baseline v 4.4) was used to generate impacts for the different services based on the LCI data used. The methods used were modified for the different sharing services, as e.g. Hygglo is a P2P facilitated sharing service, while the cargo bike sharing is classified as a sharing library example, in order to model their benefits compared to a baseline; see e.g. Figure 1.

2.1.3 General Scope and Limitations

This study is limited to greenhouse gas (GHG) emissions, expressed in CO_2-eq emissions[3]. The functional unit used to compare baseline or conventional products and services with the products available through sharing services varied for the different studies; these are outlined in the subsequent sections. However, the results are compared for annual use of the different sharing services and the potential impacts for different assumptions during the annual use in the Hammarby Sjöstad area. The following subsections provide a brief review of the sharing service and the methodology used to assess the potential environmental impacts and benefits.

[3] The project scope only included GHG emissions. Thus it is not a full LCA as it does not include other impact categories.

2.2 Hygglo

Hygglo (www.hygglo.se) provides sharing services for users to both share and rent products. The service aims to allow for private individuals to share products that are not used on a regular daily basis for a defined period agreed between the provider and the user; see an example in Figure 3. This type of service can be defined as a peer-to-peer sharing method, facilitated by Hygglo. Hygglo provides a large number of products, over 7000 listings annually (and growing) (Hygglo, 2017).

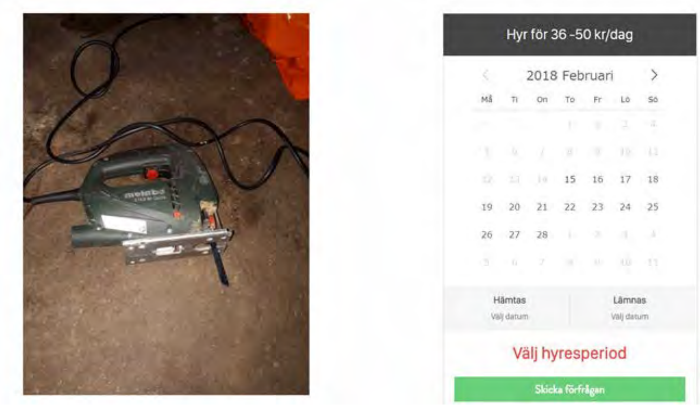

Figure 3: Screenshot from Hygglo.se (example for a jigsaw)

In order to review the potential environmental implications of this service fir he Hammary Sjöstad area, scenarios were created to review common products currently shared with a baseline where no products are shared.

2.2.1 Sharing Scenario

Information on the most popular products, searches and products shared to Hammarby Sjöstad residents was provided by Hygglo. Based on the data provided, an extrapolation to a *yearly rental* was made in order to understand the potential of sharing during a longer period; i.e. compared to one month. Table 2 provides a review of the type of products reviewed in this assessment and number of annual rentals. Thereafter, to review the impact of the production of the products being shared, it was assumed that the each product would be shared roughly three times. Thus, the number of products available is lower than the number of rentals; see also the assumption for the Reference scenario. Furthermore, in order to review the impacts of the sharing service Hygglo, details about e.g. the transportation of the products between the provider and user, the extent of the use of products and potential for the replacement of conventional products were also reviewed; see the subsequent text.

Table 2: Assumed annual rentals

Product/Service	Rentals	Number of Listings/Products
Skis (Adult)	132	44
Skis (Children)	132	44
Electric Tool (w/o battery), e.g. table saw	72	24
Electric Tool (w/o battery), e.g. circle saw, drill	12	4
Electric Tool (w/battery), e.g drill	12	4
Van	10	3
Car (Combi)	24	8
Car (Compact)	10	3
Video Game Unit	12	4
Bicycle	48	16
Cargo Bike	12	4
Cooking Equipment	24	8

Transportation for Shared Products/Services

The products rented from other individuals via Hygglo are assumed to be transported (shared) within a short distance from the owner to the renter. For all scenarios, this was assumed to have a maximum distance of roughly 10 km based on a review of available products in the region in January 2018, and assumed to be used in Hammarby Sjöstad. Two different assumptions were included here to review the sensitivity of the choice of transportation method; see Table 3. This includes sensitivity to the choice of "high-impact" transportation and "low-impact" transportation. High impact transportation included transportation of the products shared with a total distance traveled of 10 km by car (70%) and by bus (30%). Low impact transportation was assumed to take place by bus (70%) and by walking/biking (30%).

Table 3: Transportation of shared products for high and low transport assumptions

	High Impact Transport				Low Impact Transport			
Replaced Product/Serv	**Mode**	**km**	**Mode**	**km**	**Mode**	**km**	**Mode**	**km**
Skis (Adult)	Car	7	Bus	3	Bus	6	Bike/walk	4
Skis (Children)	Car	7	Bus	3	Bus	6	Bike/walk	4
Electric Tool (w/o battery), e.g. table saw	Car	7	Bus	3	Bus	6	Bike/walk	4
Electric Tool (w/o battery), e.g. circle saw, drill	Car	7	Bus	3	Bus	6	Bike/walk	4
Electric Tool (w/battery), drill	Car	7	Bus	3	Bus	6	Bike/walk	4
Van	Car	7	Bus	3	Bus	6	Bike/walk	4
Car (Combi)	Car	7	Bus	3	Bus	6	Bike/walk	4
Car (Compact)	Car	7	Bus	3	Bus	6	Bike/walk	4
Video Game Unit	Car	7	Bus	3	Bus	6	Bike/walk	4
Bicycle	Car	7	Bus	3	Bus	6	Bike/walk	4
Cargo Bike	Car	7	Bus	3	Bus	6	Bike/walk	4
Cooking Equipment	Car	7	Bus	3	Bus	6	Bike/walk	4

Use of the Product/Service

The use of the product, both by the provider and user was also reviewed, as the different products have different characteristic uses, seasons, etc. Furthermore, as the different products have associated impacts with their use (e.g. electricity use, exhaust emissions, etc.) the time used and distance traveled were also reviewed; see Table 4. The assumptions are provided in high and low use values in order to review the sensitivity[4]. Only the use of the products in Hammarby Sjöstad was reviewed in order to compare with the reference scenario; which assumes all products are owned and used in Hammarby Sjöstad. It was assumed that 40% of the products and only 20% of the vehicles (e.g. cars and vans) were available in Hammarby Sjöstad (again see e.g. data for current vehicle ownership in Foletta and Henderson (2016)). Thus only this share of impacts from the use by providers was allocated to the total impacts from the use phase in Hammarby Sjöstad; the sensitivity of this assumption is also tested in the analysis.

Table 4: Review of the number of uses (high and low assumptions) and respective details for different products shared.

	Provider	Shared Number of uses (High)			Shared Number of uses (Low)		
Replaced Product/Serv	Provider (Uses)*	User (Uses)	Per Use	Unit	User (Uses)	Per Use	Unit
Skis (Adult)	1	5	-	-	2	-	-
Skis (Children)	1	5	-	-	2	-	-
Electric Tool (w/o battery), e.g. table saw	8	5	20	min	20	20	min
Electric Tool (w/o battery), e.g. circle saw, drill	8	5	20	min	20	20	min
Electric Tool (w/battery), drill	8	5	20	min	20	20	min
Van	20	5	5	km	100	5	km
Car (Combi)	40	5	5	km	200	5	km
Car (Compact)	40	5	5	km	200	5	km
Video Game Unit	40	5	60	min	100	60	min
Bicycle	120	5	20	km	300	20	km
Cargo Bike	120	5	20	km	300	20	km
Cooking Equipment	60	5	-	-	150	-	-

*Once again this is only 40% of the provider uses

Platform and Infrastructure for Sharing

As the sharing services takes place through an internet-based platform, the impact of the platform, e.g. data and energy use for searchers, databases, servers, etc. were also modeled in the review. Table 5 reviews the number of assumed advertisements/listings reviewed by users and providers to find and share products and service; with an assumption of roughly triple the number of searches per advertisement/listing. This entails that a potential user reviews (i.e. searches for) at least 3 products of the same type before facilitating the sharing service. Furthermore, it was assumed that products were shared several times, and thus the number of listings on Hygglo, were assumed to be roughly half the number of shared products reviewed in this assessment. In order to review the impact of the sharing service platforms, electricity demand per data storage and search engine use were developed based on details provided in Malmodin et al. (2014), Costenaro and Duer (2013), Google (2009; 2014) and Apple (2016); see Appendix.

[4] Use figures for the different products were obtained through an internal questionnaire at IVL

Table 5: Number of listings and searches due to sharing platform

Product/Service	Number of Listings/Products	Number of Searches
Skis (Adult)	44	132
Skis (Children)	44	132
Electric Tool (w/o battery), e.g. table saw	24	72
Electric Tool (w/o battery), e.g. circle saw, drill	4	12
Electric Tool (w/battery), drill	4	12
Van	3	10
Car (Combi)	8	24
Car (Compact)	3	10
Video Game Unit	4	12
Bicycle	16	48
Cargo Bike	4	12
Cooking Equipment	8	24

Potential for Replaced Products

As a consequence of the sharing platform, it was assumed that conventional products may be replaced. This entails that by providers sharing a product, the users of that product would potentially avoid purchasing that same product. For many products there could be large potential to avoid purchasing a new product. In the case for vehicles, it was assumed that this was less likely. However, for most products, roughly half of the products shared were assumed to avoid purchases of new products. To review the sensitivity, both high and low estimates of replacement were reviewed in this study; see Table 6.

Table 6: Review of the number of assumed replaced products due to sharing (high and low assumptions)

	High		Low	
Replaced Product/Serv	Replace (%)	Replaced Prods.	Replace (%)	Replaced Prods.
Skis (Adult)	50%	66	25%	33
Skis (Children)	50%	66	25%	33
Electric Tool (w/o battery), e.g. table saw	50%	36	25%	18
Electric Tool (w/o battery), e.g. circle saw, drill	50%	6	25%	3
Electric Tool (w/battery), drill	50%	6	25%	3
Van	1%	1	1%	1
Car (Combi)	11%	3	5%	1
Car (Compact)	11%	1	5%	1
Video Game Unit	50%	6	25%	3
Bicycle	50%	24	25%	12
Cargo Bike	50%	6	25%	3
Cooking Equipment	50%	12	25%	6

Lifetime of the Shared Products/Services

In order to determine, and allocate emissions to the product for the annual use in the Hammarby Sjöstad area, the product lifetime was used. The lifetime of the products was assumed to be the same in the high and low scenarios; see Table 7.

Table 7: Lifetime of products

Replaced Product/Serv	Lifetime (Years)
Skis (Adult)	5
Skis (Children)	5
Electric Tool (w/o battery), e.g. table saw	5
Electric Tool (w/o battery), e.g. circle saw, drill	5
Electric Tool (w/battery), drill	5
Van	15
Car (Combi)	15
Car (Compact)	15
Video Game Unit	5
Bicycle	15
Cargo Bike	15
Cooking Equipment	4

2.2.1.1 Review of "High" and "Low" Scenarios

The preceding sections outline the figures which are applied in the corresponding, high and low scenarios. Table 8 provides a qualitative review of the overall differences between the scenarios for further interpretation.

Table 8: Reviewing the qualitative differences between Sharing-High and Sharing-Low Scenarios

Scenario	Production	Use	Lifetime	Transport	Digital Infrastructure	Replaced Products
Sharing-High	Same	High	Same	High Impact	Same	High
Sharing-Low	Same	Low	Same	Low Impact	Same	Low

2.2.2 Baseline Scenario

Assuming that no sharing service was available, a baseline (or reference) scenario was also developed to show the potential benefits of ownership versus sharing. In the scenario, it is assumed that all products would be purchased and used by residents in the Hammarby Sjöstad area, with varying degrees of use during one year.[5] The assumptions used for the use of the productions in the reference scenario are outlined in Table 9.

Table 9: Review of the baseline scenario

Product/Service	Per use	Unit	Number of Uses
Skis (Adult)	3	days	2
Skis (Children)	3	days	2
Electric Tool (w/o battery), e.g. table saw	20	min	20
Electric Tool (w/o battery), e.g. circle saw, drill	29	min	20
Electric Tool (w/battery), drill	20	min	20
Van	5	km	100
Car (Combi)	5	km	200
Car (Compact)	5	km	200
Video Game Unit	60	min	100
Bicycle	10	km	300
Cargo Bike	10	km	300
Cooking Equipment			150

[5] As in the sharing scenarios, extent of the use, were based on input from an internal questionnaire with selected individuals at IVL.

2.3 Cargo Bike Sharing

The use of cargo bikes (a.k.a. freight bicycles, carrier cycles, freight tricycles, box bikes, etc.) have increased in popularity in recent years in urban areas for sustainable-minded mobility as an alternative to transportation by car, and even traditional freight(Riggs, 2015, 2016; Schliwa et al., 2015). They can be classified as a more robust bicycle, with an open (or enclosed) platform/box, mounted to the frame, typically with 2 or 3 wheels. They are able to carry larger loads, and volumes, compared to a traditional bicycle; see Figure 4.

In the future, it is hoped that a cargo-bike sharing pool can be realized in the Hammarby Sjöstad area in order to improve the use and availability of this transportation method. This study, therefore, reviews the use of a cargo bike sharing pool[6] at apartment buildings in the Hammarby Sjöstad area to assess the potential environmental benefits in comparison to traditional forms of transportation. The scope is limited to reviewing the use of cargo bikes for shopping trips to and from a nearby shopping area, namely Sickla.

Figure 4: Example of cargo bike reviewed in the study

In order to assess the potential of a larger sharing service for cargo bikes, and consequences for transportation emissions, scenarios were created to compare with current transportation systems, i.e., a baseline (by car, bike, bus and walking). These included a fleet of cargo bikes and electric cargo bikes, as the latter is becoming a popular choice.

General Assumptions

As the assessment reviews the potential for cargo bikes, it was assumed that all transport to the shopping area of Sickla is conducted by cargo bike with a load of 20 kg. It was assumed that roughly 45 trips to-from Hammarby Sjöstad to Sickla were performed per household for shopping (e.g. food and other products) with a round trip of 5 km assumed for all scenarios. Thus, the functional unit was set to the yearly trips to purchase food and other products in order to compare transportation options. In order to assess the number of cargo bikes, statistics on the number of households, population, etc. were taken from Stockholm (2016). It was assumed that there are roughly 30 households per apartment building. Thereafter, both a high and low number of bikes were assumed to be made available per building; 131 and 65 respectively.

[6] This form of sharing service can be classified as a sharing/collaborative library; see Figure 1.

Table 10: Assumptions for number of households and trips made by cargo bike in Hammarby Sjöstad

Apartments	7 856
Population	17 619
Persons per Apartment	2.2
Households per Building	22
Distance per trip (km)	5
Number of Trips per Year	45
Individual Trips	212 112
Number of Households	262

Impacts from the production of new cargo bikes were developed based on the method from the Blocket (2014) calculations for products, as no data was available for cargo bike production emissions. As such, a cargo bike was assumed to have an impact of 275 kg CO_2-eq per bike. For this assessment, it was assumed that a cargo bike has a lifetime of roughly 20 years. Furthermore, in order to review the impacts per electric cargo-bike, an additional impact of roughly 66 kg CO_2-eq/bike was included to cover the increased resource consumption for batteries and electric motors. The electric bikes also included impacts for electricity consumption for charging the 13 Ah batteries at 36 V, and having a range of 30 km per charge.

It was assumed that the bikes are locked and unlocked using no digital infrastructure, thus no impacts were allocated to the ICT infrastructure used to share/rent the bikes at the different households. However, as cargo bikes will require availability and storage, impacts for the construction of a garage to house the bikes is included. It was assumed that 10 bikes fit in each garage with an area of 15 m^2; with a lifetime of roughly 50 years.

2.3.1 Reference Case

Based on information provided in Foletta and Henderson (2016), the current mode of transportation by Hammarby Sjöstad residents is made up by 21% trips by car, 52% by public transportation and 27% by biking and walking. These figures were used for the assumptions on current transportation modes for shopping. It was assumed that the 20 kg load carried from the shopping trip could be transported in all cases. No additional impacts from the production of buses, cars or bikes were included, as it was assumed that these are currently available to the residents of Hammarby Sjöstad; which also allows for the comparison of consequences of the changes in transportation methods.

2.4 QLocx

QLocx provides storage with a digital locking service to increase the availability, and reduce transportation from logistic companies, for deliveries of packages. When a package is sent and delivered, the recipient is notified, e.g., through a mobile application, and the postbox, locker or room, can be opened digitally through the application or by a code. By providing such services, households and citizens can share products among themselves, and logistic companies can deliver packages with a reduced number of delivery attempts; see Figure 5 for a depiction of a typical QLocx postbox/locker.

Figure 5: Postbox/Locker for Deliveries using QLocx

As the QLocx services opens for potential increases in sharing of products, the services were also reviewed in this assessment. This was done to understand the potential for reduced emissions and transportation, first and foremost from traditional package deliveries.

In order to review the potential of the deliveries using this system, the review includes the use of QLocx services in all apartment buildings in Hammarby Sjöstad. Table 11 provides assumptions used to determine the number of deliveries and boxes in each of the apartment buildings in Hammarby Sjöstad.

Table 11: Assumptions for Packages and number of QLocx Lockers

Households	7 856
Population	17 619
Households per Building	30
Number of Packages	141 408
Number of Buildings/Lockers	262
Packages Delivered to QLOCX lockers	50%

It was assumed that each household receives 36 packages per year[7], roughly 3 per month, and that half of these packages are delivered to QLocx postboxes. This is due to the assumption that QLocx would initially provide a delivery method for only a selected few postal logistics companies (e.g., Bring, DHL, MovebyBike, etc.) while PostNord packages would be delivered to local package handling stations.

The boxes were assumed to be installed as new QLocx specific mailboxes; assumed to be made from roughly 10 kg of galvanized steel. The boxes use magnetic locking systems. Based on information provided, the impacts for the use of AA batteries to operate the locks were included in the LCA and were based on data for lithium-ion batteries in Ecoinvent v. 3.3; require 2 AA batteries per box and year. Furthermore, the QLocx system uses a web-based code locking/unlocking. The impact for this was also included in the assessment; see Appendix for more details.

For deliveries and the potential reduction of attempted deliveries by using the QLocx lockers, estimates were provided by a postal operator. It was identified that an average of roughly 1.9 trips were required to deliver a package. Thus, using the QLocx boxes may reduce these trips significantly. The environmental impacts of these deliveries were also reviewed. Traditional LCI data for freight transportation is not optimal to be used for the highly complex logistics of mail carriers. Therefore, instead of freight datasets in Ecoinvent, the DHL carbon calculator was used to assess the impacts of shipping a package, which takes into account volume of the package and weight, among other factors such as delivery routes, etc. It was assumed that the package was shipped from Solna to Hammarby Sjöstad. The average package was assumed to be roughly 0.06 m^3 according to dimensions provided on the QLocx homepage for maximum size of packages in the postbox system, and assuming an average weight of 5 kg. With these factors, the environmental impacts were calculated to have an impact of 0.012 kg CO_2-eq emissions per attempted package delivery[8]. Data for upstream emissions of the package (i.e., for all transportation and freight up to the delivery to the logistics center in Solna) were not included, nor the emissions of the products within the packages.

QLocx also has the aim to deliver products with the MovebyBike service. As such, no impacts for transport were included for the bikes, although there may be impacts from MovebyBike storage and management of the operations. Nonetheless, these were not included as they were considered outside the scope (and were not reviewed in the other logistics posts). Furthermore,, the potential for QLocx for improving sharing possibilities and potential environmental impact reductions in the Hammarby Sjöstad is also reviewed in the subsequent section, *Results-Integration of Sharing* Services.

[7] Once again in the context of this project, the number of packages received by each household was estimated based on an internal questionnaire at IVL.

[8] Based on data and calculative methods in the Carbon Calculator from DHL (https://www.dhl-carboncalculator.com/).

2.5 Integrated Scenario

The sharing services reviewed in this assessment have the potential for integration, i.e. being conducted individually but in synergy. Figure 6 provides are revision of Figure 2 to represent a case with integration between Hygglo and QLocx system.

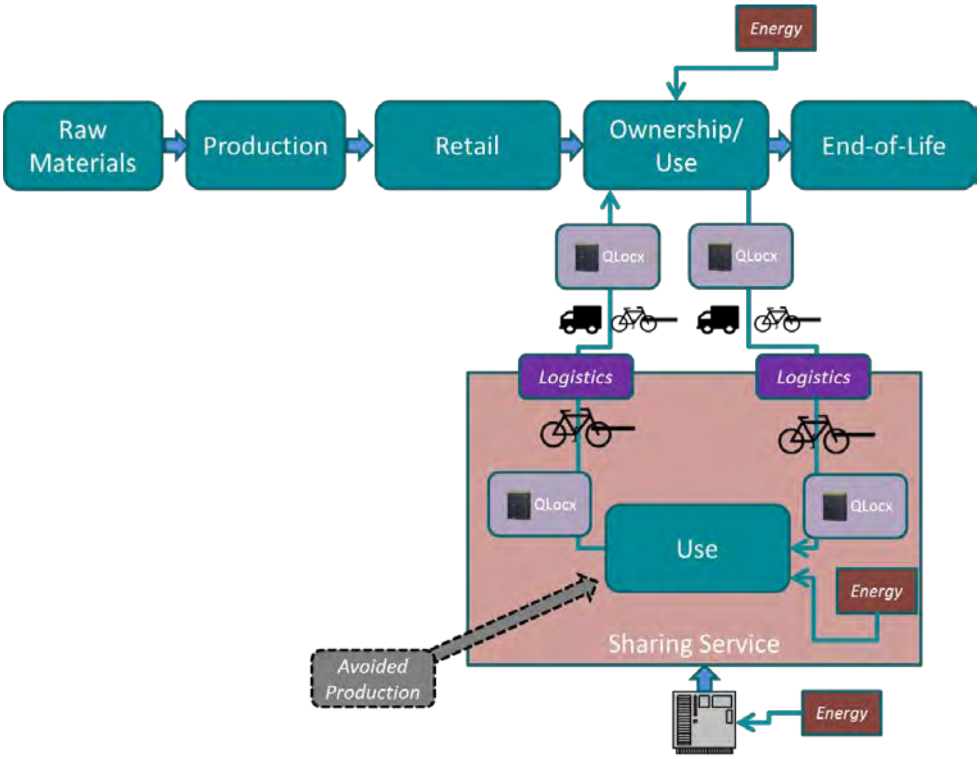

Figure 6: Review of the integrated scenario

In order to review the implications of an integration of the two services, it was assumed that all products shared in the Hammarby Sjöstad area employ the use of QLocx boxes. This entails that the products are put in the QLocx box or lockers (e.g. for the case of skis), picked up by a logistics company and thereafter placed in another QLocx. Previous products reviewed, such as cars, vans and bikes were not included in the assessment as the review was focused only on products which could fit in QLocx boxes and lockers. As such, the assessment was dissimilar to the previous Hygglo scenario reviewed above, and not compared with these results. To compare with the Hygglo scenario (without the sharing of cars, vans and bikes) results were also extracted for sharing of the remaining products. In the integrated scenario, transportation of the packages is altered to include pick-up and delivery by logistic services and impacts from the use of QLocx boxes. A high and low transport impact was also tested; again with a total distance of 10 km total. The high impact transportation (labeled *Sharing Integ. Trans. Logistics* in Figure 20) included picking up the package by conventional diesel vehicle (e.g. Bring or DHL), distributing to a central logistics center and delivering the package to the user by cargo bikes (e.g., using Movebybike). The trip back to the provider was assumed to have the same route. The package therefore is posted, picked-up, delivered, posted and returned using QLocx boxes and logistics services. Using this method also increases the impact of the sharing infrastructure impacts as well, due to added data use for the mobile applications needed for the QLocx system. As in the QLocx review above, the impacts from the boxes were also included. The low impact transportation (labelled *Sharing Integ.*

Trans. Bike in Figure 20) included only logistics by bike. Finally, as the integration may increase sharing due to the ease at which packages can be picked-up and dropped-off, another scenario was included to review an increase in sharing. In this scenario it was assumed that twice as many products would be shared given the same number of advertisements and availability for sharing (labelled *Sharing Integ. Incr. Sharing* in Figure 20).

3 Results and Analysis

3.1 Hygglo

3.1.1 Total Emissions

As Figure 7 illustrates, the sharing services provided by the Hygglo services showed large potential for reducing GHG emissions compared to baseline emissions. If no sharing services were in place, and products were instead purchased and used in the Hammarby Sjöstad region (see Baseline scenario), the GHG emissions were found to be roughly 22 000 kg CO_2-eq annually for the products reviewed. The sharing scenarios, both high and low, have the potential to reduce emissions by over 18 000 kg CO_2-eq emissions per year. With a reduction in product ownership, a reduced impact from the production of the reviewed products is illustrated. The impacts from the use of the products was found to decrease in the sharing scenarios, due to an overall reduction in use in the Hammarby Sjöstad area. However, the impacts for the use of the products (including outside of Hammarby Sjöstad) may increase due to an increased total number of uses of the product (but again less than the baseline scenario, see the analysis). The impacts from the digital infrastructure were found to be nearly negligible (less than roughly 1 kg CO_2-eq annually) for the data transmission, storage and energy use for searching, uploading and storing the information in the sharing scenarios, and were thus included in the use phase. Furthermore, as the study also reviewed the effects that sharing of products may have for avoided purchases of similar products, the use of sharing services can lead to even larger benefits (i.e., large credits) if replacement of products is also included. As such, in Figure 7, the "Total" indicator is the difference between the sum of the impacts from use, production, transport and infrastructure and the credits.

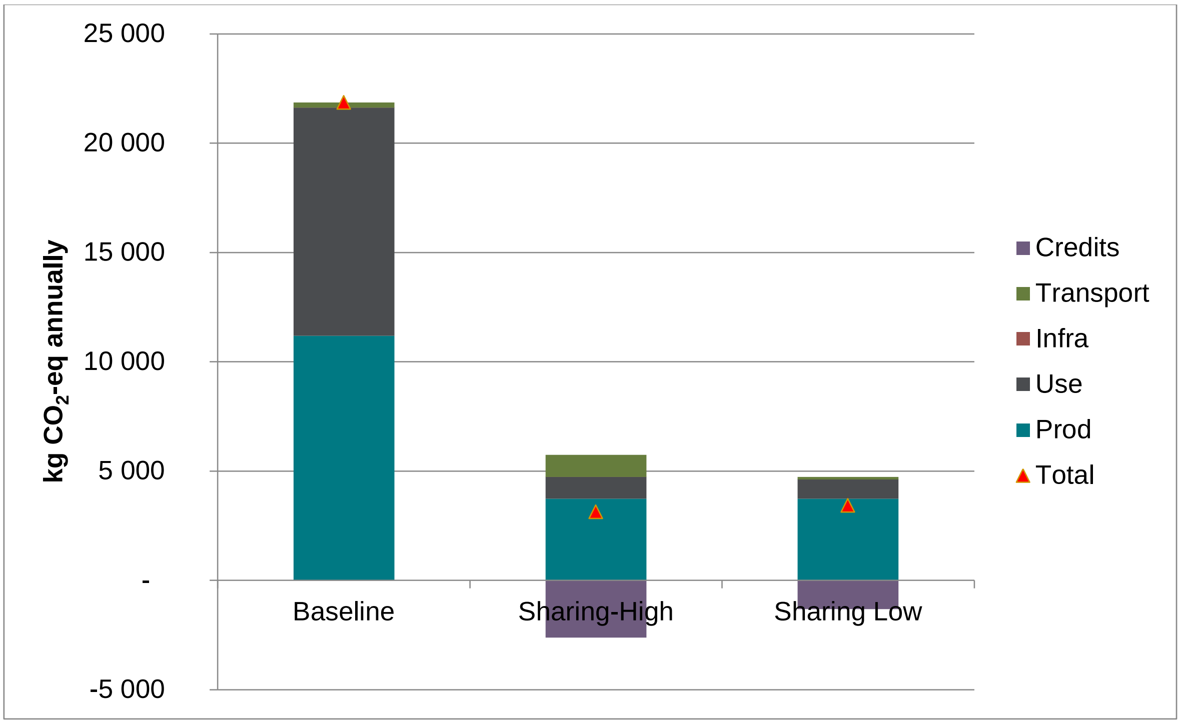

Figure 7: Annual emissions for the reviewed scenarios, including Credits for Avoided Product Purchases

Figure 8 illustrates the total impacts (split once again into credits, transport, use and production) for the separate products. As shown, it was estimated that the largest impacts may be due to the use of vehicles; which were also rented only a limited number of times. The electric products, such as tools and video game units, were illustrated to have very small overall impacts. Due in part to the low number of products rented. See further analysis of the sensitivity to assumptions on the use of the products in subsequent sections.

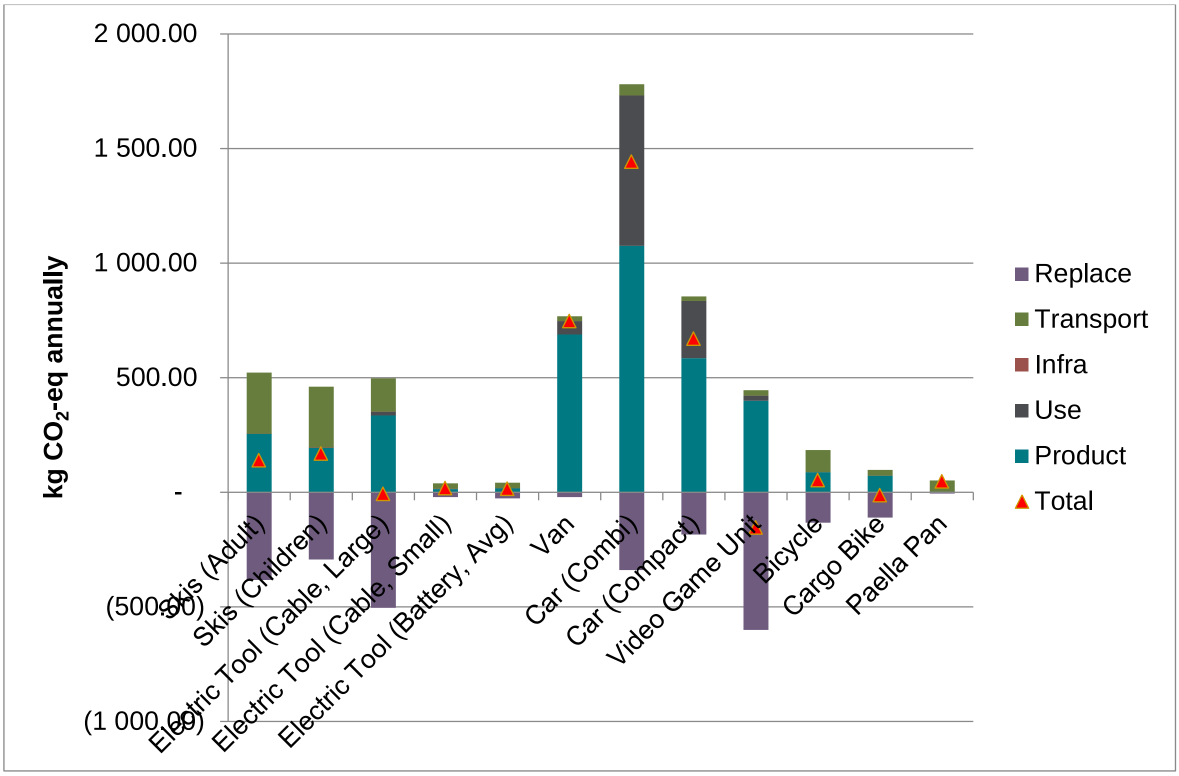

Figure 8: Emissions per product shared for Sharing-High scenario

Figure 9, as a compliment to the figure above, shows the contribution of the different impact categories (or LCA phases), to the overall impact, i.e., without the credits. It is important to show such information, as the products have different inherent properties, and while some have little to no impact for the use phase, others may be high. Again, the use phase impacts of the vehicles are shown to be large in comparison to the other products.

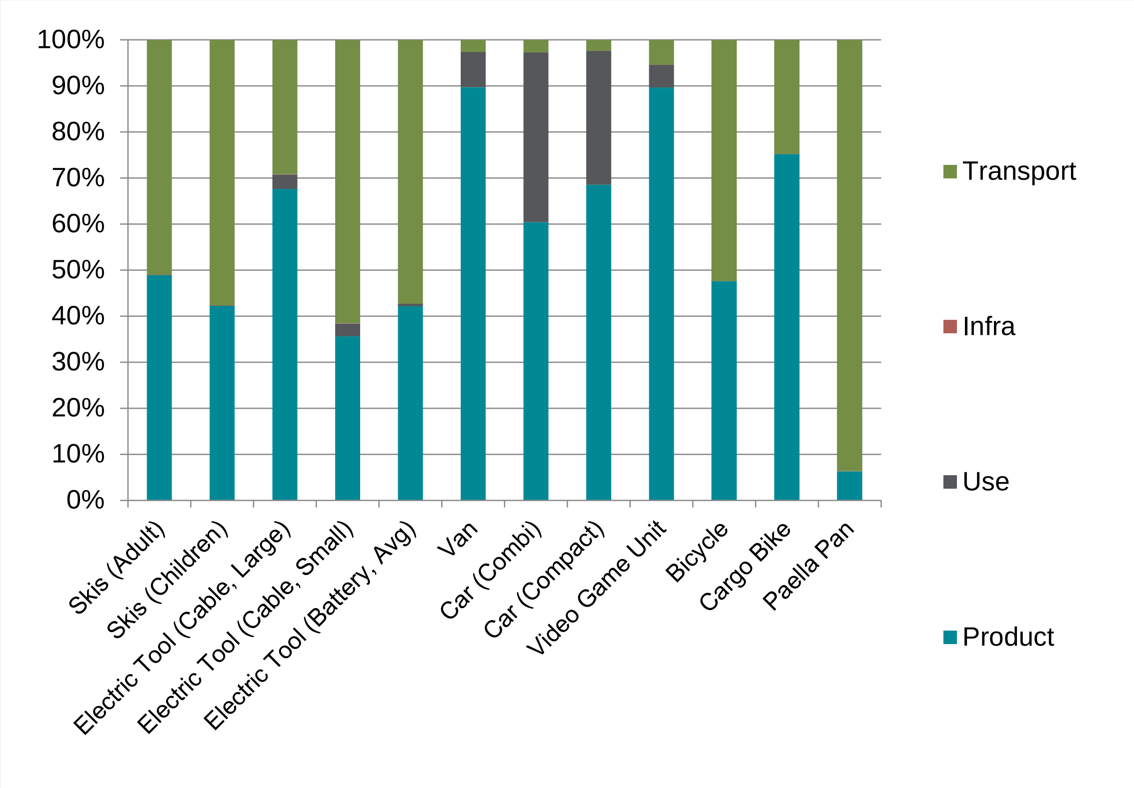

Figure 9: Contribution of different impact categories to overall GHG emissions per product shared for Sharing-High scenario

3.1.2 Per Use

The products with the largest number of shared items are the skis and the tools. As illustrated in Figure 10, per use, these have a very low impact. However, the products with the lowest total sharing, i.e. vehicles, had a large impact per use.

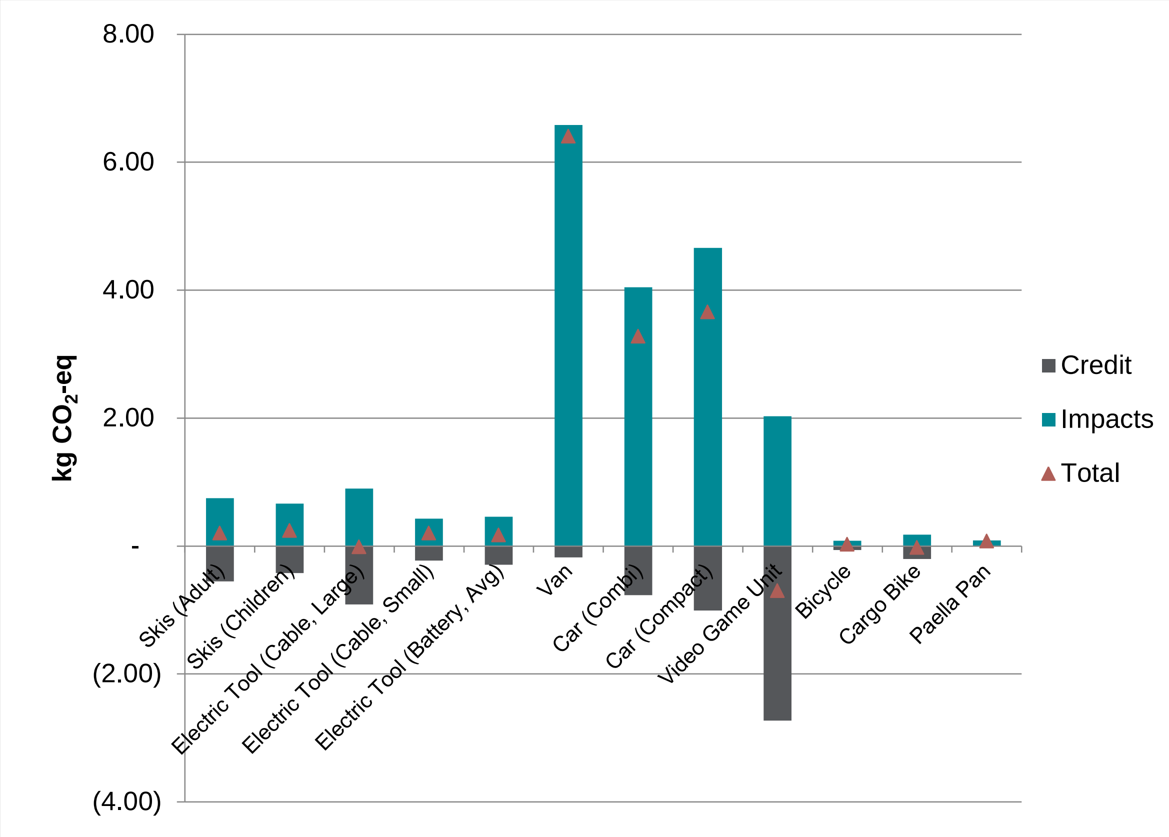

Figure 10: Annual emissions per use of all products sharing-high scenario

3.1.3 Sensitivity to Choices

The previous review of the results for the different scenarios illustrates the large potential for impacts and benefits based on the assumptions made; thus there could be large sensitivity to the assumptions made for the review. The following sections review and analyze further the sensitivity of assumptions, namely the number or extent of replaced products, the lifetime of products and transportation distance.

Replaced Products

Figure 11 illustrates, by increasing, or decreasing the amount of products replaced by 50% respectively, there are large changes in the overall annual impacts for the system compared to the assumed replacement share for products. This is due primarily to a decrease and increase in conventional products replaced. When increasing the conventional products replace, (illustrated in the *Sharing-High Repl. +50%* scenario), an overall decrease in emissions of 42% is possible. For the respective *Sharing-Low- Repl. -50%* scenario, an increase in emissions is illustrated, due to a reduction in conventional products replaced.

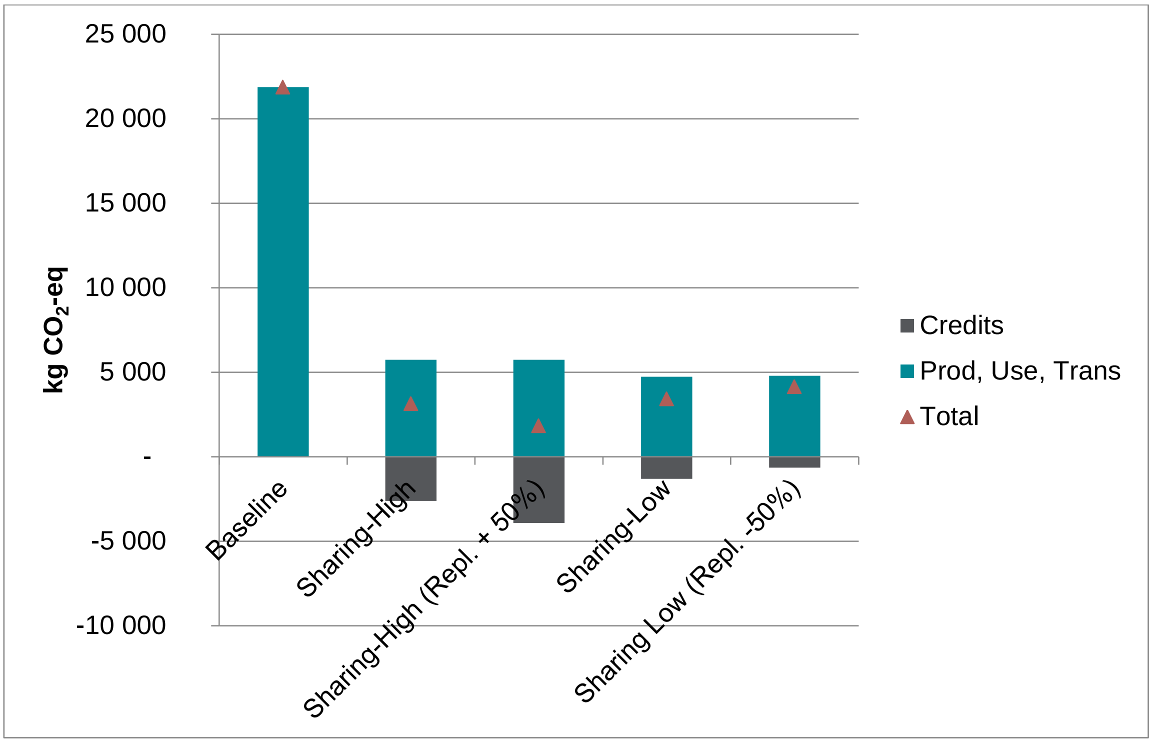

Figure 11: Reviewing the sensitivity for choices in number of replaced products

Product Lifetime

In both the high-use and low-use sharing scenarios, the product lifetime of the products shared was assumed to be the same as the lifetime for the baseline scenario. As the product lifetime may be reduced with increased use, it is important to review the effect that this may have on the overall impacts. For the *Sharing High (Life)* scenario and *Sharing Low (Life)* the lifetime of the product was assumed to decrease and increase by 30% respectively. As Figure 12 illustrates, there is no longer a lower impact for the sharing-high scenario, as the production and use impacts are increased, due primarily to a lower "denominator" for dividing the impacts per year, as the higher use scenario assumes a lower lifetime.

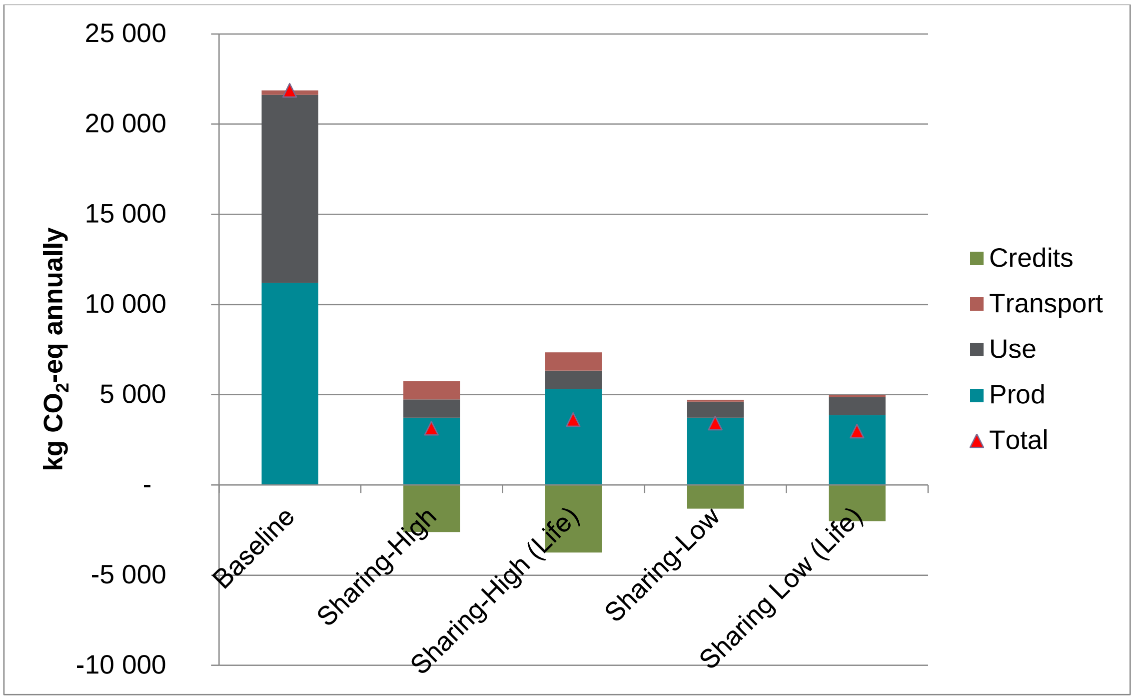

Figure 12: Reviewing the influence of assumed lifetime for products in sharing scenarios

Distance/Transportation

In order to review the sensitivity and potential impact of increased transportation, two scenarios were added to the assessment. These are named in Figure 13 as *Sharing High (Trans.)* and *Sharing Low (Trans.)* for which the transportation distance was increased by a factor of 5. In the *Sharing High (Trans.)* scenario, the distance traveled was increased from 10 to 50 km roundtrip for products being shared by car and bus, and in the *Sharing Low (Trans.)* scenario, the distance increased from 5 to 25 km by bus and walking. Additionally, in the *Sharing Low (Trans.)* scenario, it was assumed that 90% of the travel would be done by bus.

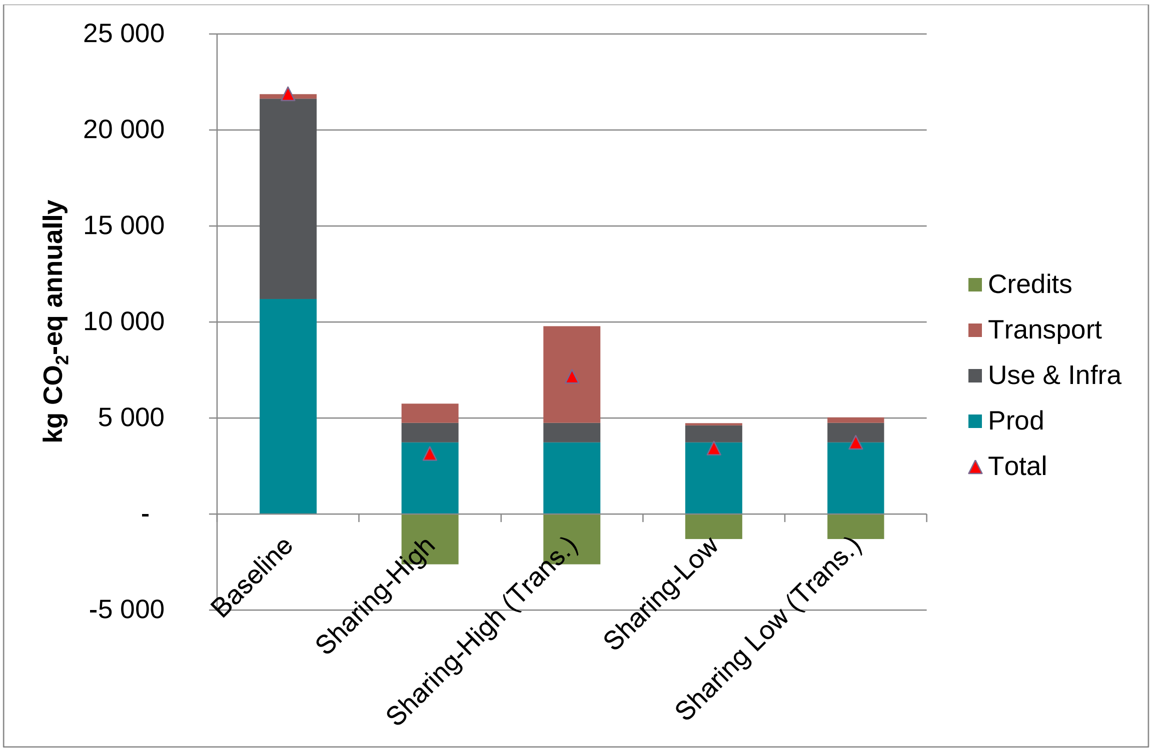

Figure 13: Reviewing the influence of transportation distance for sharing scenarios

By increasing the distance traveled for sharing products between users, there is the potential for significantly increased emissions. In the case of the *Sharing-High (Trans.)* scenario, the total impacts are increased by roughly 130%, with the transportation impacts being increased by over 400%. In the *Sharing-Low (Trans.)* scenario, no significant increases in total impacts were illustrated (an increase of roughly 9%) although there was an increase in transportation (primarily due to the increased use of bus transport) of roughly 150%.

Use of the Products

As shown in Figure 14, there is a possibility for significant increases in impacts from the use of the products if all use by providers is included. Previous figures review only an allocated share (roughly 40%) of the impacts from providers; assumed to be those providers owning the products within Hammarby Sjöstad. As such, the use phase adds to a large share of the impacts of the products being shared compared to the *Sharing-High* and *Sharing-Low* scenarios, as outlined earlier. Nonetheless, compared to the reference scenario, the emissions are still significantly lower.

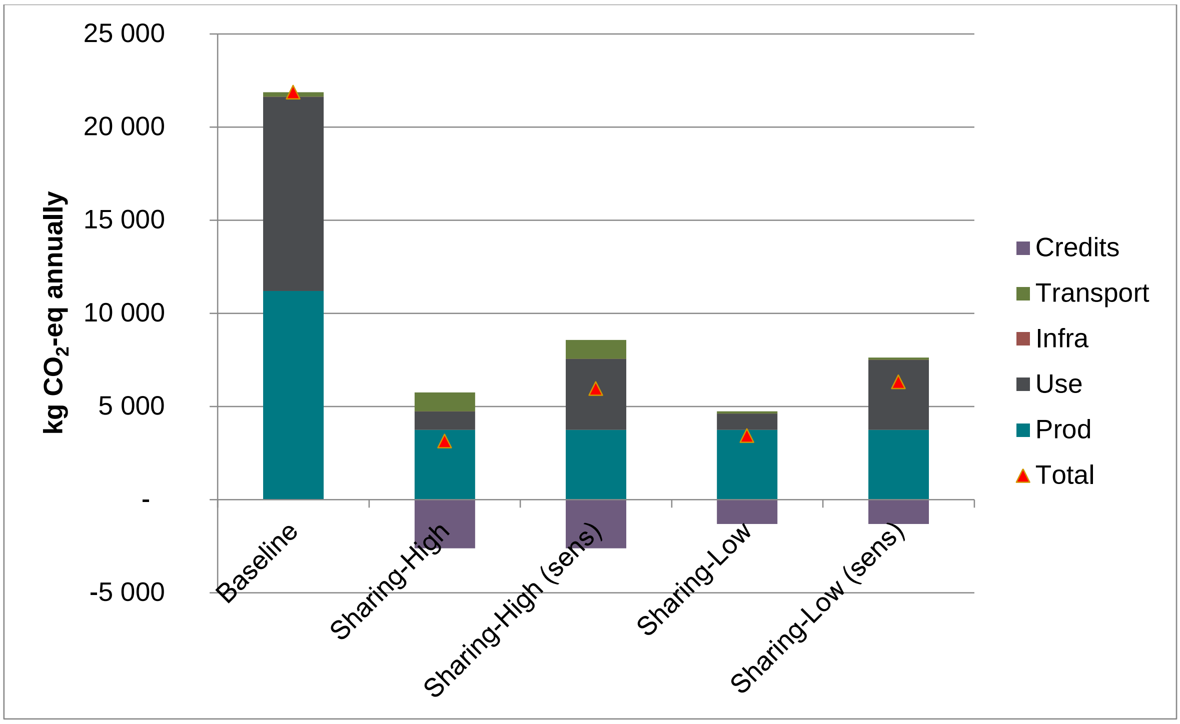

Figure 14: Sensitivity to the use by the providers. Sharing High (sens) and Sharing-Low (sens) show inclusion of all impacts for use by providers (both providers within and outside of Hammarby Sjöstad). Other sharing scenarios show only the impacts from use by providers in Hammarby Sjöstad.

3.2 Results QLocx

The results of the assessment of QLocx services suggest that the service could reduce GHG emissions in comparison to a baseline (*Conventional*) scenario. When comparing QLocx using conventional shipping, GHG emissions from transportation, or delivery, can be reduced by over 1 500 kg CO_2-eq emissions per year. However, overall the emissions reductions were roughly 1 000 kg of CO_2-eq emissions per year due to added emissions from the services, e.g. for the availability of the locker and batteries used to power the magnetic locks. These amounted to roughly 500 kg CO_2-eq emissions per year, and thus non-negligible. If the delivery of the packages were however done by bike, represented by the *Qlocx Locker (Bike)* scenario, the annual emissions would decrease by roughly 2 700 kg CO_2-eq per year. As in the review of the Hygglo service, the impacts of the digital infrastructure were negligible, i.e., less than 0.5% of the overall impacts.

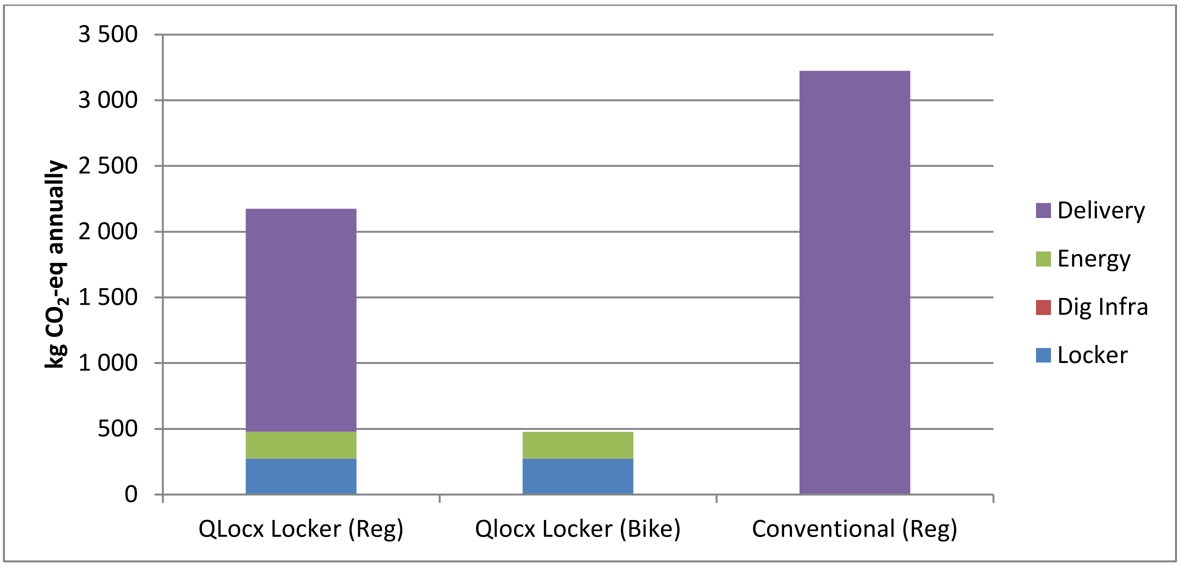

Figure 15: Comparisons of emissions for the QLocx service vs. the baseline scenarios

3.2.1 Sensitivity

In this study, the data available for logistics can affect the overall carbon emissions. If the study instead used impacts provided in Edwards and McKinnon (2009), which outline the emissions of average deliveries to roughly 0.18 kg CO_2-eq per delivery, the consequences for the results were significant compared to the current 0.012 kg CO_2-eq per delivery based on data from DHL's carbon calculator; see Figure 16. As such, the impact reductions could be roughly 23 tonnes CO_2-eq per year assuming transport to QLocx uses conventional deliveries, or up to 48 tonnes CO_2-eq annually assuming it is done by bike.

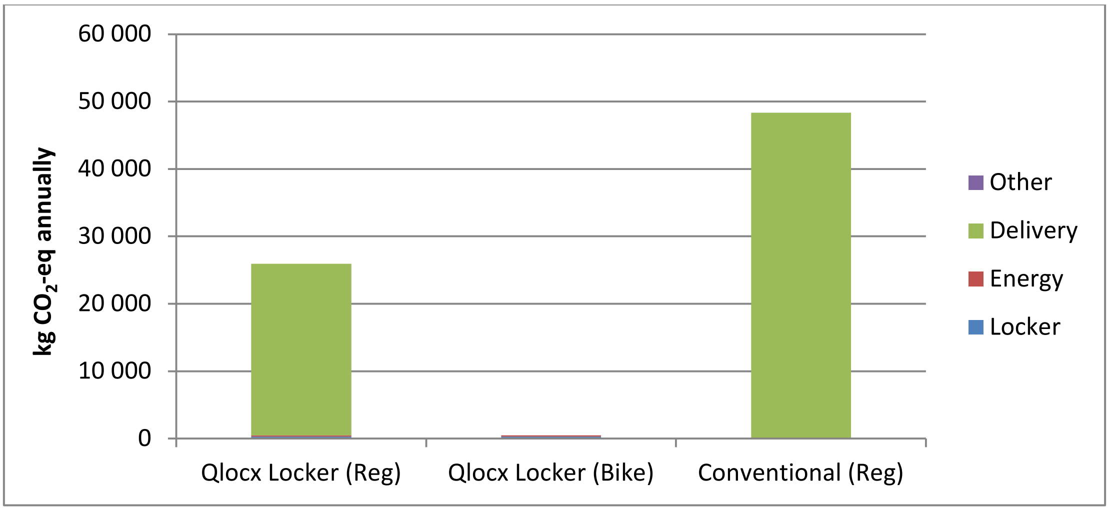

Figure 16: Reviewing the impacts using data for delivers by Edwards and McKinnon (2013)

3.3 Results-Cargo Bike Sharing

The availability of cargo bikes for shopping trips to the area of Sickla showed significant emissions reductions. Figure 17 reviews the GHG emissions for the cargo bike scenarios reviewed. Thereafter, Figure 18 reviews the emissions for the cargo-bike scenarios compared to a baseline scenario for typical transportation modes in Hammarby Sjöstad. By using cargo bikes, there is a potential to reduce GHG emissions by over 400 thousand kg CO_2-eq annually. Using electric cargo bikes also had significant, but not as large, emission reductions due in part to increased emissions for the production of the bikes and electricity use.

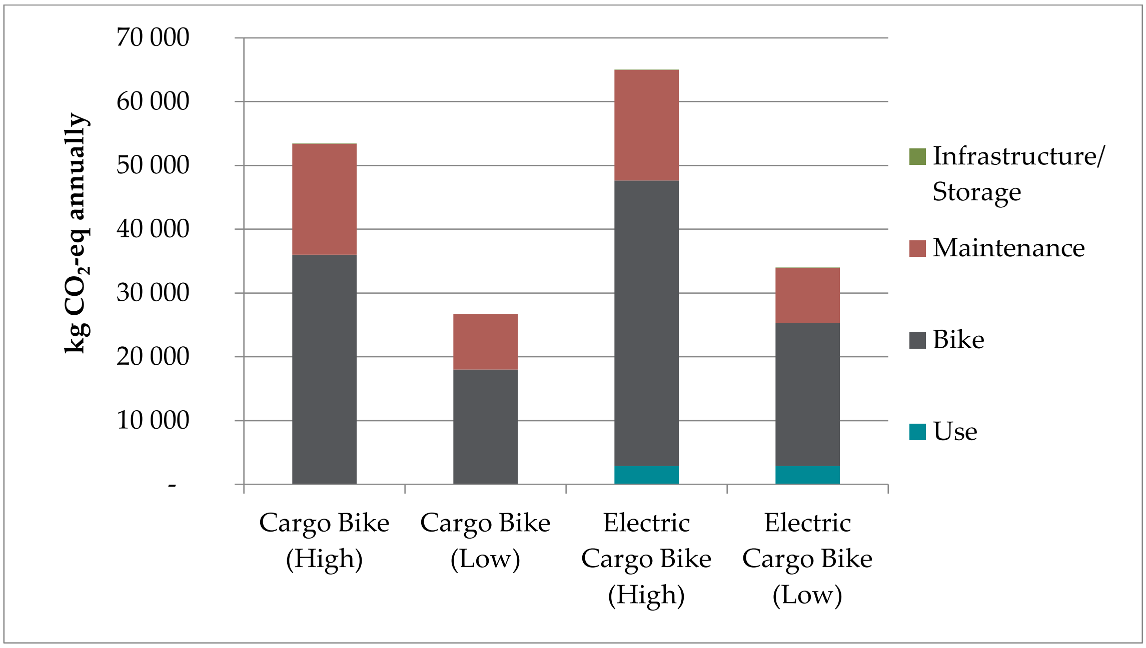

Figure 17: Comparison of GHG emissions for shopping trips by conventional cargo-bikes and electric cargo-bikes

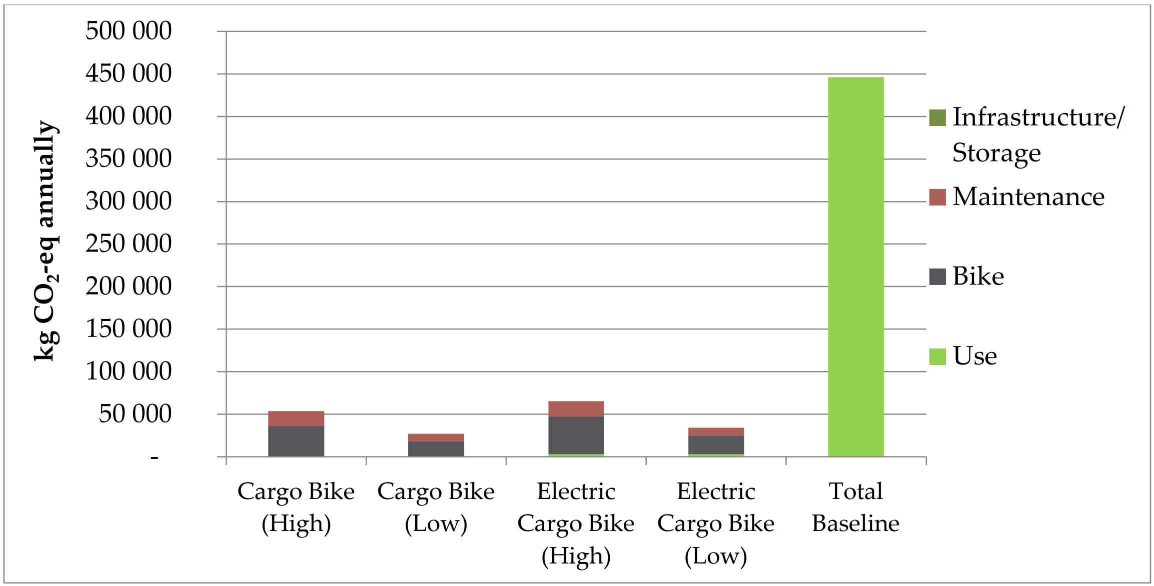

Figure 18: Comparing the cargo-bike scenarios with baseline emissions with conventional transport methods

3.3.1 Sensitivity

The main sensitivity identified in the study of the cargo bikes is the overall emissions from transportation. For example, the baseline for transportation is based on figures provided in Foletta and Henderson (2016). However, if the transportation was entirely by car, or by bus, the relative emissions reductions would be increased or decreased dramatically showing the sensitivity to the choice for baseline emissions when comparing the modes of transport; see Figure 19.

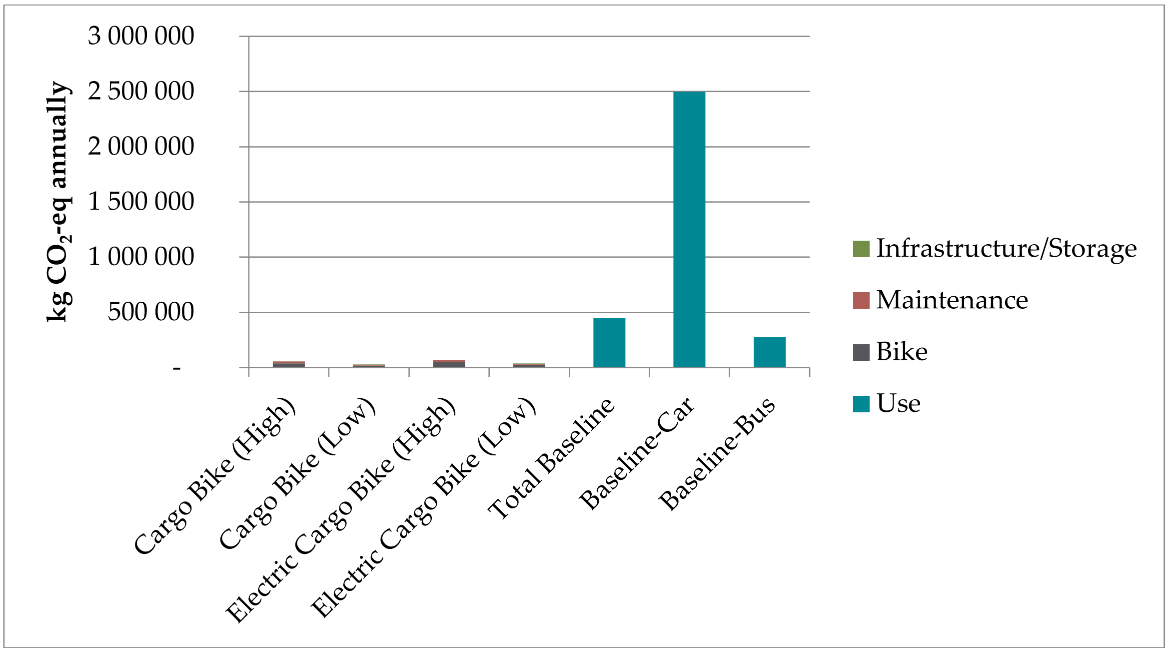

Figure 19: Reviewing the sensitivity to choice of baseline transportation mode

3.4 Results-Integration of Sharing Services

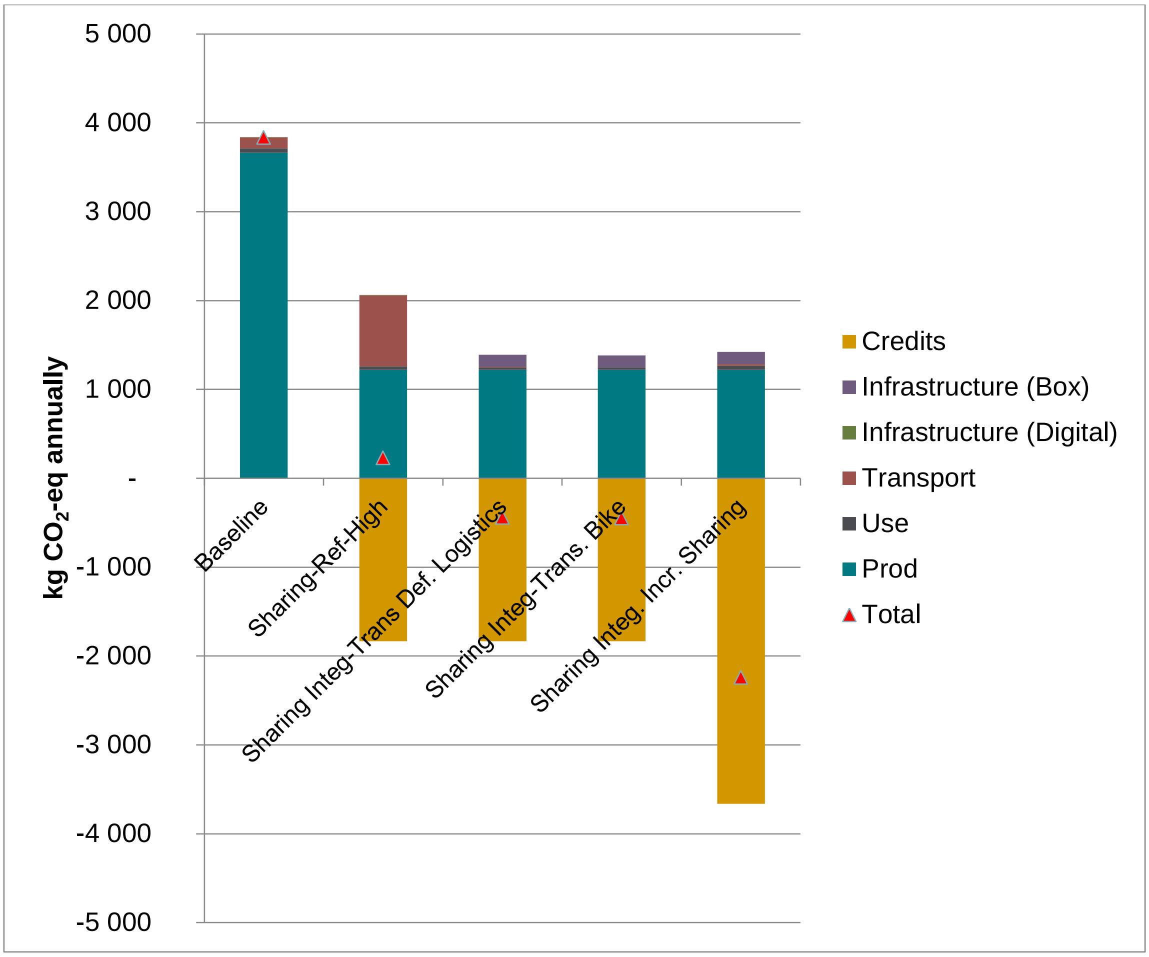

Figure 20: Comparison of baseline impacts with sharing scenarios from Hygglo (Sharing-Ref) and with Hygglo and QLocx integration (Sharing Integrated).

As shown in Figure 20, there is significant potential to reduce impacts from sharing services through integration. When comparing the *Sharing-Ref-High* scenario with the *Sharing Integ. Def. Logistics* scenario, a large reduction in impacts from transportation is seen. This is due to the integration using QLocx and logistic services. Transportation emissions are also eliminated in the *Sharing Integ. Trans Bike* scenario, as all transports are assumed to take place with cargo bikes. In the final scenario reviewed, Sharing Integ. Incr. Sharing, it was assumed that an increase in sharing may be possible due to the ease at which packages can be picked-up and dropped-off. Thus, there is a large potential to replace purchases of conventional products with the same range of products available for sharing. As with the other scenarios, these may also be sensitive to the choice of data and assumptions, although they are not reviewed again.

4 Discussion

4.1 Assumptions

The results presented show significant benefits from the use of sharing services. However, it should be identified that these results could be over or underestimations of the potential impact reductions as the results are sensitive to the assumptions made. These were therefore reviewed in the analysis above.

As shown, significant changes in overall impacts are apparent for the Hygglo scenarios when reviewing the consequences of sharing for product ownership; i.e. potential for avoiding the purchase of new products. While sharing services have the potential for avoiding the purchase of new products, there is a lack of studies in the literature reviewing such behavioral changes; thus more work will be needed, despite studies identifying the social and economic motives for using sharing services (Böcker and Toon, 2017).

The assumptions for transportation of the products from one user to another also had a significant impact for the products being shared. The results, therefore, agree with those of a recent study by Zamani et al. (2017) on clothing libraries. In the study, transportation was shown to be an important factor affecting the overall environmental impacts. Nonetheless, in their study, the use of physical deliveries of products for different options (i.e. online or physical stores) was limited. While their study, discusses the potential for postal service options for such web-based sharing platforms, they were not reviewed. This study, in the Hygglo review, included only transportation by car, bus, bike and walking, although the use of postal services could become an option to improve the extent of sharing products through, e.g. Hygglo. As such, the integrated scenario showed the significance for this to reduce emissions. This is further validated in the review of impacts from the distribution of packages in the QLocx assessment; illustrating low impacts for optimized logistics systems versus deliveries by car, bus, etc. It may be important to understand the "maximum" distance for product sharing before the purchase of new products may take over.

4.2 Integrating Services

This study reviews the impacts of the services conducted separately, and in integrated systems, as there are many potential synergies available between these services. For example, and as discussed in the preceding section, logistics for product sharing using QLocx could provide a platform to improve the availability and ease by which products can be shared locally, but also across larger distances. By doing so, and through the use of the optimized logistics services in postal systems, the impacts from the transport of the products could be greatly reduced. The results suggest that this could greatly reduce the impacts from the Hygglo service, and potentially lead to increased sharing. As such, it will be important to understand the types of products would thus be shared, availability and efficient utilization of space provided by e.g. It will also be important to assess such behavioral changes as the sharing would become more accessible and effortless. Furthermore, assessments may need to include life cycle costing, to review the economic aspects of installing QLocx boxes and storage rooms, in addition to the business models and costs for optimized value. Such questions may need to be developed between, e.g. Hygglo and QLocx and corresponding postal logistics providers.

Our results have concurred with suggestions discussed in Zamani et al.. (2017), suggesting that integration with logistic services may lead to reduced impacts for e.g., fashion libraries. In the scientific literature there is limited availability of such reviews. Thus this study provides a unique perspective for the potential of integrating sharing services. Further studies such as this will need to be developed in the literature as web-based sharing services, may be integrated in the future, requiring more research on the implications of such synergies or what could become a "service-symbiosis" for the sharing economy. Significant insights can also be obtained about the development of such business ecosystems as more and more web-based applications and information become available in what is also known as "mesh business"; see, e.g. Gansky (2010).

4.3 Impacts of Services

Although identified as a minor impact in this study, as an increase in web-based sharing platforms and services will increase in the future, it will be important to review the potential impacts created by the use of the web-based services for data transfer, storage, etc. However, such concerns are insufficient in the literature. In a study by Suckling and Lee (2015), they found that the addition of phones, and their use of internet services, will require more and more servers and data storage platforms in the future. At the time, they estimate that the data usage of roughly 400 phones (based on data use at the time) per server would be required. As Malmodin et al. (2014) discuss, Sweden has the highest data traffic per capita in the world, and this continues to increase. Nonetheless, as phones, servers, cloud services, etc. become increasingly efficient and multi-functional, the review of such impacts may also provide an additional obstacle to overcome in order to allocate impacts; see, e.g. Judl et al. (2013). The impact of internet use has been debated extensively in the media. Recently, Google came under fire for energy use for search engine searches; which were thereafter found to be misleading and Google responded with a more "accurate" review of energy use[9]. Van Loon (2014) also reviews the impact of retail suggests that improvements may be needed to review the actual impacts occurring, not only from the use but also rebound effects. Börjesson-Rivera et al. (2014) suggest available metrics for reviewing impacts from servers and the use of internet is difficult, and many available figures for carbon emissions are very dissimilar. In studies such as Blocket (2013), produced by IVL, internet use for users is not included, but the impacts for company energy use (including servers) is included as it was difficult to review other impacts. It is important that such information is made more transparent (and included) in assessments to show the impacts of internet-based sharing systems.

4.4 Methodological Considerations

The methodological considerations for the sharing services vary considerably between the studied systems which makes it important to understand when reviewing sharing services. This is due to the fact that they are based on "user" shared products and services, product "library" systems and booking systems, with different temporal, spatial and material considerations. There are many improvements which should be reviewed, and also discussed previously.

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[9] See e.g. https://www.technewsworld.com/story/Harvard-Prof-Sets-Record-Straight-on-Internet-Carbon-Study-65794.html

Life cycle inventory data for products such as those reviewed in this study are currently lacking. As such, the project relies on data developed based on material specifications and other databases for representative data, e.g., Ecoinvent v. 3.3. However, the robustness of such assessments would be improved with a broader range of product data. Furthermore, downstream impacts may also be important to understand given the potential for extending the lifetime of products, in terms of uses. This study does not handle the impacts from waste handling of the products. This is an important limitation to highlight. In future assessments, it will be important to understand the implications this may have for a reduction in potential material flows (i.e. circular material flows), energy recovery from waste incineration, etc.

In certain spheres, the potential of sharing services have been suggested to be comparable, by e.g. a framework for reviewing the systems for national support. However, it is important that caution be warranted in accepting all sharing services as beneficial. Bond (2015) suggests- 'Local governments should embrace Uber because it is primed to benefit from the Baby Boomer to Millennial shift due to its peer-reviewed model of service.' Nonetheless, there are few assessments to review the actual implications of such systems; and even fewer reviewing system for reduced resource consumption, e.g., Hygglo, Blocket, etc. As such, aside from the discourse and speculations on the potential environmental improvements, the empirical evidence is scarce and is extremely challenging and complex to demonstrate the potential environmental improvements at an aggregate level, despite attempts at reviewing the potential e.g. in the Nordic region; see Norden (2017). As such, first-order effects, such as those reviewed in this study may be possible to review, but net impact at an aggregated socio-economic level should also be considered; see, e.g. Martin & Shaheen (2010).

4.5 Rebound Effects

It will also be important to review the potential rebound effects associated with sharing services. This can transpire due to the money saved by sharing. If the additional wealth (saved) is instead spent on other energy or carbon-intensive products or services, there may be an increase in emissions. In this study, an example could be the added ease by which products can be purchased and delivered through online platforms. By doing so, this may promote increased consumption of products. However, at the same time, and as discussed previously, there may also be the possibility for the QLocx system to lead to an increase in sharing of products. There is therefore a need, and currently a lack of studies, for determining behavioral changes with the increased use of sharing services and other collaborative economy models.

4.6 Future Possibilities

Due to the limitations of this study, and based on the previous discussions, there is a large potential to improve and extend the environmental implications and the use of LCA for reviewing sharing and collaborative services. The following list provides many of these possibilities identified during the course of this research.

- Improved details on the extent of use, energy use, statistics, etc. for sharing services and products reviewed
- Develop improved statistics on the provider-user sharing in terms of distance, mode of transport, etc. for improving baseline reviews and potential to improve synergies with other, more environmentally benign, options for transport

- Assess the potential implications of waste handling for shared products vs. conventional use
- Review the resource efficiency (resource use) of the product portfolio in baseline vs. sharing scenarios
- Review the potential "break-even" point for transportation options for sharing products
- Review the implications of increased web-based applications for resource use (including the resource use for the data infrastructure, which is rarely reviewed)
- Compare the "needs" or searched items with those currently shared to review the divergence of available products and those which are sought after to improve sharing services
- Make users and providers more aware of the environmental benefits for society they are part of when sharing products and services through feedback mechanisms
- Improved life cycle inventory data for typical products reviewed
- Interviews and follow-ups to understand the behavioral changes present when sharing services are used
- Extend the reviews of, e.g. the infrastructure needed for sharing services and the potential impacts these have
- Assess, review and outline the potential for integrating different services
- Develop more research on the potential for rebound effects, or the opposite, based on a wider availability and adoption of sharing services

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Appendix

Appendix Table 1: LCI data values used for products

Product	kg CO_2-eq/ unit	Unit
Slalomskidor, vuxen	29	pair
Slalomskidor, barn	22.16	pair
Elverktyg utan batteri, 20 kg (tex bordssåg, högtryckstvätt)	70	pcs
Elverktyg utan batteri, 5 kg (tex cirkelsåg, sticksåg, borrmaskin)	17.5	pcs
Elverktyg med 2*batteri(1,5kg), 3 kg (tex skruvdragare/borrmaskin)	22.25	pcs
Minibuss	3100	pcs
Bil (combi)	2015	pcs
Bil (liten)	2635	pcs
Spelkonsol	500	pcs
Cykel	82.5	pcs
Lådcykel	275	pcs
Cooking pan (Paella)	1.62	pcs

Appendix Table 2: Assumptions for the Energy Use of Mobile Phones based on Malmodin et al. (2014)

Amount	Unit
28	GWh/year
10	million mobile phones
2.8	kwh per person/mobile phone/year
525 600	minutes/year
5.32E-06	kwh/minute/person

Appendix Table 3: Assumptions for the Energy Use of Computers based on Malmodin et al. (2014)

Amount	Unit
1 850	GWh/year
8.5	million computers
217.6	kwh/person/year
525 600	minutes/year
4.14E-04	kwh/minute/person

Appendix Table 4: Assumptions used/Data for impacts for Data Infrastructure for QLocx

Amount	Unit

2 min on mobile phone	1 Qlocx Locking/Opening
2 MB Data Used	1 Qlocx Locking/Opening
1.06E-05	kg CO_2-eq /mobile use
6.03E-06	kg CO_2-eq /data infrastructure service

Appendix Table 5: Assumptions used/Data for impacts for Data Infrastructure for Hygglo

Amount	Unit
3 min	Searching/Browsing on mobile phone
3 min	Searching/Browsing on Computer
15 MB	Data on Server
1.26E-03	kg CO_2-eq/search
4.53E-05	kg CO_2-eq /data infrastructure service

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