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Climate impact assessment of retail payment services

Niklas Arvidsson, Fumi Harahap, Frauke Urban and Anissa Nurdiawati

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Abstract

Money and payments are central to modern economies and societies, yet there are increasing concerns over the environmental impacts of various payment services, particularly from a climate perspective. This report examines the climate impact of retail payments in Sweden in 2021, including cash, card, Giro payments, Swish payments, and payment apps. Its goal is to develop a method for measuring the climate impact of existing retail payment services in the Swedish market and to evaluate their individual and aggregate climate impact. The study identifies areas that can be targeted to reduce the overall impact and provide valuable information for sustainable decision-making related to payment services.

Keywords: Environmental Impact, Retail Payment, LCA

JEL classification: G29, L89, O39

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Executive summary

This report focuses on climate effects of retail payments in Sweden in 2021, i.e., cash, card, giro payments, Swish payments, and payment apps. The aims of the study are: i) to develop a method to measure the climate impact of existing retail payment services on the Swedish payment market, and ii) to evaluate the climate impact of existing retail payment services as well as their aggregate climate impact, to help further identify aspects that can be targeted to reduce the impact. The environmental footprints from different payment services provide valuable information for sustainable decision-making related to payment services.

The environmental impact of cash, card, and app payments are analysed by performing a full life cycle assessment (LCA), in line with ISO standard 14040. Meanwhile, Giro and Swish payments apply a screening LCA, where only energy and GHG emissions are considered. Aspects that are included and excluded in the analysis are explained in the respective chapters.

The climate effects from cash payments in 2021 is 2735 tCO_2eq for all transactions and 8.7 gCO_2/transaction based on a total of 315 million transactions. The emissions per transaction is equivalent to a person in Sweden driving 3.3 kilometre of a 2020 VOLVO V60. The total use of cash payments is equal to the per capita CO_2 emissions per year of nearly 855 persons in Sweden. The transport of banknotes and coins contributed to 56% of total GWP in Sweden which is due to long transport distances between cash depots, banks and ATMs as Sweden is a sparsely populated country with large geographic distances. Switching diesel fuel to HVO would provide opportunities for reducing the climate impact of cash payments in Sweden to 7 gCO_2/transaction, and down to 5 gCO_2/transaction by replacing them with electric vehicles.

Moving on to card payments, the study indicates a climate impact of 3242 tCO_2eq for all transactions and 0.85 gCO_2/transaction in Sweden based on a total of 3,825 million transactions. The total use of card payments is equal to the per capita CO_2 emissions per year of about 1013 persons in Sweden. Introducing recycled PVC for card material could bring down the climate impact to 0.78 gCO_2/transaction. Reducing the production of physical card to 50% and replace them with apps offers a slight environmental impact reduction to 0.76 gCO_2/transaction. Additionally, extending the lifetime of a Point of Sale (POS) terminal from 5 to 10 years has the potential to further reduce the impact to 0.52 gCO_2/transaction.

The study quantifies the GHG emissions resulting from the operational energy use (i.e., fuels, electricity) for retail payment services in Sweden 2021, which allows comparison of all existing payment services. Cash transactions have the highest operational carbon footprint from energy use per transaction at 3.9 gCO_2, followed by payment-app (0.03 gCO_2/transaction) and card and Swish (0.02 gCO_2/transaction). Notably, Giro transactions demonstrate the lowest operational carbon footprint per transaction at 0.01 gCO_2 respectively.

Glossary

Attributional LCA	Attributional LCA is defined by its focus on describing environmentally relevant physical flows to and from a life cycle and its subsystems.
Carbon footprint	The amount of GHG emissions to the atmosphere by an individual, organization, process, product, or event from within a specified boundary. It can be obtained by applying LCA method.
Consequential LCA	Consequential LCA is defined by its aim to describe how these flows will change in response to possible decisions
Cradle-to-grave assessment	An approach to evaluate environmental performance by considering the potential impacts from all stages of manufacture, product use (including maintenance and recycling), and end-of-life management
ISO 14040	ISO 14040:2006 describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements
Life cycle analysis (LCA)	A methodology that evaluates and quantifies the environmental impacts, compares the environmental performance of different systems and technologies, points out processes with high environmental impact, and introduces measures in order to improve the system's environmental performance.
Life cycle inventory (LCI)	The methodology step that involves creating an inventory of input and output flows for a product system. Such flows include inputs of water, energy, and raw materials, and releases to air, land, and water.
Operational energy use	It is the energy required during the life cycle such as electricity, heating, transport fuels.
Screening LCA	A screening LCA provides a high-level overview of the major impacts or "hot spots" of the different phases of a product life cycle. It provides sufficient environmental insights to identify and understand the main drivers of high impacts within the value chain, as well as the aspects that require deeper examination.
System boundary of LCA analysis	A system boundary shows all unit processes that are included in the LCA analysis

1 Introduction

1.1 Background

Money and payments are central to modern economies and societies, yet there are increasing concerns over the environmental impacts of various payment services, particularly from a climate perspective. This study is focusing on the climate effect of different payment services in the Swedish retail payment system, which includes infrastructure, systems, and services provided by a multitude of public and private actors. The environmental impact of cash, card and app payments are analysed by performing a full life cycle assessment (LCA), in line with ISO standard 14040. Meanwhile, Giro and Swish payments apply a screening LCA, where only energy and GHG emissions are considered. The expected audience for the study is Sveriges Riksbank, external stakeholders and the general public. A separate but related study is analysing the climate impact of a retail Central Bank Digital Currency (Arvidsson et.al., 2024).

1.2 Overview of retail payment services

Five retail payment services are analysed in this study, cash, card (debit and credit), payment-app, Giro and Swish, where the year studied is 2021, which served as the reference year for the assessment. 2021 was chosen as the reference year, because it is the year with the latest data available. The number of transactions and their value of transactions of each payment method are presented in Table 1.

Table 1 Number of transactions and value of transactions of existing payment methods for Swedish retail payment in 2021

	Payment type	Number of transactions (millions)	Value of transactions (billions SEK)
1	Cash	315 (1)	89 (2)
2	Card (debit and credit)	3,825 (1)	1,182 (1), (3)
3	Payment app	36.45 (4)	10.3 (4)
4	Giro	1,639 (1), (3)	18,725 (1), (3)
5	Swish	770 (1)	397 (3)

(1) Source: (Sveriges Riksbank, 2023a)

(2) Source: (Sveriges Riksbank, 2023b). The value of cash payments is determined by multiplying the estimated volume of cash transactions with the average value of a debit card transaction in 2021, which was 283 SEK.

(3) Source: (Sveriges Riksbank, 2022a)

(4) The total of P2B transactions is approximately 3,645 million, in which about 99% of in-store P2B transactions are conducted via cash, card and Swish. Out of this total, based on household survey, it is assumed that 1% (Riksbank, 2022) or 36.5 million transactions are executed through payment apps.

2 Climate impact of Swedish cash payments

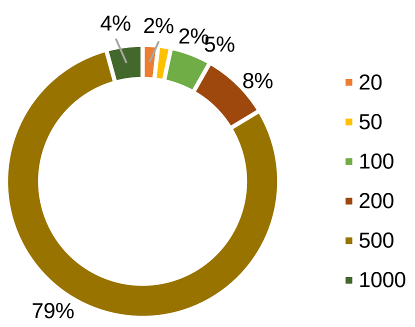
The system for cash handling in Sweden (Sveriges Riksbank, 2022b) starts from cash being issued and provided by the Riksbank, which makes cash the only available central bank money in retail payments in Sweden. The Riksbank is the key actor in the infrastructure related to cash and has the responsibility to provide cash in the volume demanded by the market, i.e. by banks, merchants, and consumers. The Riksbank also runs a cash handling board (Sveriges Riksbank, 2018a) that focuses on solving operational problems related to cash handling.

The printing of Swedish is procured by the Riksbank from a private company, and cash is transported to and within Sweden by so-called cash-in-transit (CIT) service providers. It is stored in depots in different locations in Sweden operated by the Riksbank, CIT service providers, bank-owned companies, and/or by a consortium of banks.

Banks have the primary responsibility to provide cash handling services, i.e. access to cash and the possibility to deposit cash, which is done via retail bank offices, ATMs, and/or other facilities, e.g., retailers. Cash is primarily used by consumers when paying for goods and services provided by retailers and other companies, which means that consumers and companies also store and use cash in their homes and businesses. The study does not include cash-based person-to-person payments since there is not reliable access to data on transactions as well as other factors like transportation of cash by private persons. The main factors in cash payments related to our study therefore concern the production, transportation, and end-of-life handling of Swedish cash.

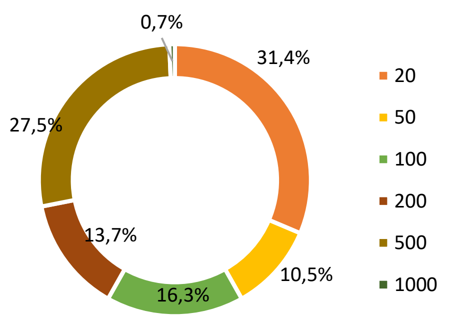
2.1 Cash in circulation and use

Brief overview and cash payment statistics in Figure 1.



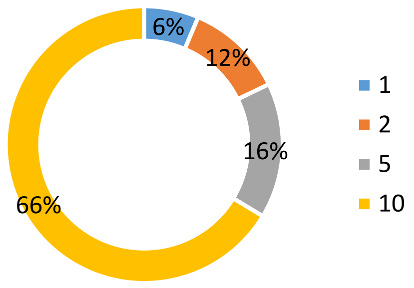
Valid banknotes in circulation and use by value in 2021.

Total 52,989 million SEK



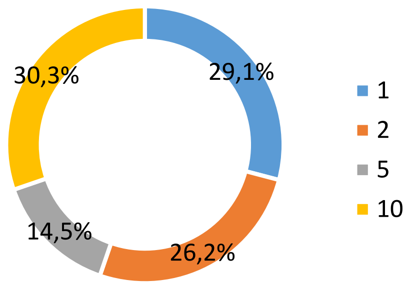
Valid banknotes in circulation and use by quantity in 2021.

Total 153 million banknotes



Coins in circulation by value in 2021.

Total: 3,132 million SEK



Coins in circulation by quantity in 2021.

Total: 686 million coins

Figure 1 Banknotes and coins in circulation by value and quantity in 2021

(Sveriges Riksbank, 2022b and Personal Communication)

2.2 Methodology

The environmental impact of cash payments is analysed by performing a full LCA, in line with ISO standard 14040 (ISO, 2006). LCA is concerned with the environmental impact of a product throughout its whole life cycle from raw material extraction, manufacturing, transport and up to waste disposal. The LCA enable us to identify the impact throughout the system and potential areas for improvement. In this work, the analysis covers the raw material extraction, manufacturing processes, cash logistics as well as disposal of the banknotes and coins. For all the processes under review, raw materials used and emissions in air, water and soil are analysed and evaluated.

The standardised LCA methodology consists of four main stages: the goal and scope definition, inventory analysis, impact assessment and results interpretation. Attributional LCA is selected as the study mainly assesses the potential environmental impacts of the system, rather than the consequences from changes in the studied system. Additionally, a retrospective approach is taken using the data from cash payment systems in 2021. The IPCC Global Warming Potential (GWP) method is used to calculate the climate impact of the cash payment system, which is expressed in CO_2 equivalents (CO_2 eq.) (IPCC, 2007). The LCA model was created using the Simapro Software 9.4.0.1. Life Cycle Inventory (LCI) database,e.g. Ecoinvent 3.7 (May 2023) provides data for the raw and processed materials, energy, fuels and supporting processes in the background system.

2.3 Goals and scope

The objective of the LCA of cash payment is to obtain quantitative insight on the climate impact of cash transactions in Sweden in 2021. Further, the results of the study serve as the basis for comparing the environmental impacts of cash with other payment services.

LCA relies on a "functional unit" (FU), i.e. a quantified description of the function of a product that serves as the reference basis for all calculations regarding impact assessment.

Six functional units are defined for assessing cash payment system:

- FU1: the entire cash payment system in Sweden with all cash transactions in 2021.
- FU2: one cash payment in Sweden in 2021.
- FU3: per-value of cash payment in Sweden in 2021.
- FU4: operational energy use of all cash transactions in Sweden in 2021.
- FU5: operational energy use of one cash payment in Sweden in 2021.
- FU6: operational energy use per-value of cash payment in Sweden in 2021.

2.4 System boundary

The initial stage involves identifying the areas are to be included in the LCA, followed by defining system boundaries. This study is a cradle-to-grave carbon footprint assessment considering impacts across all life cycle stages from extraction of raw materials from the environment through to final disposal at end of life. Some processes may not have a substantial impact on the results and thus may be excluded.

The cash circulation consists of both Swedish banknotes and coins, which have different life cycles and assessed separately. The main processes considered and selected system boundaries are described in Figure 2 below.

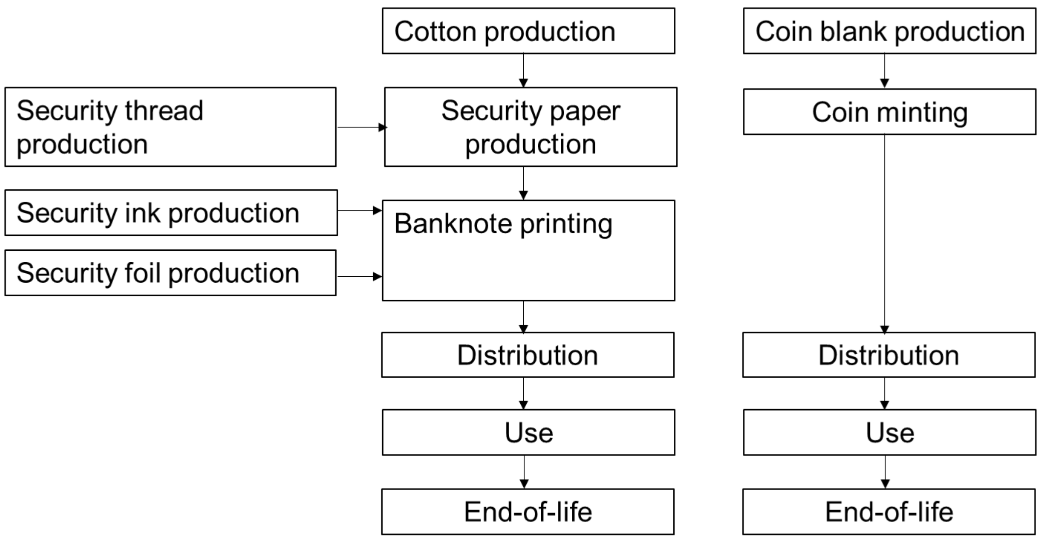


Figure 2 System boundaries for the cash analysis

Table 2 Aspects considered within the scope of the LCA analysis of the cash payments

Bank notes	Coins
• production and processing of raw materials (i.e., cotton, thread, foil and ink), which are combined in two processes, i.e., security paper production and banknote printing; • transport of raw materials (i.e., cotton) from production site to intermediate manufacturing facility (e.g. paper mill,); • manufacturing of products (paper) • printing of bank notes; • disposal of production wastes; • distribution of bank notes from the Riksbank cash centres to cash depots (Bankomat) by CiT company • distribution of bank notes from bank depots to retailers, banks, ATMs, etc • use phase impacts associated with ATMs; • sorting and counterfeit-checking of notes at the Riksbank cash centres; • disposal of banknotes	• production and processing of raw materials (mining of metal ore); • transport of raw materials from production site to intermediate manufacturing facility (e.g. smelter, refinery); • manufacturing of blank (*rondell*) • transport of coin to minting facility; • minting; • distribution of coins from minting facility to the Riksbank cash centres; • distribution of coins from the Riksbank cash centres to cash depots by CiT company; • distribution of coins from cash depots to retailers, banks, etc; • disposal of coins

Aspects that are excluded, considering the confidentiality of the information and these impacts will be negligible compared to the impacts of bank notes themselves:

- Security transports of banknotes paper from paper mill to printworks and banknotes from printworks to the Riksbank cash centre, due to security reasons.
- Security transports on behalf of the commercial banks and other agencies as well as the public's use of banknotes, due to security reasons.
- Impacts of the production of capital goods for manufacturing (machines and facilities) is negligible compared to the impacts of bank notes themselves (Hanegraaf et al., 2020).
- Impacts of packaging of material related to the raw materials is negligible compared to the impacts of bank notes themselves (Hanegraaf et al., 2020).

- The unfit banknotes due to production errors that were not issued in circulation, due to unavailability of the data.

This study models the distribution and utilisation of banknotes within Sweden, which are produced using raw materials sourced from various global regions. The manufacturing locations dictate the geographical scope of the study. For instance, while the cotton paper used for banknotes is produced in Sweden, the bank printing is done in UK.

2.5 Data and assumptions

Background data (mainly raw materials, energies, fuels, and ancillary materials) have mostly been obtained from the Ecoinvent 3.7 database. See Table 3.

Table 3 Summary of material and energy inventory inputs per unit process. FU: entire cash payments in Sweden in 2021

	Unit processes	Amount		Inventory input	Source
A	**Banknote production**				
A1.	Cotton production	4.15	ton	Fibre, cotton {ROW}| fibre production, cotton | Cut-off, U	Primary
		26.98	ton	Fibre, cotton {IN}| fibre production, cotton, organic, ginning| Cut-off, U	Primary
		3.46	ton	Fibre and fabric waste, polyester {GLO}| fibre and fabric waste, polyester, Recycled Content cut-off | Cut-off, S	Primary
		235569	tkm	Transport, freight, sea, container ship {GLO}| transport, freight, sea, bulk carrier for dry goods | Cut-off, U	Primary
A2.	Foil production (safety traps)	0.52	ton	Polyester-complexed starch biopolymer {GLO}| market for | Cut-off, U	Secondary
		0.34	ton	Aluminium, production mix, at plant/RER S Primary	Secondary
		0.76	ton	Maleic unsaturated polyester resin {GLO}| market for | Cut-off, U	Secondary
		0.37	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary
		73.92	MJ	Heat, district or industrial, natural gas {ROW} heat production, natural gas, at industrial furnace low Nox >100 kW cut-off U	Secondary
A3.	Security thread production	0.19	ton	Aluminium, primary, ingot {IAI Area, EU27 &EFTA} | market for | Cut-off, U	Secondary
		0.14	ton	Polyester-complexed starch biopolymer {GLO}| market for | Cut-off, U	Secondary
		0.0001	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary
		0.02	MJ	Heat, district or industrial, natural gas {ROW} heat production, natural gas, at industrial furnace low Nox >100 kW cut-off U	Secondary
A4.	Banknote paper production	26.98	ton	Paper, newsprint {RER}| paper production, newsprint, virgin | Cut-off, U	Primary
		27.09	ton	Chemi-thermomechanical pulp {RER}| chemi-thermomechanical pulp production | Cut-off, U	Primary
		377.88	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
		189.89	MWh	Diesel, low sulfur {Europe without Switzerland}|	
		8703.38	m3	Water, completely softened {RER}| market for water, completely softened | Cut-off, S	Primary
	Waste & energy recovery	5.75	ton-biomass	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
		0.15	ton	Sludge from pulp and paper production {Europe without Switzerland}| treatment of sludge from pulp and paper production, sanitary landfill | Cut-off, S	Primary

	Unit processes	Amount		Inventory input	Source
		0.80	ton	Wastewater, average {Europe without Switzerland}| treatment of wastewater, average, wastewater treatment | Cut-off, S	Primary
A5.	Ink production	2.71	ton	Printing ink, offset, without solvent, in 47.5% solution state {RER}| printing ink production, offset, product in 47.5% solution state | Cut-off, S	Secondary
		1884.88	tkm	Transport, freight, lorry 16-32 metric ton, EURO5 {RER}| market for | Cut-off, U	Secondary
A6	Printing works	3.92	ton	Acetone, liquid {RER}| market for | Cut-off, U	Secondary
		2.51	ton	Waste newspaper {GLO}| market for | Cut-off, U	Secondary
		0.67	ton	Polyethylene terephthalate, granulate, amorphous {Europé without Switzerland}| market for | Cut-off, U	Secondary
		0.18	ton	Polyethylene, low density, granulate {GLO}| market for | Cut-off, U	Secondary
		3.99	ton	Corrugated board box {RER} | market for corrugated board box | Cut-off, U	Secondary
		0.15	ton	Waste paperboard, sorted {GLO}| market for | Cut-off, U	Secondary
		36.96	MWh	Electricity, medium voltage {GB}| market for | Cut-off, S	Secondary
		0.11	ton	Nickel-rich materials {GLO}| market for nickel-rich materials | Cut-off, U	Secondary

2.5.1 Banknote production

In 2021, there were 153 millions of banknotes in circulation and use, shown in Figure 1. Since the exact number of banknotes produced cannot be reported for security reasons, the estimated number of banknotes produced in 2021 is roughly calculated using the lifetime of each denominations, as presented in Table 4. The distribution over the different denominations has been derived from the Riksbank data based on valid banknotes in circulation and use[1]. The banknote distribution has been used to create an estimated (average) banknote, which is used as a tool for calculations.

Table 4 Description of some key physical properties and circulation characteristics of the banknotes

Denomination	Dimensions (mm)[a]	Weight (g)[a]	Estimated lifetime (years)[b]	Estimated number of banknote production (millions)	Notes
20-krona	120 x 66	0.7920	3	12.67	Mass density of paper is 100 g/m^2.
50-krona	126 x 66	0.8316	3	4.44	
100-krona	133 x 66	0.8778	5	4.39	
200-krona	140 x 66	0.9240	6	3.23	
500-krona	147 x 66	0.9702	6	6.79[c]	
1000-krona	154 x 66	1.0164	8	0.13[c]	

[a] Source: (Sveriges Riksbank, 2023b)

[b] Source: Personal communication

[c] 50% hoarding is assumed for higher denominations

The composition of banknote was assumed to be similar to Euro's banknote (Hanegraaf et al., 2020), which 85% of cotton, 9% ink, 1% safety thread and 5% foil.

Subsystems:

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[1] The banknotes from old series that became invalid between 2013 – 2017 are not taken into consideration since they were no longer in use after that (Sveriges Riksbank, 2018b).

2.5.1.1 Cotton production

Cotton is used for the manufacturing of Swedish banknotes. The cotton material types used for pulp and paper production of Swedish banknotes encompass 78% of organic cotton, 10% recycled organic cotton, and 12% cotton linters. Cotton linters, by-products generated alongside cotton fibers in the standard production process, are co-produced during cotton cultivation. The allocation of environmental impacts from cotton production is based on the economic valuation of these by-products. It is estimated that the environmental footprint of 1 kg of cotton linters is equivalent to that of 0.136 kg of raw cotton fibers (Bank of England, 2013). The organic cotton was produced in India (6,409 km average distance to Sweden), recycled organic cotton was produced in Sweden, and cotton linters produced in USA and China (7,745 km average distance to Sweden). The cotton was assumed to be transported to Sweden by transoceanic freight ships.

2.5.1.2 Papermaking

The paper is produced by mixing cotton, additives, chemicals and water into a pulp. During the manufacturing process, most of water is vaporized. An efficiency of 78% of the banknote paper and cotton were applied to estimate the total security paper production (Personal communication). Similar Ecoinvent processes were used to approximate impact of security paper production (approximated by newsprint paper production). The pulping process is a semi-chemical process. The pulp undergoes chemical treatment (bleaching) and mechanical (grinding). There are four chemicals used to bleach the cotton, i.e.: hydrogen peroxide, sodium hydroxide, sequestering agents and stabilizer agents.

The Ecoinvent process for paper and pulping processes were adjusted to only account the paper production process and direct emissions. They have been adapted to avoid double counting of material and energy inputs as well as waste generation by removing the use of water, wood, electricity and the waste output.

The energy use for papermaking is 12 MWh/ton-paper. The electricity production share is 99.5% grid electricity (mainly nuclear and hydropower), 0.3% fuel oil and 0.2% diesel. Total water use was 275 m^3/ton-paper. Total waste generated was 0.23 ton-waste/ton-paper consists of 35% energy recovery from wood waste, 44% energy recovery from paper waste, 2% landfill, 11% hazardous waste, 8% material recycling (mainly metal scraps, irrelevant to paper production, thus excluded). The energy recovery from wood waste and paper waste were estimated using LHV of 18.6 MJ/kg-wood and 13.5 MJ/kg-paper, as well as 30% electrical efficiency.

2.5.1.3 Foil, safety thread, ink production and printing works

As there is no primary data obtained for the security features (foil and thread) used and printing works in the production of Swedish banknotes, the proxy values of banknotes' composition from Hanegraaf et al. (2020) were applied.

2.5.2 Coin production

In 2021, there were 684 millions of coins in circulation (Sveriges Riksbank, 2022a). It is worth noting that a significant number of coins were minted in 2016 in denominations of 1,2 and 5 krona to ensure a sufficient supply of coins for the changeover in that year. Furthermore, coins have a relatively lengthy lifespan of around 25–30 years. As a result, coins manufactured in 2016 or earlier were still being used by customers after 2021. Since the exact amount of coins produced cannot be reported for security reasons, the estimated number of krona coins produced in 2021 is roughly estimated using the lifetime of coins of approximately 30 years.

Table 5 Description of some key physical properties and circulation characteristics of the coins

Denomination	Weight (g)[a]	Estimated lifetime (years)[b]	Estimated number of banknote production (millions)
1-krona	3.6	30	6.6
2-krona	4.8	30	6
5-krona	6.1	30	3.3
10-krona	6.6	30	6.9

[a] Source: (Granath et al., 2016)

[b] Source: Personal communication

2.5.2.1 Coin blank production and minting

The extraction of iron, copper, aluminium, zinc ores, and coal, essential for the production of coins, will occur in multiple locations worldwide. However, this investigation has not conducted any monitoring of the mining sources of these materials, nor have we traced the blank manufacturing facilities where the ores are processed into metal blanks. Statistically speaking, most of the ore will be mined in Brazil, India and Australia and the blank manufacturing will take place in Europe (Granath et al., 2016). Therefore, general data for the metals have been used.

The metal blanks, produced through blank manufacturing, are transported to a smelter in Stolberg in western Germany where alloys are manufactured. These alloys are then distributed to two different facilities, one in Freiberg in eastern Germany and one in Madrid in Spain. At these facilities, shiny coins are produced from the alloys. Both facilities are responsible for producing blank coins for 1 and 2-krona, while only the facility located in Freiberg produces blank coins for 5-krona. After the blank production process, the blanks from both facilities are forwarded to Koninklijke Nederlandse Munt (KNM) in Utrecht for minting.

Table 6 Size, weight and material composition of the coins

(Granath et al., 2016; Sveriges Riksbank, 2018b)

Denomination	1-krona	2-krona	5-krona	10-krona
Diameter, mm	19.5	22.5	23.75	20.5
Thickness, mm	1.79	1.79	1.95	2.9
Weight, g	3.6	4.8	6.1	6.6
Composition (%)				
Steel	94%	94%		
Copper	6%	6%	67%	89%
Aluminum			3%	5%
Zinc			3%	5%
Tin			2%	1%
Recycled copper			22%	
Recycled aluminum			1%	
Recycled zinc			1%	

2.5.3 Operation phase of banknotes and coins

The Riksbank serves as the starting and ending point for the circulation of money in society, as it produces and destroys banknotes and coins when necessary. As of 2022, Bankomat operates four cash depots, which are responsible for transferring cash to banks and retailers via cash-in-transit services. The general public has access to cash through ATMs, bank accounts, and the retail trade. See Figure 3.

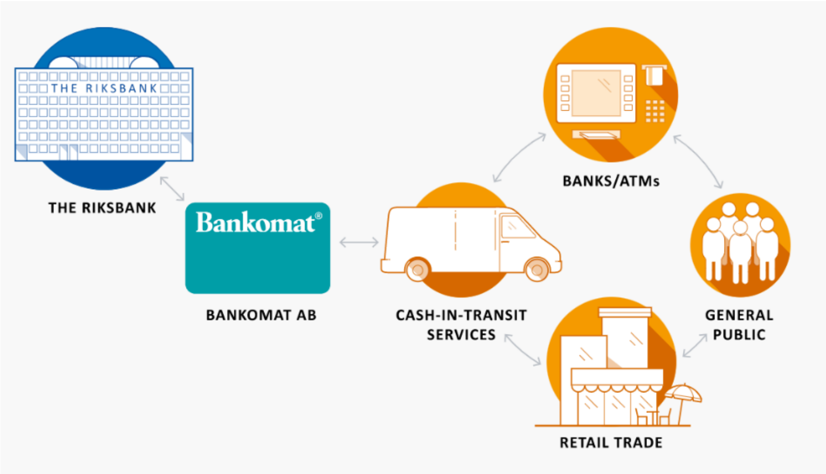


Figure 3 Circulation flow of cash in Sweden.

Source: (Sveriges Riksbank, 2022b)

2.5.3.1 Transport

a. Banknotes

The transportation of banknotes for LCI data includes transport from the Riksbank's warehouse to the cash depots and from the depot to various points of circulation which includes transportation to banks, ATMs, and other financial entities. This encompasses a considerable total distance of 5,391,952 kilometers (Personal Communication).

The type of vehicles used for transportation of banknotes are Euro 5 and Euro 6. The share of Euro 5 vehicles was 57.45% and Euro 6 vehicles are 42.55%. The total fuel consumptions are 821,297 liter of diesel fuel (78%) and 233,384 liter of HVO (22%). The climate impact includes fuel production, fuel distribution and fuel consumption. The climate impact from transporting banknotes includes the downstream (direct emissions per km from vehicle manufacturers) and the upstream emissions (fuel production and distribution). It is assumed that the consumption of HVO does not result in direct emissions, given that the emissions are biogenic.

b. Coins

Once the coins are minted at KNM, they are transported via truck to a port (Velsen Noord). At the port, the coins are then loaded onto ships, which are responsible for transporting them to a designated port in Central Sweden. Upon arrival, the coins are received at the Riksbank's warehouse and stored until further arrangements are made. Subsequently, the coins are transported via truck from the warehouse to cash handling office in Broby, Sigtuna. From the Riksbank's distribution facility, the coins are shipped out of the country by cash-in-transit (CiT) company. The CiT companies pick up the coins by truck and drive them to their intermediate storage facilities around the country.

Table 7 Transportation of coins

	Transportation mode	Total distance (km)	Sources of LCI data
Transport from Stolberg to Madrid and Freiberg	Truck	101,900	(Granath et al., 2016)
From Freiberg and Madrid to Utrecht	Truck	109,200	
From alloy manufacturer to Sweden	Truck and ship	122,791	

2.5.3.2 ATM

The Swedish market for ATMs consists of ATM owners (Bankomat, Nokas and ICA Banken), suppliers of ATMs (Diebold Nixdorf and NCR) and suppliers of the machines' software (Evry).

Table 8 Energy demand of ATMs

Energy use of an ATM	Value		Unit
	Stand-by	Active	
ATM - indoor	3.27	5.34	kWh/ATM.day
ATM - outdoor	3.27	5.34	kWh/ATM.day
CRS - indoor	4.83	11.78	kWh/ATM.day
CRS - outdoor	4.83	11.78	kWh/ATM.day
Additional heating*		10.00	kWh/ATM.day

* If the temperature drops below zero Celsius a heater is required for through the wall ATMs that significantly increases energy consumption. On average, the heater is estimated to be needed for approximately 20% of the days each year, based on the total number of days with temperatures below 0°C.

Embodied carbon in ATM is based on Environmental Product Declaration of ATM models ProCash 8000 and CINEO C4060, with lifetime of 8 years. The GWP from manufacture and recycling processes are considered in the analysis.

2.5.3.3 Cash handling

Counting and checking/sorting banknotes

The energy use in cash depots of the Riksbank was 1300 kWh consisting of 2 counting machines with average operation of 2 hours per week and energy consumption of 12.5 kWh per machine. Energy use in other cash depots consisting of 85 machines was also estimated by assuming average operation of 2 hours per week and energy consumption of 12.5 kWh per machine.

2.5.4 Packaging

Packaging was used for banknotes during their transportation to cash depots and circulation. Two types of plastics were used, 2 339 kg virgin plastics and 11 211 kg recycled plastics. There were more than 2 million of high safety bags were used, however due to no primary data exists on the specification of the bags, this factor is excluded from the analysis.

2.5.5 End-of-life

2.5.5.1 Banknotes

The share of returned banknotes that will be destroyed for final disposal was assumed to be similar to the returned banknotes that became invalid in 2016 and 2017, which was 92% (Sveriges Riksbank, 2018b). When the Riksbank finally destroys the returned banknotes, the waste material is burned in the incineration plant in Sweden for energy recovery.

2.5.5.2 Coins

Coins are recycled, i.e. melted down and the metal recycled, either into new coins or something else. The share of returned coins that will be recycled is presented in Table 9.

Table 9 The value of returned coins that became invalid in 2017 and the percentage of returned coins in relation to 30 September 2015.

(Sveriges Riksbank, 2018b)

Denomination	Returned, SEK millions	Returned, per cent
1-krona	702	50
2-krona	1	50
5-krona	730	55

2.6 Scenario analysis

2.6.1 Scenario Switching Fuel from Diesel to HVO

As outlined in Section 2.5.3.1, 78% of fuel used for transporting the banknotes and coins is diesel fuel. This scenario assesses the switch from diesel-based vehicles to HVO-based vehicles. This implies that emissions from transport of banknotes only account for the upstream emissions of HVO production and distribution.

2.6.2 Scenario Switching Diesel to Electric Vehicles

This scenario analyses the shift of diesel-based trucks to electric vehicles. The total diesel consumption of 821,297 liter is equal to 28,515 GJ of electricity (diesel heating value is 42.6 MJ/kg and density is 0.815 kg/l). In this scenario, the electricity is supplied by the Swedish grid.

2.7 Results and discussions

The total climate effects from cash payments in 2021 is 2735 tCO_2eq, 8.7 gCO_2/transaction, and 0.03 gCO_2/krona-transacted (see Table 10). The comparison with other products or services is illustrated in Figure 4.

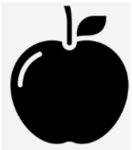
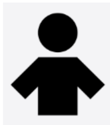
			
The total carbon footprint of all cash transactions in Sweden is equivalent to 5161 passengers flying one way from Stockholm to Beijing in economy class[2].	The carbon footprint of 23 cash transactions in Sweden is equivalent to the carbon footprint of producing 1 kg of apple in Sweden[3].	The average carbon footprint of one cash transaction per person above 18 years old in Sweden[4] is equivalent to 3.3 km drive of a 2020 VOLVO V60[5].	All cash transactions are equal to the per capita CO_2 emissions/year of nearly 855 persons in Sweden[6].

Figure 4 Comparison of the climate effects of Swedish cash and other products or services

[2] The environmental impact of a passanger flying economy class direct one way flight from Stockholm to Beijing is 0.53 tCO_2 (Carbon Fooptrint Ltd, n.d.)

[3] The environmental impact of 1 kg apple production in Sweden is 200 gCO_2 (RISE, 2021)

[4] Total population in Sweden above 18 years in 2021 is 8,189,264 (Statistikmyndigheten, 2023)

[5] The environmental impact of driving 1 km of a 2020 VOLVO V60 is 100 gCO_2 (Carbon Fooptrint Ltd, n.d.)

[6] Per capita Swedish emissions is 3.2 tCO_2/year (IEA, 2023)

The transport of banknotes and coins contributed to 58% of total GWP, which is due to long transport distances between cash depots, banks and ATMs as Sweden is a sparsely populated country with large geographic distances. Switching the diesel-fuelled vehicles to HVO reduces the carbon footprint of all cash transactions to 2193 tCO_2eq or 7 gCO_2/transaction, a reduction of 20%. Replacing the diesel car to electric vehicles provides opportunities for reducing the climate impact of cash payments in Sweden further down to 5 gCO_2/transaction.

Table 10 The climate impact of cash payment in Sweden in 2021

Functional Unit (FU) - 1	All cash transactions in 2021		
	tCO2eq	tCO2eq, scenario: switching fuel from diesel to HVO	tCO2eq, scenario: switching diesel to electric vehicles
Banknote production	122	122	122
Coin production	383	383	383
Transport of banknotes and coins	1711	1168	550
Cash handling	3.3	3.3	3.3
ATM	626	626	626
Packaging of banknotes	9	9	9
End-of-life of banknotes and coins	-119	-119	-119
Total	2735	2193	1575
Functional Unit (FU) - 2	One cash transaction in 2021		
	gCO2/transaction	gCO2/transaction, scenario: switching fuel from diesel to HVO	gCO2/transaction, scenario: switching diesel to electric vehicles
Average one cash transaction	8.7	7.0	5.0
Functional Unit (FU) - 3	Per-value of cash transaction in 2021		
	gCO2/krona-transacted	gCO2/krona-transacted, scenario: switching fuel from diesel to HVO	gCO2/krona-transacted, scenario: switching diesel to electric vehicles
Average one krona cash transacted	0.03	0.02	0.02

Functional Unit (FU) - 4	Operational energy use of all cash transactions in 2021
	tCO2eq
Transport of banknotes and coins	1077
Cash handling	3.3
ATM	149
Total	1230
Functional Unit (FU) - 5	Operational energy use of one cash transaction in 2021
	gCO2/transaction
Average one cash transaction	3.90
Functional Unit (FU) - 6	Operational energy use per-value of cash transaction in 2021
	gCO2/krona-transacted
Average one krona cash transacted	0.01

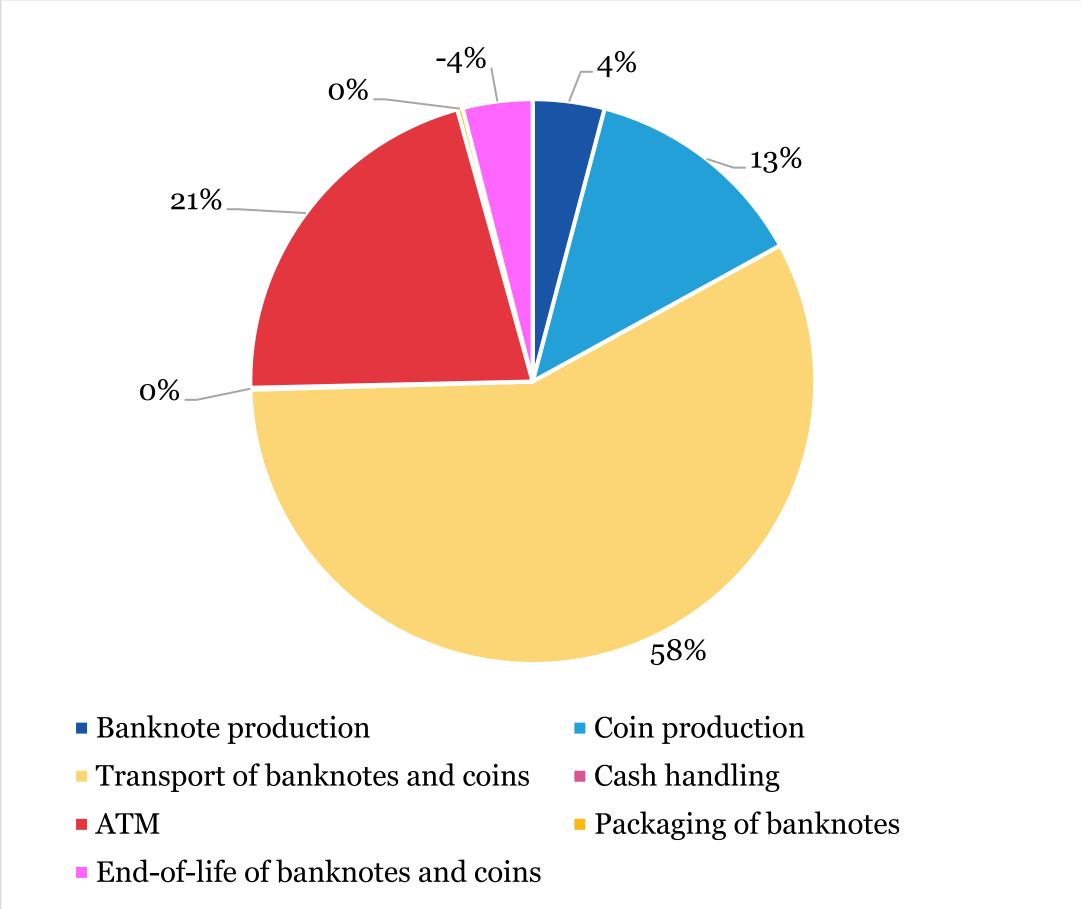


Figure 5 Summary of climate impact cash payment (FU1: all transactions in 2021)

3 Climate impact of Swedish card payments

3.1 Card use

In 2021, Swedish consumers carried out 3.33 billion debit card transactions amounting SEK 943 billion (Sveriges Riksbank, 2023a, 2022a). While half of all payments in Sweden were made using cards, marking them as the dominant form of transaction in the country, only a four percent of payments were conducted in cash (Sveriges Riksbank, 2023a). Credit card usage in Sweden is comparatively low, with a total of 0.5 billion credit card transactions and a value of SEK 239 billion (Sveriges Riksbank, 2023a, 2022a). Alongside the growing popularity of Swish, a variety of other payment methods are also on the rise. The survey data indicates that 16% of respondents have access to alternative mobile applications for transactions, including well-known platforms like Samsung Pay, Google Pay and Apple Pay (Sveriges Riksbank, 2022a). These mobile payment systems, designed to complement traditional banking systems, enable users to digitally store their debit or credit card information on their smartphones, facilitating contactless payments through their devices.

3.2 Methodology

The environmental impact of card payments is analyzed by performing a full LCA, in line with ISO standard 14040 (ISO, 2006). In this work, the analysis covers the raw material extraction, card, Point of Sale (POS) terminal and datacenter manufacturing processes, operational energy use as well as disposal. For all the processes under review, raw materials used and emissions in air, water and soil are analyzed and evaluated.

Attributional LCA is selected as the study mainly assesses the potential environmental impacts of the system, rather than the consequences from changes in the studied system. Additionally, a retrospective approach is taken using the data from card payment systems in 2021, which served as the reference year for the assessment. The IPCC Global Warming Potential (GWP) method is used to calculate the climate impact of the cash payment system, which is expressed in CO_2 equivalents (CO_2 eq.) (IPCC, 2007). The LCA model was created using the Simapro Software 9.4.0.1. LCI database, e.g. Ecoinvent 3.7 (May 2023) provides the life cycle inventory data for the raw and processed materials, energy, fuels and supporting processes in the background system.

3.3 Goals and scope

The objective of the LCA of card payment is to obtain quantitative insight on the climate impact payment, based on the product system for POS debit card and credit card payments in Sweden in 2021.

Six functional units are defined for assessing cash payment system:

- FU1: the entire card payment system in Sweden with all card transactions in 2021.
- FU2: one card payment in Sweden in 2021.
- FU3: per-value of card payment in Sweden in 2021.
- FU4: operational energy use of all card transactions in Sweden in 2021.
- FU5: operational energy use of one card payment in Sweden in 2021.
- FU6: operational energy use per-value of card payment in Sweden in 2021.

Due to the unavailability of data to distinguish between POS and online shopping, we attribute the entire climate impact to POS transactions. The environmental impact of debit cards serves as a proxy for credit cards, although it's important to note that the energy consumption associated with billing is unique to the credit card payment system.

3.4 System boundary

Cradle-to-grave carbon footprint assessment is performed considering impacts across all life cycle stages from extraction of raw materials from the environment through to final disposal at end of life.

The debit card payment system is divided into three subsystems: the debit card, used by consumers to initiate a debit card payment at the POS, the payment terminal at the POS, which reads and approves debit card payments, and the datacenters, which process the debit card payments, following approach by (Lindgreen et al., 2018).

The main processes considered and selected system boundaries are described in Figure 6.

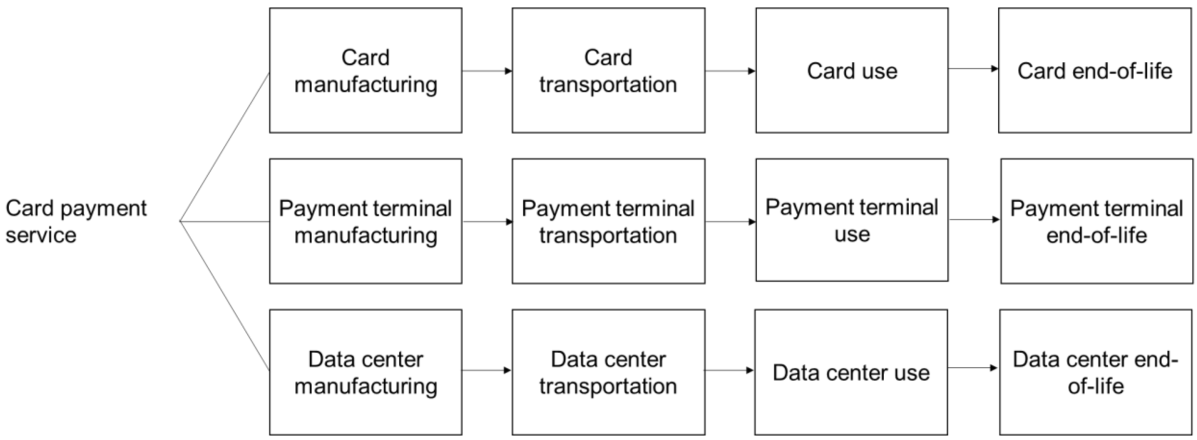


Figure 6 Schematic overview of the boundaries within the card payment system

The following aspects are considered within the scope of this assessment:

- Raw material extraction and the manufacturing of card, POS terminal and datacenter
- Transportation of card and POS terminal
- Use phase impacts associated with payment terminal and data center
- Disposal of card and POS terminal

Aspects that are excluded, considering these impacts will be negligible compared to the impacts of debit card payment themselves:

- Production of capital goods for manufacturing (machines and facilities)
- Material and energy use for producing the user devices (e.g., smartphone, laptop, etc).
- Printing receipt
- Packaging of material
- Transportation and end-of-life of data center (Whitehead et al., 2015)

3.5 Data and assumptions

Background data (energies, fuels) have mostly been obtained from the Ecoinvent 3.7 Database. See Table 11.

Table 11. Summary of energy inventory inputs per unit process. FU: entire card payments in Sweden in 2021

	Unit processes	Amount	Unit	Inventory input	Source
A	**CARD LIFE CYCLE**	4.5	million card	Swedish Banker's Association	Secondary
		23	ton-card	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary

B	**POS TERMINAL LIFE CYCLE**				
B1	POS terminal production	55013	terminal	POS terminal production carbon footpring	Secondary
B2	POS terminal transport	70142	tkm	Transport, freight, sea, container ship {GLO}| transport, freight, sea, bulk carrier for dry goods | Cut-off, U	Secondary
B3	POS terminal use	760	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary
B4	POS terminal end-of-life	11	ton	Waste electric and electronic equipment {GLO}| market for waste electric and electronic equipment | Cut-off, S	Secondary

C	**DATACENTER**				
C1	Datacenter production	0.04	MW	Proxy of typical annual embodied carbon in European Datacenter	Secondary
C2	Datacenter use				
	Bank	114	MWh	Electricity, high voltage {SE}| electricity production, wind, >3MW | Cut-off, U	Primary
		7	MWh	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U	Primary
	Payment networks	230	MWh	Electricity, high voltage {GB}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, S	Primary
		153	MWh	Electricity, low voltage {GB}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S	Primary
	Merchants	14	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary

3.5.1 Cards

Secondary data from the website of a key supplier, renowned for providing bank cards in the EU, was utilized to estimate the life cycle carbon footprint of the cards. The estimated average carbon footprint of a standard PVC banking card is approximately 150 $gCO_2eq.$, with 60g attributed to the card body material, 50 g from manufacturing processes, and the remaining 40 g. arising from other factors such as transport and packaging (Thales, 2023).

A typical banking card consists of multiple layers of laminated plastic, such as PVC, and ink used for printing cards featuring a magnetic stripe. Metal oxide particles with solvents are often the basis for inks (Thales, 2024a). PVC is a composite material made from polymers of vinyl acetate and vinyl chloride. Approximately 40% of the PVC molecule is derived from petroleum, while the remainder is chlorine. This material exhibits density and resistance to water. When polyvinyl chloride acetate is blended with plasticity-enhancing additives like phthalates, it yields a robust and flexible material. Similar to other well-known petroleum-based plastics, PVC is not biodegradable (Thales, 2024b).

In the disposal phase, it is presumed that all debit cards will ultimately be discarded as part of the general municipal waste and subsequently incinerated. The estimated total energy recovered from incinerating a single debit card, based on the assumption that the card weighs 5 grams, with PVC's lower heating value (LHV) being 41.3 MJ/kg and a power generation efficiency of 30%, is calculated for this process.

3.5.2 Payment terminals

The number of POS terminals in Sweden in 2021 was 275,066 (Sveriges Riksbank, 2022a). The impact assessment of POS terminals considers the transactions made at the physical store. Given there was 2,930 million of debit card transactions, 411 million of credit card transactions and approximately 36.5 million of payment app transactions in 2021 (Sveriges Riksbank, 2022a), the average number of transactions per terminal in 2021 was 12,279 and the average number of transactions per terminal per day was 34. It should be noted that POS terminals support transactions beyond just debit cards, so the environmental impact associated with the manufacturing of POS terminals should be allocated among debit cards, credit cards, and payment apps for payment at the physical store.

The material inventory of a ‘model’ terminal was retrieved from study by (Lindgreen et al., 2018), which include polycarbonate casing, LCD screen, rubber keypad, lithium battery or power supply, thermal printing paper, and internal electrical components such as the printed circuit board and integrated circuits. This inventory also accounted for manufacturing processes such as injection moulding, metalworking, and assembly. The carbon footprint was subsequently estimated using data from the Ecoinvent v3.7. The typical lifetime of a payment terminal is assumed to be 5 years. The energy consumption of the terminal was estimated using proxy data from (Lindgreen et al., 2018) with the average energy use per transaction per terminal calculated to be 0.23 Wh.

The end-of-life of a POS terminal is modelled in Simapro using Waste electric and electronic equipment {GLO}| market for waste electric and electronic equipment | Cut-off, S.

3.5.3 Datacenters

Data centers play a crucial role in various stages of the payment process, spanning across multiple entities such as merchants, acquiring banks, issuing banks, and card network operators. The primary data source from the issuing and acquiring bank data centers put specific focus on the total energy consumption attributed to the card payment of a Swedish bank. This estimation takes into account the total card transactions, electricity and cooling use of a Swedish bank's data center. The clearing counterparts (RIX system) of the Riksbank is excluded, which leads to a slight underestimation of energy use.

In the case of merchants, the energy use for their data centers follows the methodology outlined by (Lindgreen et al., 2018). We attribute approximately 12% of the issuing bank's datacenter energy use to merchants, given their role in 'forwarding' the transaction. The estimation of operational energy use per transaction is derived from data obtained from various payment actors, as detailed in Table 12.

Table 12 Operational energy use per card transaction

Actors	Estimated energy use per transaction (kWh/transaction)	Source
Card network operator	0.0001	Personal communication
Swedish bank*	0.000031	Personal communication
Merchants	0.0000038	12% of bank's data center

*Electricity and cooling

To estimate the embodied carbon of data centers, which refers to the carbon footprint associated with their manufacturing, proxy data was used. This data was based on the carbon footprint of a typical EU data center with an IT power capacity of 2 MW and Power Usage Effectiveness (PUE) of 1.7 reported by SINTEF (Moen et al., 2022), and by assuming a linear relationship between the carbon footprint and the IT power capacity. The average PUE value for data centers in Sweden is 1.56 (RADAR, 2020). IT infrastructure typically includes servers, storage systems, and network equipment arranged in server racks in corridors, as well as necessary cooling, ventilation, power supply, security, and surveillance systems. These main components of data centers including building structures, each having varying lifespans, significantly impact their overall carbon footprint; for detailed assumptions and specifications of these reference data centers, see (Moen et al., 2022). The estimated annualized embodied carbon for all data centers related to card payment processing, calculated over a 30-year operational period, is 70 tons of CO_2 eq. per year, based on their collective IT capacity.

3.6 Scenario analysis

3.6.1 Scenario Recycled PVC Card

The first analysis focused on substituting the card material with recycled PVC. The recycled PVC replaces first-use plastic in bank cards while using plastic waste from the packaging and printing industries. The material requirement for PVC is 7.5 grams per card, and recycled PVC demonstrates a carbon footprint 96% lower than virgin PVC (Lewandowski and Skórczewska, 2022).

3.6.2 Scenario Extending POS Terminal's Lifetime

The second analysis assessed the impact of increasing the reuse factor of the POS terminal. Specifically, we examined the effects of doubling the reuse factor, extending the terminal's lifetime from 5 years to 10 years.

3.6.3 Scenario Reducing the Production of Physical Card

The third scenario evaluated the implications of reducing 50% of physical card resulting the increase in using the digital payment through payment-app.

3.7 Results and discussions

The total climate effects from card payments in 2021 in this report is 3242 tCO_2eq, 0.85 gCO_2/transaction, and 0.003 gCO_2/krona-transacted (see

Table 13). The comparison with other products or services is illustrated in Figure 7.

Introducing recycled PVC for card material could bring down the climate impact to 0.78 gCO_2/transaction. Reducing the production of physical card to 50% and replace them with apps offers a slight environmental impact reduction to 0.76 gCO_2/transaction. Additionally, extending the lifetime of a POS terminal from 5 to 10 years has the potential to further reduce the impact to 0.52 gCO_2/transaction.

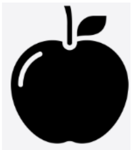
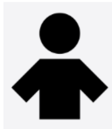
			
The total carbon footprint of all card transactions in Sweden is equivalent to 6118 passengers flying one way from Stockholm to Beijing in economy class[7].	The carbon footprint of 236 card transactions in Sweden is equivalent to the carbon footprint of producing 1 kg of apple in Sweden[8].	The average carbon footprint of one card transaction per person above 18 years[9] old in Sweden is equivalent to 4 km drive of a 2020 VOLVO V60[10].	All card transactions are equal to the per capita CO_2 emissions/year of nearly 1013 persons in Sweden[11]

Figure 7 Comparison of the climate effects of Swedish card transaction and other products or services

[7] The environmental impact of a passanger flying economy class direct one way flight from Stockholm to Beijing is 0.53 tCO_2 (Carbon Fooptrint Ltd, n.d.)

[8] The environmental impact of 1 kg apple production in Sweden is 200 gCO_2 (RISE, 2021)

[9] Total population in Sweden above 18 years in 2021 is 8,189,264 (Statistikmyndigheten, 2023)

[10] The environmental impact of driving 1 km of a 2020 VOLVO V60 is 100 gCO_2 (Carbon Fooptrint Ltd, n.d.)

[11] Per capita Swedish emissions is 3.2 tCO_2/year (IEA, 2023)

Table 13 The climate impact of card payment in Sweden in 2021

Functional Unit (FU) - 1	All card transactions in 2021			
	tCO2eq	tCO2eq, extending POS terminal lifetime	tCO2eq, recycled PVC card	tCO2eq, 50% physical card
Card	668	668	406	334
POS terminal	2530	1279	2530	2506
Datacenter	44	44	44	44
Mobile device use				19
Total	3242	1991	2980	2904
Functional Unit (FU) - 2	One card transaction in 2021			
	gCO2/transaction	gCO2/transaction, extending POS terminal lifetime	gCO2/transaction, recycled PVC card	gCO2/transaction, without physical card
Average one card transaction	0.85	0.52	0.78	0.76
Functional Unit (FU) - 3	Per-value of card transaction in 2021			
	gCO2/krona-transacted	gCO2/krona-transacted, extending POS terminal lifetime	gCO2/krona-transacted, recycled PVC card	gCO2/krona-transacted, without physical card
Average one krona card transacted	0.003	0.002	0.003	0.002
Functional Unit (FU) - 4	Operational energy use of all card transactions in 2021			
	tCO2eq			
POS terminal	28			
Datacenter	44			
Total	73			
Functional Unit (FU) - 5	Operational energy use of one card transaction in 2021			
	gCO2/transaction			
Average one card transaction	0.02			
Functional Unit (FU) - 6	Operational energy use per-value of card transaction in 2021			
	gCO2/krona-transacted			
Average one krona card transacted	0.0001			

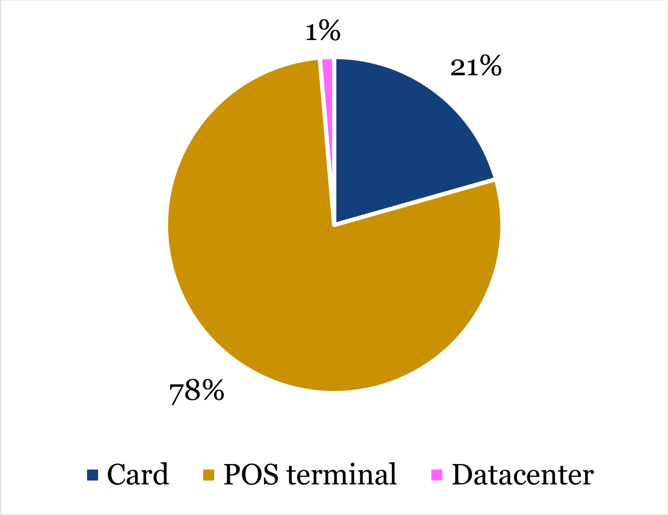


Figure 8 Summary of climate impact card payment (FU1: all transactions in 2021)

4 Climate impact of Payment-Apps

4.1 Overview of payment app and statistics

As payments are continuing to be made digitally, payment applications such as Apple Pay and Google Pay are becoming more popular. To calculate the total number of in-store person-to-business (P2B) transactions made via payment apps, we begin with data from a household survey on payment patterns in 2021 conducted by the Riksbank in 2023, which indicates that 1% of all in-store P2B transactions are made through means other than cash, card, and Swish (Riksbank, 2022). Consequently, the remaining 99% of in-store P2B transactions, amounting to approximately 3,645 million, are conducted via card and Swish. Out of this total, it is assumed that 1%, or 36.45 million transactions, are executed through payment apps.

The estimated value of payment app transactions, totalling 10.3 billion SEK, is calculated by multiplying the estimated volume of cash transactions with the average value of a debit card transaction in 2021, which was 283 SEK.

4.2 Methodology

In estimating the climate impact of payment app transactions, the climate impact of card payments is used as a proxy. This includes considering the proportional impact attributable to both the card itself and the POS terminal, according to the number of transactions. This methodology allows for a more accurate assessment of the environmental footprint of payment apps by drawing parallels with the well-established infrastructure and usage patterns of card payments.

4.3 Goals and scope

The objective of the LCA of payment App is to obtain quantitative insight on the climate impact payment, based on the product system for POS and energy use in device for payment App payments in Sweden in 2021.

Six functional units are defined for assessing payment-app system:

- FU1: the entire payment-app system in Sweden with all card transactions in 2021.
- FU2: one payment-app transaction in Sweden in 2021.
- FU3: per-value of payment-app transaction in Sweden in 2021.
- FU4: operational energy use of all payment-app transactions in Sweden in 2021.
- FU5: operational energy use of one payment-app transaction in Sweden in 2021.
- FU6: operational energy use per-value of payment-app transaction in Sweden in 2021.

4.4 System boundary

The system boundary of the payment app encompasses the card payment system and the energy for device use. As explained in Section 3.4, for card climate impact, cradle-to-grave carbon footprint assessment is performed considering impacts across all life cycle stages from extraction of raw materials from the environment through to final disposal at end of life. The material and energy use for producing the user devices (e.g., smartphone, laptop, etc) are excluded in the analysis.

4.5 Data and assumptions

The effect of card payment system attributed to payment app is 1% since the majority of payment app users still hold physical bank card (Personal communication). The energy use in the device for payment app system is assumed to be similar to Swish payment. See data and assumptions for Swish payment in Section 6.5.2.

Table 14 Summary of energy inventory inputs per unit process. FU: entire payment-app transactions in Sweden in 2021

	Unit processes	Amount	Unit	Inventory input	Source
A	**DATA CENTER**				
A1	Datacenter production	0.000	MW	Proxy of typical annual embodied carbon in European Datacenter	Secondary
A2	Datacenter use				
	Bank	1.1	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
		0.1	MWh	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U	Primary
	Payment networks	2.2	MWh	Electricity, high voltage {GB}| electricity production, wind, 1-3MW turbine, onshore | Cut-off, S	Primary
		1.5	MWh	Electricity, low voltage {GB}| electricity production, photovoltaic, 570kWp open ground installation, multi-Si | Cut-off, S	Primary
	Merchants	0.01	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary
B	**CARD LIFE CYCLE**	0.43	tCO2eq	1% of Total GWP of card without allocation	Secondary
C	**POS TERMINAL LIFE CYCLE**	6.37	tCO2eq	1% of Total GWP of card without allocation	Secondary
D	**DEVICE USE**	9.97	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary

4.6 Results and discussions

For all transactions in 2021, the total climate impact is 31.27 tCO_2eq. This impact is distributed across different categories, with card transactions contributing 6.37 tCO_2eq, POS terminal activities contributing 24.11 tCO_2eq, data center activities contributing 0.4 tCO_2eq, and device use contributing 0.36 tCO_2eq. The comparison with other products or services is illustrated in Figure 9.

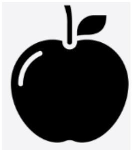
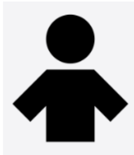
		
The total carbon footprint of all payment-app transactions in Sweden are equivalent to 59 passengers flying one way from Stockholm to Beijing in economy class[12].	The carbon footprint of 233 payment-app transactions in Sweden is equivalent to the carbon footprint of producing 1 kg of apple in Sweden[13].	All payment-app transactions are equal to the per capita CO_2 emissions/year of nearly 10 persons in Sweden[14]

Figure 9 Comparison of the climate effects of Swedish payment app transaction and other products and services

The environmental impact of a single payment app transaction in 2021 is quantified at 0.86 gCO_2/transaction, which is slightly higher than the impact of card payments due to the use of energy in mobile devices and the fact that physical cards also were distributed to app users even if these physical cards were not used. When considering the per-value environmental impact of payment app transactions in Sweden in 2021, the average environmental impact per krona transacted is 0.003 gCO_2.

[12] The environmental impact of a passanger flying economy class direct one way flight from Stockholm to Beijing is 0.53 tCO_2 (Carbon Fooptrint Ltd, n.d.)

[13] The environmental impact of 1 kg apple production in Sweden is 200 gCO_2 (RISE, 2021)

[14] Per capita Swedish emissions is 3.2 tCO_2/year (IEA, 2023)

Table 15 The climate impact of payment-app in Sweden in 2021

Functional Unit (FU) - 1	All transaction in 2021
	Total GWP (t CO_2 eq/FU)
Card	6.37
POS terminal	24.11
Datacenter	0.4
Mobile device use	0.36
Total	31.27
Functional Unit (FU) - 2	One payment app transaction in 2021
	gCO_2/transaction
Average one payment-app transaction	0.86
Functional Unit (FU) - 3	Per-value of payment-app transaction in Sweden in 2021
	gCO_2/krona-transacted
Average one krona payment-app transacted	0.003
Functional Unit (FU) - 4	Operational energy use of all payment-app transactions in 2021
	tCO_2eq
POS terminal	0.283
Datacenter	0.432
Mobile device use	0.363
Total	1.079
Functional Unit (FU) - 5	Operational energy use of one payment-app transaction in 2021
	gCO_2/transaction
Average one payment-app transaction	0.030
Functional Unit (FU) - 6	Operational energy use per-value of payment-app transaction in 2021
	gCO_2/krona-transacted
Average one krona payment-app transacted	0.00010

5 Climate impact of credit transfer services – Giro payment

5.1 Credit transfer services: brief overview and payment statistics

A Giro payment could, for instance, be when a person makes a purchase in a store which is paid via an invoice. In Sweden, both credit transfers and direct debits are processed by Bankgirot, the clearing house owned by the major banks, and settled on accounts with the Riksbank (Sveriges Riksbank, 2023a). The total transactions and value of transactions for Giro payment for retail payment in 2021 is presented in Table 16.

Table 16 Total payments credit transfer services – Giro

Type of Giro transactions	Number of transactions (million)	Value of transactions (billion SEK)
Number of electronic/digital transactions (millions), excluding payment-app	1,610 (1)	17,992 (1), (2)
Number of paper-based invoice transactions (millions)	29 (2)	733 (1), (2)
Total	1,639	18,725

(1) Source: (Sveriges Riksbank, 2023a)

(2) Source: (Sveriges Riksbank, 2022a)

5.2 Methodology

The LCA method requires the calculation of emission impact for the entire life cycle of the individual components used to create the ICT system, whose value has to be considered. For what concerns credit transfer services, the energy used for the production of servers, for its transportation and installation, for its usage and disposal at the end of its useful life should therefore be considered. However, for many ICT goods and services like digital payment system, the use stage dominates the total emissions (Tiberi, 2021). Usage stage emissions are primarily caused by the ICT hardware's use of electricity (Tiberi, 2021). In this case, the assessment for Giro payments does not represent a complete LCA, but could better be described as a screening LCA, where only energy and GHG emissions are considered, and the end-of-life is not considered.

5.3 Goals and scope

The objective of the LCA of credit transfer services – Giro is to obtain quantitative insight on the climate impact payment, based on the product system for POS and energy use in device for Giro payments in Sweden in 2021.

Three functional units are defined for assessing Giro payment system:

- FU1: the entire Giro payment system in Sweden with all Giro transactions in 2021. This FU also represents the operational energy use.
- FU2: one Giro payment in Sweden in 2021.
- FU3: per-value of Giro payment in Sweden in 2021

5.4 System boundary

The carbon footprint assessment for Giro considers impacts on operational energy use in related datacenters, transport for paper-based invoice and costumers' device. Data centers process electronic payment transactions. Processing takes place into following steps: the authorization, the payment/clearing and the settlement.

Aspects that are excluded, considering these impacts will be negligible or outside the scope of the study:

- Production of capital goods for manufacturing (machines and facilities)
- Material and energy use for producing the user devices (e.g., smartphone, laptop, etc).
- Energy use in BankID
- Printing receipt

The study has excluded the production and disposal of devices used for accessing digital payment (e.g., Swish, payment app, Giro) from the system boundary. To determine what should be excluded from the study, a cut-off criteria was applied, which is based on the device's usage time as a proxy for energy. The energy consumed by the device for viewing statements has already been considered in the study. Obtaining data on the embodied energy in devices is challenging and varies greatly. As a result, the cut-off criteria used in this study relates to the amount of time the device is used to view a statement compared to its total usage time over its lifespan. These devices, such as laptops, PCs, tablets, and smartphones, are multifunctional and are not solely purchased for the purpose of using payment apps. Therefore, since insignificant percentage of the device's total lifespan of active usage is spent on the app, it is excluded from the inputs to the study.

5.5 Data and assumptions

Background data (energies, fuels) have mostly been obtained from the Ecoinvent 3.7 Database (May 2023). See Table 17.

Table 17. Summary of energy inventory inputs per unit process. FU: entire Giro payments in Sweden in 2021

	Unit processes	Amount	Unit	Inventory input	Source
A	**DATACENTER USE**				
	Bank	51	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
		3	MWh	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U	Primary
	Automated clearing house	91	MWh	Electricity, high voltage {SE}| electricity production, wind, >3MW | Cut-off, U	Primary
	Merchant	6.5	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary
B	**DEVICE USE**	440	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
C	**TRANSPORT**				
	Paper based invoice	1450	km	Direct emissions per km from vehicle manufacturer	Secondary
		315	liter	Diesel, low sulfur {Europe without Switzerland}|	Secondary
		185	liter	HVO Production - Distribution	Secondary

5.5.1 Datacenters

The energy related datacenters can be divided into four subsystems: i) acquiring bank datacenters; ii) automated clearing house datacenters; iii) merchant datacenters. The primary data source from the issuing and acquiring bank data centers put specific focus on the total energy consumption attributed to the Giro payment of a Swedish bank. This estimation takes into account the total Giro transactions, electricity and cooling use of a Swedish bank's data center. The estimation of merchants' data centers is similar to the card payment, as outlined in Section 3.5.3. The clearing counterparts (RIX system) of the Riksbank is not considered. This assumption leads to a slight underestimation of energy use.

For operational energy use per transaction is estimated from data from payment actors as tabulated below:

Table 18 Operational energy use per Giro transaction

Actors	Estimated energy use per transaction (kWh/transaction)	Source
Automated clearing house	0.00006	Personal communication
Swedish bank*	0.000033	Personal communication
Merchants	0.0000039	12% of bank's data center

*Electricity and cooling

5.5.2 Transport of paper-based invoice

The average transport distance for paper-based invoice was assumed to be 50 km (own assumption). In this analysis, the transport distance is not a sensitive parameter. The type of transport fuels and the share of renewable fuels used by mail delivery was assumed to be similar to PostNord's own and procured transportation was 37% in 2021 (PostNord, 2022). The predominant fuel is HVO100, which can be used in existing diesel vehicles.

5.5.3 Device use

The energy consumption in the Giro payment device is assumed to be comparable to that of the Swish payment device. See data and assumptions for Swish payment in Section 6.5.2.

5.6 Results and discussions

For all transactions in 2021, the climate impact from the operation of Giro payment is quantified at 21.18 tCO_2eq. This impact is distributed across different categories, with data center activities contributing 4.6 tCO_2eq, transport contributing 0.55 tCO_2eq, and device use contributing 16.03 tCO2eq. The climate impact from the operation of Giro payment of a single transaction in 2021 is at 0.01 gCO_2. When considering per-value of Giro transaction, the impact is exceptionally low at 0.000001 gCO_2. The comparison with other products or services is illustrated in Figure 10.

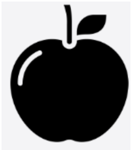
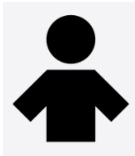
		
The total climate impact of all Giro transactions in Sweden is equivalent to 40 passengers flying one way from Stockholm to Beijing in economy class[15].	The climate impact of 15475 Giro transactions in Sweden is equivalent to the carbon footprint of producing 1 kg of apple in Sweden[16].	All Giro transactions are equal to the per capita CO_2 emissions/year of nearly 7 persons in Sweden[17].

Figure 10 Comparison of the climate effects of Swedish Giro transaction and other products or services

Table 19 The climate impact from the operational energy use of Giro payment in Sweden in 2021

Functional Unit (FU) - 1	All Giro transactions in 2021
	tCO2eq
Datacenter	4.60
Transport	0.55
Device use	16.03
Total	21.18
Functional Unit (FU) - 2	One Giro transaction in 2021
	gCO2/transaction
Average one Giro transaction	0.01
Functional Unit (FU) - 3	Per-value of Giro transaction in 2021
	gCO2/krona-transacted
Average one krona Giro transacted	0.000001

[15] The environmental impact of a passanger flying economy class direct one way flight from Stockholm to Beijing is 0.53 tCO_2 (Carbon Fooptrint Ltd, n.d.)

[16] The environmental impact of 1 kg apple production in Sweden is 200 gCO_2 (RISE, 2021)

[17] Per capita Swedish emissions is 3.2 tCO_2/year (IEA, 2023)

6 Climate impact of credit transfer services – Swish

6.1 Swish payments and statistics

Swish is a mobile payment system in Sweden. It was launched in 2012 by six large Swedish banks in cooperation with the Riksbank and Bankgirot. The numbers of costumers reached 8 million as of July 2022 (Swish, 2023). The service works through a smartphone application, through which the users' phone numbers are connected to their bank accounts, and which makes it possible to transfer money in real time, a few seconds until confirmation is received by both parties. Swish facilitates transactions for private, business, commerce, and Payout.

In 2021 and up until today, Swish payments are cleared through Bankgirot's BiR Settlement system, but they are expected to be settled directly in RIX-INST at some point in 2024. Our study will not analyze the potential difference from this change. This means settlement will take place between the banks' accounts at the Riksbank. The number of Swish transactions in 2021 was 770 million and the transaction value was 396.7 billion SEK (Sveriges Riksbank, 2023a).

6.2 Methodology

The method to perform LCA study for Swish payment is similar to Giro payment (Section 0).

6.3 Goals and scope

The objective of the LCA of credit transfer services – Swish is to obtain quantitative insight on the climate impact payment, based on the product system for POS and energy use in device for Swish payments in Sweden in 2021.

Three functional units are defined for assessing Swish payment system:

- FU1: the entire Swish payment system in Sweden with all Swish transactions in 2021. This FU also represents the operational energy use.
- FU2: one Swish payment in Sweden in 2021.
- FU3: per-value of Swish payment in Sweden in 2021

6.4 System boundary

The carbon footprint assessment for Swish considers impacts on operational and energy use in related datacenters and costumers' device. The energy related datacenters can be divided into five subsystems. First, bank datacenters that initiate the payments. Second, Swish datacenters for processing instant payments of various types. Third, automated clearing house datacenters through real-time BiR system. Fourth, merchant datacenters. Aspects that are excluded are similar to assessment for Giro payment (Section 5.4)

6.5 Data and assumptions

Background data (i.e., energies) have mostly been obtained from the Ecoinvent 3.7 Database (May 2023). See Table 20.

.

Table 20 Summary of energy inventory inputs per unit process. FU: entire Swish payments in Sweden in 2021

	Unit processes	Amount	Unit	Inventory input	Source
A	**DATACENTER USE**				
	Bank	11	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
		1	MWh	Heat, district or industrial, other than natural gas {SE}| heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | Cut-off, U	Primary
	Payment networks	165	MWh	Electricity, high voltage {SE}| electricity production, wind, 1-3MW | Cut-off, U	Primary
		9.4	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary
	BiR system	6.5	MWh	Electricity, high voltage {SE}| electricity production, wind, >3MW | Cut-off, U	Primary
	Merchants	1.5	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Secondary
B	**DEVICE USE**	211	MWh	Electricity, medium voltage {SE}| market for | Cut-off, U	Primary

6.5.1 Datacenters

The energy related datacenters can be divided into five subsystems. First, bank datacenters that initiate the payments. Second, Swish datacenters for processing instant payments of various types. Third, automated clearing house datacenters through real-time BiR system. Fourth, merchant datacenters. The primary data source from bank data centers put specific focus on the total energy consumption attributed to the Swish payment of a Swedish bank. This estimation takes into account the total Swish transactions, electricity and cooling use of a Swedish bank's data center. The estimation of merchants' data centers is similar to the card payment, as outlined in Section 3.5.3. The clearing counterparts (RIX system) of the Riksbank is not considered. This assumption leads to a slight underestimation of energy use.

For operational energy use per transaction is estimated from data from payment actors as tabulated below:

Table 21 Operational energy use per Swish transaction

Actors	Estimated energy use per transaction (kWh/transaction)	Source
Swish	0.00023	Personal communication
Automated clearing house for instant payment	0.00006	Personal communication
Issuing/Acquiring banks*	0.000016	Personal communication
Merchants	0.0000019	12% of bank's data center

*Electricity and cooling

6.5.2 Energy use in device

Total energy use in device in 2021 for Swish payment, 210 MWh, was quantified based on energy use per device (watts) multiplied by time viewing per transactions (hours) and total payments. The energy use per device is 15 W per viewing device (WSP USA, 2018). The time viewing per transactions was based on payment type (ecom, mcom, qcom, and p2p+p2b) (Personal Communication).

6.6 Results and discussions

For all transactions in 2021, the climate impact from the operation of Swish payment is quantified at a total GWP of 12.4 metric tCO2eq (FU1). This impact is distributed across different categories, with data center activities contributing 4.7 tCO2eq and device use contributing 7.67 tCO2eq. The impact of a single Swish payment transaction in 2021 is at 0.02 gCO2/transaction. When considering the per-value environmental impact of Swish transactions in Sweden in 2021, the average environmental impact per krona transacted is 0.000031 gCO2. The comparison with other products or services is illustrated in Figure 11.

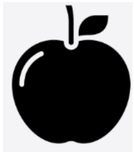
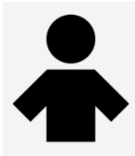
 The total climate impact of all Swish transactions in Sweden is equivalent to 23 passengers flying one way from Stockholm to Beijing in economy class[18].	 The climate impact of 12422 Swish transactions in Sweden is equivalent to the carbon footprint of producing 1 kg of apple in Sweden[19].	 All Swish transactions are equal to the per capita CO_2 emissions/year of nearly 4 persons in Sweden[20]

Figure 11 Comparison of the climate effects of Swedish Swish transaction and other products

Table 22 The climate impact from the operational energy use of Swish payment in Sweden in 2021

Functional Unit (FU) - 1	All transaction in 2021
	tCO2eq
Datacenter	4.7
Mobile device use	7.67
Total	12.40
Functional Unit (FU) - 2	One Swish transaction in 2021
	gCO2/transaction
Average one Swish transaction	0.02
Functional Unit (FU) - 3	Per-value of Swish transaction in 2021
	gCO2/krona-transacted
Average one krona Swish transacted	0.000031

[18] The environmental impact of a passanger flying economy class direct one way flight from Stockholm to Beijing is 0.53 tCO_2 (Carbon Fooptrint Ltd, n.d.)

[19] The environmental impact of 1 kg apple production in Sweden is 200 gCO_2 (RISE, 2021)

[20] Per capita Swedish emissions is 3.2 tCO_2/year (IEA, 2023)

7 Climate impact from the operational energy use of payment services in Sweden

The study also quantifies the climate impact from the operation of payment services. Electronic and digital transactions generally demonstrate lower climate impacts compared to traditional cash transactions. The total climate impact from operational energy use varies significantly among payment methods, see Figure 12, Figure 13, Figure 14. Cash transactions contribute the highest total impact at 1230 tCO2eq, with a corresponding impact of 3.90 gCO_2/transaction and 0.01 gCO_2/krona-transacted. In contrast, card transactions have a substantially lower total climate impact of 73 tCO_2eq than cash transactions, with only 0.02 gCO_2 per transaction and 0.0001 gCO_2/krona transacted. Payment-app transactions exhibit a minimal total climate impact of 1 tCO_2eq, translating to 0.03 gCO_2 per transaction and 0.0001 gCO_2/krona-transacted. Giro and Swish transactions also have relatively lower total climate impacts at 21 tCO_2eq and 12 tCO_2eq, respectively, with corresponding climate impacts per transaction and per-value transaction. Notably, Giro transaction demonstrates the lowest environmental impact per transaction at 0.01 gCO_2.

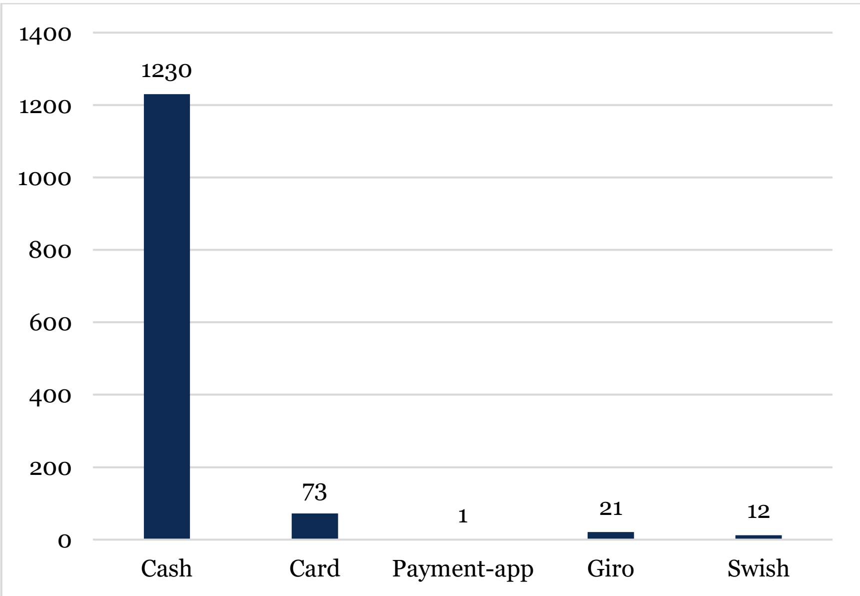


Figure 12 Total climate impact from the operational energy use of various payment services in Sweden in 2021 (tCO_2eq)

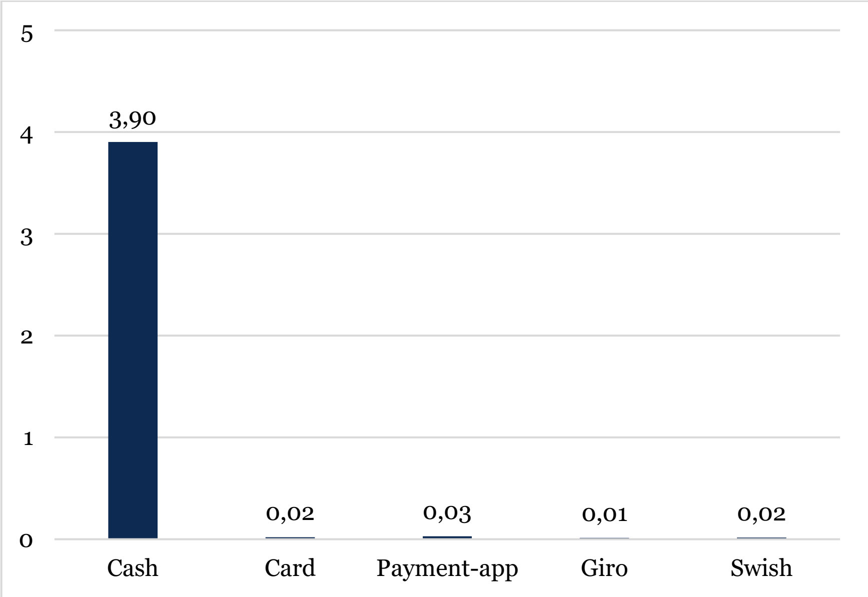


Figure 13 The climate impact of one transaction from the operational energy use of various payment services in Sweden in 2021 (gCO_2/transaction)

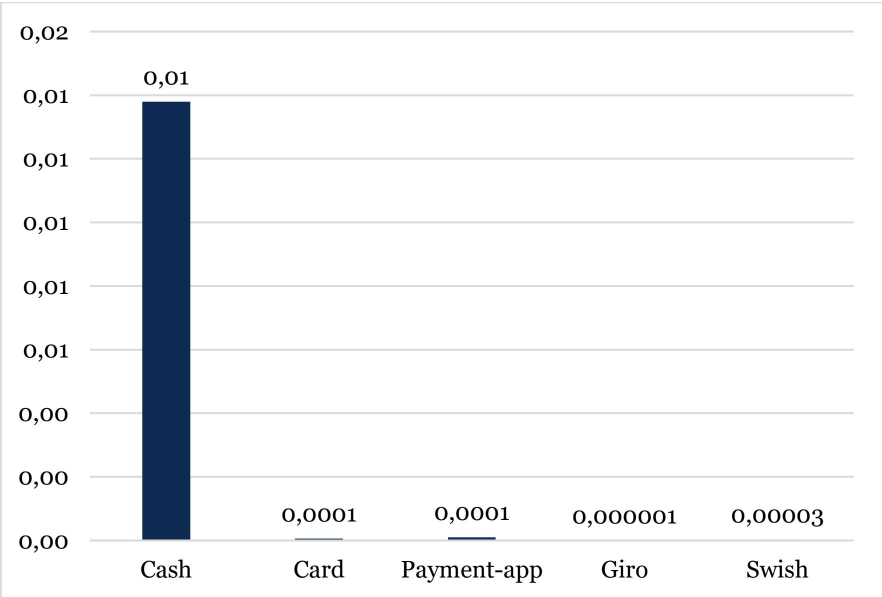


Figure 14 The climate impact per-value transaction from the operational energy use of various payment services in Sweden in 2021 (gCO_2/krona-transacted)

8 Conclusions

This report presents the results from the analysis of the climate impacts of different payment services, including cash, cards, payment apps, Giro and Swish.

The analysis shows that the emissions from cash payments in 2021 are 8.7 gCO_2 per transaction. The largest part of these emissions, namely 58%, are due to transportation of cash from and to bank depots, banks and ATMs across Sweden. The impact from ATMs accounts for about 21%. The coins production accounts for about 13% of emissions and the banknotes production accounts for about 4%. As transportation is the largest contributor to emissions from the cash payment system, replacing the diesel fuel with HVO or diesel car with electric vehicles provides opportunities for reducing the climate impact of cash payments in Sweden. Switching diesel fuel to HVO would provide opportunities for reducing the climate impact of cash payments in Sweden to 7 gCO_2/transaction and further down to 5 gCO_2/transaction through replacing them with electric vehicles. Switching to electric vehicles will require an abundance of electric charging infrastructure, which is currently mainly available in urban areas but not rural areas yet. A phased approach could be possible, with the introduction of electric vehicles for transporting cash in urban and semi-urban areas in the near future, while rural areas can be served with electric vehicles later once the infrastructure becomes available.

The analysis finds that the emissions for the entire card payments in Sweden in 2021 are 3242 tCO_2eq. More than three quarters of the emissions from card payments are due to the POS terminal (78%), while the card production accounts for 21% of emissions and data centers account for 1%. The impact per card transaction is 0.85 gCO_2. Introducing recycled PVC for card materials can reduce the climate impact to 0.78 gCO_2 per transaction. Additionally, extending the lifetime of a POS terminal from 5 to 10 years has the potential to further reduce the impact to 0.52 gCO_2 per transaction. The low emission factor of grid electricity in Sweden, the use of renewable energy source and recovering waste heat result to very low impact from the energy consumption of the data centers. The emissions from the operational energy use of one card transaction in 2021 is 0.02 gCO_2/transaction.

The climate effects of all card payments in Sweden are higher than all the cash payments. One reason is the higher number of card payments. The average impact per person above 18 years old in Sweden of cash and card transaction are relatively comparable, which are equivalent to 3 - 4 km drive of a 2020 VOLVO V60.

For payment apps, the analysis finds a slightly higher impact compared to card payment due to energy use in mobile devices. The emissions for payment apps are 0.86 gCO_2/transaction in Sweden in 2021. The operational energy use of one transaction with payment apps is 0.03 gCO_2/transaction.

The research shows that the emissions for the operational energy use from Swish and Giro are respectively 0.02 and 0.01 gCO_2 per transaction in Sweden in 2021, which is very low compared to cash and even compared to card payments. This very low score of impact is comparable to per capita CO2 emissions/year of nearly 7 and 4 persons respectively for Giro and Swish payments.

This report is focused on on climate effects of retail payments in Sweden in 2021, i.e., cash, card, Giro payments, Swish payments, and payment apps. A report on climate impact of future payments of e-krona model is submitted separately as part of the project funded by the Riksbank.

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