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Reusability and the potential environmental impact of small electronics

Literature review and discussion

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Summary

This study is part of a short assignment on behalf of Swedish Government within an investigation of possible deposit-return system for small electronics in Sweden. The report aims to explore (1) the potential of reuse of small electronics kept in stocks by households; (2) the environmental impacts/benefits of increased recycling; and (3) the environmental effects of increased reuse.

The research is mainly based on the literature review which was complemented with estimates of e-waste shares in mixed household waste and the potential economic value of metals present in electric and electronic (EEE) devices. The focus of the study was on information and telecommunication technology (ICT) products (e.g. mobiles phones, tablets and laptops).

Unused electronics kept in stocks at home represent a delayed or lost opportunity for reuse or remanufacturing. The reuse potential of such electronic devices depends on the remaining physical durability and perceived or factual technological obsolescence. The greatest potential for reuse is when the products are still within their designed lifetimes, thus products should be sent to second life as soon as they are no longer in use.

Knowledge about the quantities of reusable dormant electronics is very limited and fragmented, although a recent Swedish survey showed that there could be up to 2 million of unused functional mobile phones less than 4-year-old kept by households.[1] Nevertheless, the potential for reusing dysfunctional electronics in Sweden is low, since it requires costly repairs or remanufacturing and the demand for the newest devices far outstrips the demand for used ones.
At the same time, an extension of lifetimes of small electronics through domestic reuse could bring clear environmental (especially climate) benefits in comparison to incineration, recycling, or stockpiling electronics at home. This is particularly relevant for the ICT products with high environmental burdens in production and end-of-life phases. However, absolute savings from reuse can vary greatly between EEE groups and even within the same product group.

It has been estimated that about 8,000 tonnes of small electronics annually enter incineration together with mixed household waste. Much larger environmental and economic benefits could be attained if a more effective waste management system would be in place to divert WEEE flows towards material recovery (recycling) and especially - reuse. The magnitude and nature of the benefits depend on the quantity of collected electronics, composition, and the effectiveness and the efficiency of sorting and recycling. For instance, the theoretical value of metals present in 1 million pieces of small EEE varies from 20 to 70 million kr for mobiles, up to 24 million kr for tables and 120 million kr for notebooks.

Drawing definite conclusions about the impacts of increased collection and current recycling vs keeping WEEE in stocks is difficult as it depends mainly on future households' behaviour, the efficiency of e-waste management and strategies governing re-valorisation of e-waste.

[1] This report has been completed in 2020 and published April, 2021, when the results of a survey (within the same investigation of deposit-return system) was published. The survey focuses on households keeping stocks of unused electronic devices. Here, the amount of e.g. total amount of mobile phone was estimated in the range of 20-25 million units. The result of this survey has not been included in this report.

Sammanfattning

Denna studie är en del av ett kortare uppdrag för regeringens utredning om pantsystem på småelektronik i Sverige. Studien syftar till att undersöka (1) potentialen för återanvändning av småelektronik som lagras i samhället/hushållen; (2) miljöpåverkan / fördelar med ökad återvinning; och (3) miljöpåverkan / fördelar med ökad återanvändning.

Studien baseras främst på en litteraturöversikt, kompletterad med några grova uppskattningar (om e-avfall i blandat hushållsavfall och potentiellt ekonomiskt värde av metaller som finns i elektronik). Informations- och telekommunikationsteknologier (IKT) som mobiltelefoner, surfplattor och bärbara datorer var fokus i studien.

Mängden småelektronik som inte används, utan istället lagras i lådor i hushållen, är en fördröjd eller förlorad möjlighet att renovera eller återanvända elektroniken. Potentialen för återanvändning av oanvänd elektronik som lagras i hushåll beror på produktens hållbarhet och graden av både faktiska och upplevda tekniska föråldringar. Störst potential för återanvändning av elektronik finns inom produktens uppskattade livslängd. Därför bör produkterna skickas till återanvändning så snart de inte längre används.

Kunskap om mängden återanvändbar elektronik lagrade i hushåll i Sverige är begränsade och fragmenterade, även om en ny svensk undersökning visar att det potentiellt finns cirka 2 miljoner funktionella mobiltelefoner, yngre än 4 år, lagrade i svenska hushåll. Dock är potentialen för att återanvända dysfunktionell elektronik låg i Sverige, eftersom det kräver reparation som är kostsam. I synnerhet gäller det produkter med lägre ekonomiskt värde (exempelvis gamla leksaker) och efterfrågan på de senaste enheterna överstiger långt efterfrågan på begagnade enheter.

Sammantidigt visar vår kvalitativa litteraturöversikt att en ökad livslängd på småelektronik, genom inhemsk återanvändning, potentiellt kan klart bidra med miljöfördelar (särskilt klimatfördelar) i jämförelse med andra nuvarande alternativ. Vidare är detta särskilt relevant för IKT-produkter, vilka ofta har stor belastning på miljön. Miljöfördelarna som återanvändning kan bidra med varierar mellan olika elektroniska grupper och produkter.

Cirka 8 000 ton av småelektronik inkommer årligen till förbränning som en del av blandat hushållsavfall. Om avfallshanteringssystemet skulle vara mer effektivt i form av högre återvinnings- och materialåtervinningsgrad (särskilt för de sällsynta och ”exotiska” metallerna), skulle påtagliga miljö- och ekonomiska fördelar kunna erhållas jämfört med förbränning. Till exempel varierar det teoretiska värdet av metaller som finns i 1 miljon enheter av elektronik från 20 till 70 miljoner kr för mobiler, upp till 24 miljoner kr för surfplattor och 120 miljoner kr för bärbara datorer. Fördelarnas omfattning och karaktär beror på mängden samlad elektronik, sammansättning och effektivitet vid sortering och återvinning.

Dock är det svårt att dra definitiva slutsatser om miljöeffekterna av ökad insamling och återvinning, jämfört med miljöeffekterna av att lagra elektronik i hushållen, då det till stor del beror på framtida beteende och effektivitet av hanteringen av uttjänad elektronik.

1 Background

This study is an assignment on behalf of the Swedish Government within an investigation of the potential impacts of a deposit refund system for small electric and electronics equipment (EEE). It focuses on the reusability of small electronics that is kept in stocks and the potential environmental impact of the deposit system.

Aim

This study raises three main questions:

- What is the potential for the **reuse** of small Information and Communication Technology (ICT) electronics and household appliances? (the focus is on small electronics kept in stocks)
- What are the potential benefits and impacts of increased recycling vs other waste management alternative or keeping it in stocks?
- What can be the environmental benefits/impacts of increased reuse?

Method

The study is mainly based on literature review and some rough estimates. It presents an approximate estimation of the monetary value of materials present in small information technology and telecommunication (ICT) equipment and estimations about the volumes of small EEE in household waste that go to incineration. Relevant researchers abroad were also contacted in order to complement some identified data gaps.

Scope and limitations

The investigation of the deposit system focuses on small household electrical equipment and small information and communication technology (ICT) equipment defined according to the Swedish producer responsibility regulation[2] and the EU directive on WEEE (2012/19/EU):

- **small IT and telecommunication equipment** (of external dimension less than 50 cm): phones, GPS equipment, pocket calculators, routers, personal computers and printers;

- **small equipment**; this includes products with external dimensions less than 50cm in length, width or depth (e.g. Vacuum Cleaners, Carpet Sweepers, Appliances for sewing, Luminaires, Microwaves, Ventilation equipment, Irons, Toasters, Electric Knives, Electric Kettles, Clocks and Watches, Electric Shavers, Scales, appliances for hair and body care, Radio Sets, Digital Cameras, Video Cameras, Video Recorders, musical instruments and Hi-Fi equipment reproducing sound or images, Electrical and Electronic Toys, Sports Goods, small scale computers for e.g. biking, diving, running, rowing, etc., Smoke Detectors, Heating Regulators, Thermostats, Small Electrical and Electronic tools, small Medical Devices, small Monitoring and Control instruments, small equipment with integrated photovoltaic panels).

In this study we focus mostly on three ICT product groups: mobile phones, tablets and laptops; other small electronics are included to a lesser extent.

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[2] https://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/forordning-20141075-om-producentansvar-for_sfs-2014-1075

This study doesn't include any calculations and deeper evaluation of potential total effects of a deposit-refund outcomes, as it would require better/deeper knowledge of the current situation (i.e. quantities and product/material compositions, recycling efficiency, data on illegal exports and destination countries, etc.), which was not possible to investigate in the frame of this short assignment.

2 Potential for reuse

This chapter describes the potential of the re-use of EEE kept in stocks. The first section briefly presents current knowledge about the quantities of small electronics in stock, including Swedish and foreign examples. The second section discusses theoretical re-use potentials of the stocks. This is affected by gaps in empirical evidence and should be interpreted with caution.

2.1 EEE in stocks as an increasing problem in developed countries

Rapid technology innovations and short lifetimes of electronics result in that consumers in affluent countries possess an increasing stock of equipment kept at home. This is especially relevant for small electronics, such as e.g., mobile phones. According to a study by JRC (Cordella, Alfieri et al. 2020), unused devices in the U.S. and the UK correspond to about 58 billion USD in residual value. In the U.S., 27-36% of consumers keep an old phone because they "don't know what to do with it" and 17% stated being "too lazy" to get rid of them. Up to 60% of the Norwegian population has more than two mobile phones at home that are not in use, which corresponds around 10 million mobile phones (Baxter, Margareta et al. 2015). Consumers could be incentivised to sell their old devices if made aware of their value as well as the existence of re-sale markets/platforms. Some of these are facilitated by deposit-refund systems introduced by some original equipment manufacturers to promote the return of used phones and secure product supply for refurbishing or recycling (Cordella, Alfieri et al. 2020).

During May-June 2020 a study was conducted focusing on the mobiles under 4 years kept in household stocks in Sweden (Halebop 2020, VIA 2020). Kantar Sifo conducted a web-based survey on behalf of a mobile operator and a second-hand actor Halebop. The survey received 1,170 responses from population aged 18–79 (Halebop 2020).

Main conclusions:

- 22% of the respondents owned more than one unused functional mobile phone (<4 years);
- 26% men and 17% of women possessed more than one functional unused mobile phone at home;
- population aged 18-25 year (28% are the sample) possessed most of functional and unused mobile phones;
- main obstacles for **not** selling functional mobiles phones:
    - the old devices do not have sufficient value (38%),
    - willingness to save them for different reasons (22%),
    - didn't think about it (18%),
    - products store important personal information (17%),
    - other (22%),
    - do not know how to proceed to sell (6%).

If scaled on the national level, around 2 million functional mobile phones under 4 years old are kept at homes unused (Table 1). Assuming that a mobile phone weighs around 200 g (e.g. iPhone 6), it makes about 456 tons of phones in household stocks storage.

Table 1. Functional and unused mobile phones in Swedish households.

Quantity of stored mobile phones under 4 year old	Share of population in the survey (%)	At national level *
1 pc. functional unused mobile phone	17	*1 385 000*
2 pc. functional unused mobile phones	4	651 800
3 pc. functional unused mobiles phones	1	244 000
None unused mobiles phones at home (<4 year)	77	0
Total	**100**	**2 280 800**

* based on statistics about population of 8,147,000 (over 18 years of age) from Statistics Sweden (SCB) in 2019 (SCB 2020).

2.2 Storage of the aggregated group" small electronics and small IT"

An EU project ProSUM (2015-2017) made estimates on different electronic product groups that are in use and in stocks (storage) covering all EU countries including Sweden. The data was produced using modelling based on historic market input data of EEE from 1980 to 2015 (estimates for 2016-2020), in combination with other data (t ex on demographics, international trade statistics, EU statistics on social income and living conditions and consumer surveys on behaviour, purchasing power, product life etc.) (Figure 1 and Figure 2)

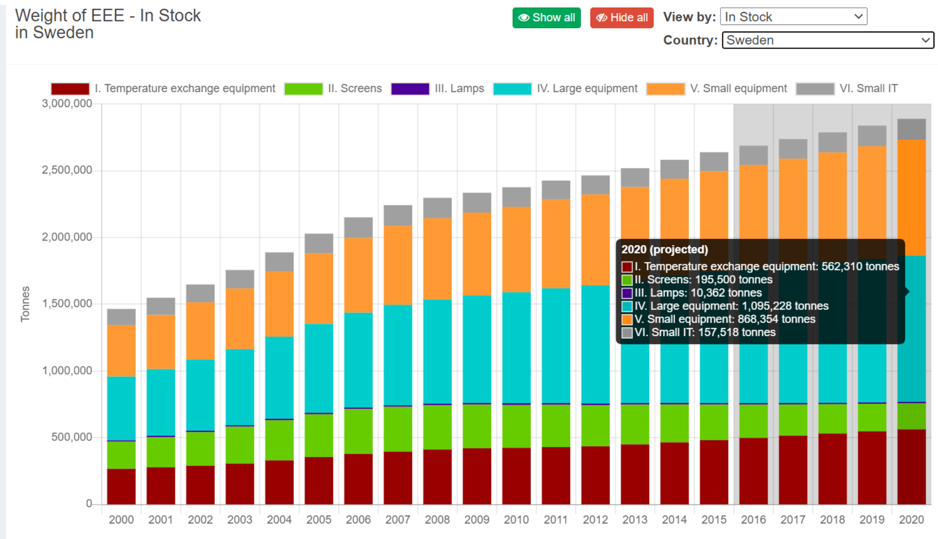


Figure 1. WEEE in stocks in Sweden (in tonnes) Source: http://www.urbanmineplatform.eu

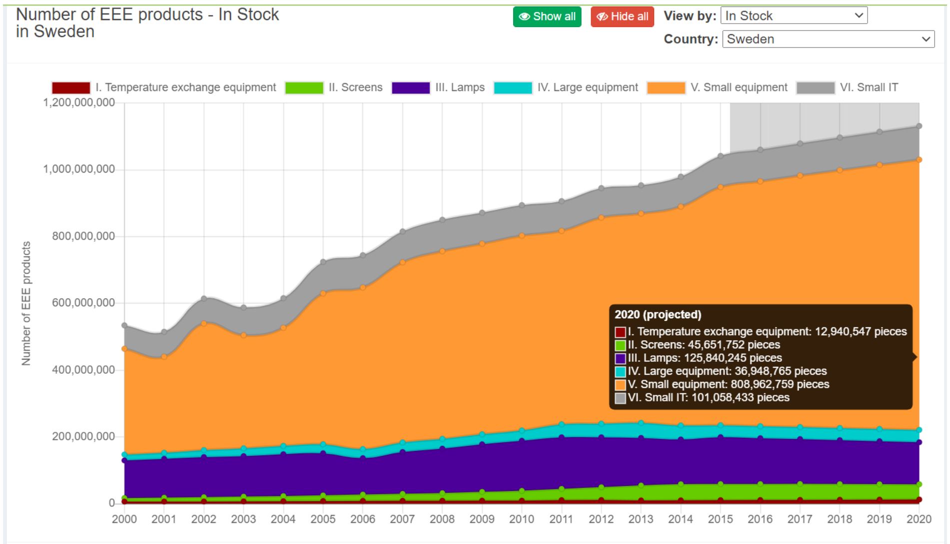


Figure 2. WEEE in stocks in Sweden (in pieces) Source: www.urbanmineplatform.eu

According to the database of EEE in stock vs. use in Sweden[3] the statistics (projection for 2020) are:

- 158,000 tons or ca 101 million pieces of small IT;
- 868,000 tons or 808 million pieces of small equipment.

The database also presents information about the available materials in stocks related to small electronics per country based on composition rates (Table 2).

Table 2. Estimated amounts of metals in small electronics in stocks *(based on data from www.urbanmineplatform.eu)*

Materials	Quantity of materials in small IT EEE in use and stocks (tonnes)		Quantity of materials in small EEE in stocks (tonnes)	
	2015	2020 (projected)	2015	2020 (projected)
Gold (Au)	1.8	1.9	0.4	0.4
Silver (Ag)	8.0	8.5	4.9	5.3
Platinum (Pt)	0.016	0.017	0.002	0.002
Paladium (Pd)	0.398	0.426	0.13	0.1
Copper (Cu)	2 687	2 897	40 983	49 117
Aliuminium (Al)	3 902	4327	56 446	63 898
Iron (Fe)	59 909	65 720	323 687	380 472

Several shortcomings should be noted for the presented estimations:

- Data for 2016-2020 are projections at the time of the study;
- Exports, as well as formal and informal reuses in Sweden were not included in the calculations. The data about the stocks include also electronics **in use**.
- Assumptions on the compositions of electronics (these are rather dynamic and can be outdated for today).

[3] www.urbanmineplatform.eu

2.3 The potential for reuse of stored electronics

Since, electronics kept in stocks are not always possible to reuse, this chapter discusses what could be important when evaluating the potentials for reusing vs recycling **defunct EEE stocks**:

- ***Durability*** vs functionality – whether still functioning electric and electronic products could be cost-effectively repaired for reuse; and
- ***Obsolescence*** – whether products can still be reusable due their technical upgradability or (probably most important) consumers preferences.

2.3.1 Durability

Many electronic products can physically function beyond their **technological** or **designed lifetime,** i.e. the maximum time that a manufacturer intends its product to remain functional. This refers to a potential mismatch between regular functionalities and performance demands induced by software and other functional regularly made upgrades available in the sector. Much is or can be decided at the product design stage, including materials, design quality, repairability, upgradability and software upgradability. These main factors determine products' durability or "*the ability of a product to remain functional when faced with the challenges of normal operation over its lifetime*"(Bachér, Dams et al. 2020).

There is no consensus on the average designed lifetime and even less on durability of electronics and information available from the literature in not consistent. For instance, designed lifespan for smartphones may vary from 2 till 8 year, with a median around 5 years (Cordella, Alfieri et al. 2020). Laptops can last 3-5 or even more years, notebooks such as iPads on average around 4 years (Walter 2020). Estimates may depend on different definitions of designed or actual lifetime (see the section below). They also depend on how the consumers use their products, e.g. how often batteries are charged, or their technical capacity to be upgraded.

The designed lifetime could be prolonged by in-built repairability of products. Recently, there are more and more debates about the so-called intentional technical obsolescence, i.e. producers intentionally shortening the life span of electronics in order to increase the profits related to new sales (e.g. slowing down after software upgrades or making not possible to easily replace the batteries).

The EU-parliament is currently discussing suggestions to introduce mandatory labelling for lifespans and reparability for some electronic products, such as mobile phones and washing machines in order to inform consumers on its potentials for re-use (Valtersson 2020).

2.3.2 Obsolescence

Another important aspect is the "moral obsolesce" of EEE products. Consumers often are not willing to use older EEE products even if they are functional when new products are available. This creates a gap between the **actual life span** and the **lifespan in consumption**. Important factors here are related to products' properties, opportunity costs and consumer's attitudes which in turn depend of the societal norms, values, and general social and cultural trends (Valtersson 2020).

Often the emotional and socio-economic factors shorten the functional (actual) lifespan of EEE products (Bachér, Dams et al. 2020). Wieser et al. (2015) found that the actual lifetime is positively related to a *consumer's age, household income and educational level*. Watson, Gylling et al. (2017) shows that old phones are more often replaced due to the desire to have the newest model rather than performance related issues (Figure 3).

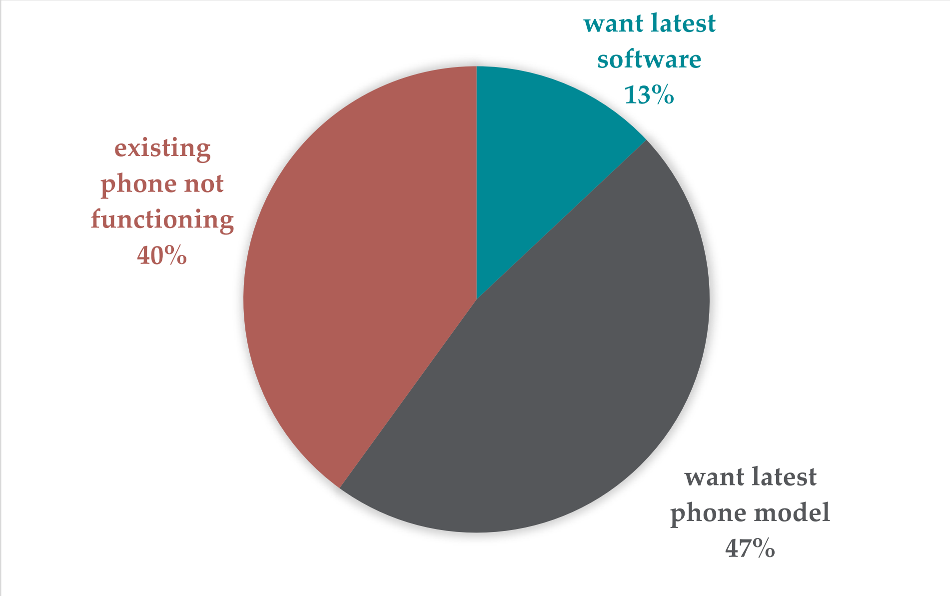


Figure 3. Reasons of purchasing a new phone (Watson, Gylling et al. 2017)

There is little consensus on the average actual lifetime of electronics. A systematic analysis of actual lifetimes in the EU is presented by Balde in the Table 3. The average lifespan of small electronics (Weibull distribution based on surveys in the Netherlands) is shown in Table 3 below. Other examples from the UK and El-Kretsen in Sweden are presented in Figure 4 and Table 4.

Table 3. The average lifespan of small electronics (Weibull distribution based on surveys in the Netherlands). (Source: K. Balde, 2020)

UNU_Key	Name	According to WEEE directive classification (EU-6)	Year	Shape β	Scale α
0114	Microwaves (incl. combined, excl. grills)	5 Small equipment	2018	2.07	17.99
0201	Other Small Household (f.i. small ventilators, irons, clocks, adapters)	5 Small equipment	2018	1.22	7.97
0202	Food (f.i. toaster, grills, food processing, frying pans)	5 Small equipment	2018	2.02	11.02
0203	Hot Water (f.i. coffee, tea, water cookers)	5 Small equipment	2018	1.18	7.61
0204	Vacuum Cleaners (excl. professional)	5 Small equipment	2018	1.22	10.59
0205	Personal Care (f.i. tooth brushes, hair dryers, razors)	5 Small equipment	2018	1.2	8.09
0301	Small IT (f.i. routers, mice, keyboards, external drives & accessories)	6 Small IT and telecommunication equipment	2018	1.3	6.15
0302	Desktop PCs (excl. monitors, accessories)	6 Small IT and telecommunication equipment	2018	1.8	10.33
0303	Laptops (incl. tablets)	2 Screens, monitors, and equipment containing screens (..)	2018	1.94	8.76
0304	Printers (f.i. scanners, multifunctionals, faxes)	6 Small IT and telecommunication equipment	2018	1.88	9.31

0305	Telecom (f.i. (cordless) phones, answering machines)	6 Small IT and telecommunication equipment	2018	1.32	7.7
0306	Mobile Phones (incl. smartphones, pagers)	6 Small IT and telecommunication equipment	2018	1.52	5.62
0401	Small Consumer Electronics (e.g. headphones, remote controls)	5 Small equipment	2018	1.3	9.87
0402	Portable Audio & Video (f.i. MP3, e-readers, car navigation)	5 Small equipment	2018	1.5	10.01
0403	Music Instruments, Radio, HiFi (incl. audio sets)	5 Small equipment	2018	2.3	10
0404	Video (f.i. Video recorders, DVD, Blue Ray, set-top boxes)	5 Small equipment	2018	1.14	8.33
0405	Speakers	5 Small equipment	2018	1.13	12.54
0406	Cameras (f.i. camcorders, photo & digital still cameras)	5 Small equipment	2018	1.19	6.75
0501	Small lighting equipment (excl. LED & incandescent)	5 Small equipment	2018	1.42	8.72
0506	Household Luminaires (incl. household incandescent fittings)	5 Small equipment	2018	2.34	16.59
0507	Professional Luminaires (offices, public space, industry	5 Small equipment	2018	2	12.5
0601	Household Tools (f.i. drills, saws, high pressure cleaners, lawn mowers)	5 Small equipment	2018	1.77	14.98
0701	Toys (f.i. car racing sets, electric trains, music toys, biking computers)	5 Small equipment	2018	1.43	4.56
0702	Game Consoles	6 Small IT and telecommunication equipment	2018	1.14	4.78
0801	Household Medical equipment (e.g. thermometers, blood pressure meters)	5 Small equipment	2018	1.99	13.46
0901	Household Monitoring & Control (alarm, heat, smoke, excl. screens)	5 Small equipment	2018	1.55	5.89

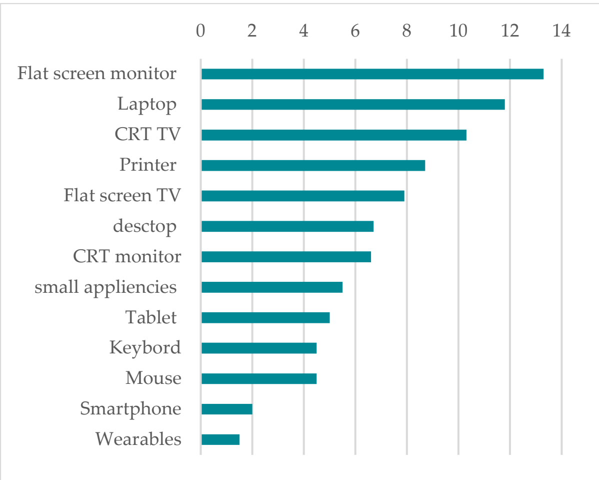


Figure 4. An example of average lifespan of EEE in UK (Statista 2020)

Table 4. Lifespan of electronic products according to Swedish producer organisation El-Kretsen 2012-2017 (Source: SMED, 2020)

Group	Products	Median age
Household appliances	Electric toothbrushes	8
	Electric mixer	16
	Power strip	18
	Iron	14
	Sewing machine	30
	Waffle maker	20
IT and telecommunication products	Kombiapparater	7
	Printer	10
	Scanner	13
	Copy machine	13
	Mobile phone	5 [a] / 8 [b]
	Smartphone	4 [a] / 5 [b]
Portable screen products	Laptop	12[4]
Audio-video	CD, tape recorder, Record Player	27
	Dvd, Vhs, Blu-ray player	13
	Radio och receiver	24

[a] phones collected in 2017, [b] phones collected in 2012.

The above examples of product lifetime refer to an average time from purchase to discarding. As some (especially small) electronic items are kept at home without being used for some time, the greatest potential for their reuse is the time in stocks when the items are still within their designed lifetime slots (period "1" in the Figure 5). In time, the reuse potential decreases (period 2) due to changing consumer preferences and technological obsolescence. Idling products (e.g. mobile phones) usually have low intrinsic value for their owners given there are more technologically superior alternatives in the market. However, if there would be a deposit-value attached to a device, it may motivate its owner to consider its re-use or recycling sooner than later. Higher awareness about the environmental or social "good" by reusing disused electronic devices could also push some owners to pass it on without a financial reward (e.g. to second-hand markets in less developed countries).

[4] According to other data source the average lifespan for a laptop is 18 year El-Kretsen (2019). Från återvinnare till råvarulevarantör – plast och elektronik.

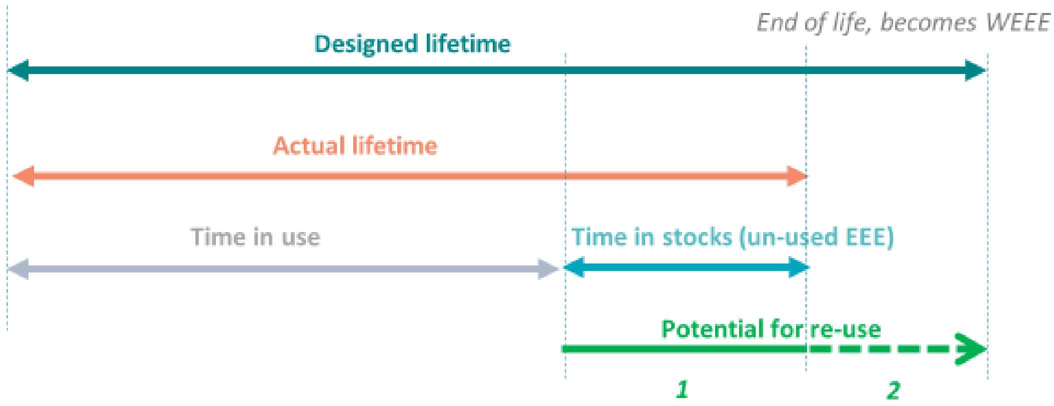


Figure 5. Very simplified scheme for functional products lifetime in stocks and its potentials for reuse. (1) – refers to greatest potential for 2nd life, (2) – refers to decreasing potential off 2nd life

Clearly, the reuse potential of stored electronics decreases with time. So far, we have very little to no data about the value-thresholds for reuse for different products. Data by Balde (Table 3) and SMED (Table 4) refers to the age of products reaching their end-of-life but does not detail for how much longer disused products may have been kept in stock before entering different waste streams. The variation could be significant between different product groups (e.g. higher quality/more valuable electronics). The reuse potential might increase in other (lower purchasing power) countries, where also life extension by cheap repairing of the products is more available.

Box 1. Example of smartphones.

An estimated designed lifetime of a smartphone in Germany is 2-8-years with the average use time of 2 years reaching its end-of-life at 6th year (Cordella, Alfieri et al. 2020). In other countries, like e.g., Sweden, smartphones on average reach their end-of-life at around 4th year (Table 4), although more than half of Nordic consumers have a smartphone for less than two years (Deloitte 2019).

If functional phones are kept in stock after the 2 years of their average use, the remaining functional lifetime is in the range of 2-3 years depending on quality and upgrades. According to Halebop, at least 20% of consumers still at least 4-year-old functional phones at home, corresponding to around 2 million units in Sweden (Halebop 2020).

Shares of phones in storage and those given/sold for 2nd life is not well known in Sweden. Studies in Germany and the U.S. showed that up to **two thirds of smartphones** live a 2nd life (Cordella, Alfieri et al. 2020). Products of best quality are typically re-circulated in domestic markets and can be competitive with mid- to low-end device depending on depreciation rates of different brands and the perceived quality. Products of lower quality usually are destined to markets with lower purchasing power.

There is still a knowledge gap regarding how EEE is handled after their 2nd life. An investigation on mobile phones of 2016 showed that up to 95 % collected by Swedish mobile providers go to reuse in other European countries, of which ca. **35%** end up in in Asia or Africa, in countries lacking proper waste management systems (SverigesNatur 2016). The remaining EEE is either kept at homes or go into end-of-life waste management system along with mixed municipal or sorted electronic waste.

Box 2. Example of vacuum cleaners.

For some electronics (e.g. home appliances) where consumer obsolescence plays a minor roll, the reuse potential could be minor or even no-existent. For instance, a study by EIONET (Bachér, Dams et al. 2020) argues that consumers expect standard mains-operated domestic vacuum cleaners to last longer than they actually do (actual-life time is around 8 years vs expected lifetimes of 10.3 years). For such products there is no or low reuse potential without available cost-effective repair infrastructures. It is unlikely that larger functional home appliances, such as vacuum cleaners (except smaller, like robot vacuum cleaner) are kept at home unused.

2.3.3 Functional vs dysfunctional electronics

Unused EEE items kept at home could be divided into functioning and dysfunctional.

The potential of reusing **dysfunctional EEE** is usually very low, especially for items of low economic value (e.g. old toys) or outdated electronics (e.g. ICT, above their designed lifetime). Their repair costs are often much higher than the residual value. Some EEE products lose value rather rapidly. In Europe, for instance, the value of a smartphone is halved after 1 year and can be as low as 20% of the original value after 3 years. Meanwhile, replacement of a broken display can cost about 15-40% of the products original price and up to 10% for other smaller repairs (see Table 5). Only products of higher economic value (such as ICT products) could be potentially reused if their repair requires minor efforts/resources (e.g. change of batteries). The reuse potential might increase if cheaper repairs are available (e.g. in countries with lower labour costs). Some companies, like e.g. GEAB in Lund (Sweden) exploits the lower repair costs in other countries, like Poland, where repaired phones are re-sold for reuse.

Table 5. Summary of information on products costs for smartphones (Europe)

Cost category	Average value (based on values in 2018)
Purchase price	
- Low-end	< 130 EUR/product
- Medium	320 EUR/product
- High-end	>480 EUR/product
Value of product (reuse)	54% of original price after 1 year, 32 % of after 2 years, 20% after 3 years
Repair/refurbishment costs	About 15-40 % of the product price for display; usually above 10% of the products price for other repairs

Source: Cordella, Alfieri et al. (2020) OBS. Values includes VAT, lower VAT for repair is used in Sweden.

Meanwhile **functional EEE** have a much higher potential to be reused, but it still depends on a product group. Some products, like e.g. ICT (smartphones, tablets and laptops) are perceived to age rapidly by consumers and their demand for a 2nd life might be uncertain. For some rapidly aging products, the quality, brand and make might play a positive role. However, little information is so far publicly available. Companies repairing large volumes of used electronics, like Inrego, might have useful insights in such issues.

3 Potential impacts/benefits of circular solutions

The potential environmental impact of a deposit-refund system for EEE depends on how it balances with the existing management systems for WEEE. This chapter discusses several potential outcomes induced by the introduction of a deposit-refund system for small electronics and discusses the pathways of:

- Increased recycling vs incineration;
- Increased recycling vs storage;
- Increased domestic reuse vs recycling.

As data were not sufficient for any meaningful quantitative calculations of scenario impacts, the discussion is based on qualitative evaluation based on a few examples. Hence, the discussion should be regarded merely as a theoretical elaboration of possible impacts. Better insights require more examples and in particular, more Swedish-based case studies.

3.1 Increased recycling vs incineration

3.1.1 Current situation

Some electronics (most often small) might enter mixed waste flows, and thus later end up in landfills or are incinerated. According to several compositional studies for mixed household waste in Sweden, in 2018 around 0.5 % of total municipal waste by weight were diverse WEEE and batteries (Avfall Sverige 2019). According to another study (Avfall Sverige 2016), around 70% of this flow is electronics (i.e. excluding batteries and other hazardous waste). In 2019, 2.42Mt of mixed household waste was incinerated (Avfall Sverige 2019), which translates to ca. 8 000t of small electronics. This data is uncertain regarding the types of electronics that enter the mixed waste flow, i.e. whether they are smaller than 50 cm or it could also include products such as light bulbs, which are not in the focus of this study. How much of WEEE ends up in mixed waste flows from commercial and waste imported for incineration is even less known.

If considering that around 74,300 tonnes of small electronics are consumed annually in Sweden[5] (SMED, 2020), this makes that around 10% end up in incineration. As this stream most likely contains electronics of low economic value, a potentially large part of it could be affected by a deposit on EEE in terms of more organised returns.

3.1.2 Potential impact/benefits

In order to estimate the potential environmental impact of WEEE, both the composition of the WEEE (by products) and the average composition (by materials) within different product groups needs to be investigated, since large variations in terms of materials exists among different product groups.

[5] Internal consumption=import+production-export

At this point, we could not find relevant empirical assessments comparing recycling and incineration of just WEEE flows that enter incineration in Sweden. However, there are some available examples that can illustrate the benefits of recycling.

3.1.2.1 Recycling

There several potential benefits of WEEE recycling in formalised (regulated) waste management systems:

1. ***Material efficiency and related environmental benefits.***

   - **Direct environmental savings**. WEEE contains a large variety of materials. The extraction of some materials (e.g., precious metals, CRMs) can have large environmental footprints due to high energy intensities, risks of pollution at material extraction places, associated greenhouse gas (GHG) emissions, significant amounts of solid waste and different social impacts in less regulated countries). The recycling of several materials present in WEEE usually has lower environmental and social burdens. A replacement of primary materials by secondary materials, can contribute to potentially high environmental savings.

   - **Indirect environmental savings.** Recycling of critical raw materials from WEEE might address the supply volatility of several critical raw materials, especially if they sourced from countries with unstable socio-economic systems or those holding the monopolies of supply. Many critical materials are highly relevant to enable sustainable technologies (such as solar panels, wind power equipment, electrical cars etc.), thus limitations in access to such materials might indirectly compromise the future of green innovations.

2. *Socio-economic benefits*:

   - **May contribute to higher supply security** of **CRMs** and **other valuable materials** required in different high-tech sectors. Virgin deposits of CRMs increasingly required by the ICT and other sectors are situated in politically unstable countries. Some countries outside the EU today stand for up to 95% of mining and extraction of rare-earth elements, which makes the EU reliant on imports. Increased recycling of CRM from WEEE in the EU might contribute to securing the supplies. In some cases, the working conditions at specific sites can be sub-standard by the modern requirements (Bachér, Dams et al. 2020), which can be indirectly prevented if more CRM recycling took place in the EU.

   - **May contribute to conflict avoidance**. The extraction of some virgin materials for EEE is often located in conflict zones. Usually, armed groups finance their activities by informal minim of critical raw materials based on underpaid or even forced labour. For instance, the critical raw material tantalum (used in capacitors) is extracted from the columbite-tantalite ore mined in conflict zones, such as Rwanda and Congo (Miliute-Plepiene and Youhanan 2019).

   - **Economic benefits**. WEEE contains many valuable materials, such as rare and precious metals. Their recycling from WEEE may break even with virgin materials and bring economic and job-related benefits. There are little to no technological limitations for this, except for possible inefficiencies in WEEE management and insufficient volumes for economic actors to justify their costs. Reducing WEEE losses and improving sorting can provide more economic viability for CRM recycling from WEEE (Miliute-Plepiene and Youhanan 2019).

The main economic and often the environmental benefits of WEEE recycling relate to the presence of valuable materials, and it is important to better understand the composition and the volumes of different WEEE streams. An example of composition is presented in tables below.

Especially ICT products contain many critical materials. For instance, of the 83 stable and non-radioactive elements in the periodic table, more than 60 can be found in smartphones(Cordella, Alfieri et al. 2020). The majority are metals and some like iron and aluminium, available in large quantities. Precious metals, such as gold, have since long ago been for interest for the recycling industry.

Table 6. An example of materials present in smartphones and its use. Blue – critical raw materials (CRMs), gray – conflict materials (Based on *Manhart A, Blepp M et al. (2016) & Andrae A. (2016) in (Cordella, Alfieri et al. 2020)*)

Material	Common use in smartphones	Content per smartphone (g) (Based on Manhart et al. 2016)	Content per smartphone (g) (Based on Andrae 2016)
Aluminium (Al)	Case	22.18	8.69
Cooper (Cu)	Wires, alloys, magnetic shielding, PCB, speakers, tactile engines	15.12	36.25
Plastics	Case	9.53	
Magnesium (Mg)	Case	5.54	
Cobalt (Co)	Lithium-ion battery	5.38	
Tin (Sn)	Solder paste	1.21	2
Iron (steel) (Fe)	Case	0.88	16.25
Tungsten (W)	Vibration alert module	0.44	
Silver (Ag)	Solder, PCB	0.31	0.198
Gold (Au)	PCB	0.03	0.121
Neodymium (Nd)	Speakers Magnets	0.01	
Tantalum (Ta)	Capacitors	0.02	
Indium (In)	Display	0.01	
Palladium (Pd)	PCB	0.01	0.034
Gallium (Ga)	LED-backlights	0.0004	
Gadolinium (Gd)	LED-backlights	0.0002	
Europium (Eu)	LED-backlights	0.0001	
Cerium (Ce)	LED-backlights	0.00003	
Nickel			1.5
Zinc			1.213
Acrylonitrile butadiene styrene			22.500
Poly(methy methacrylate)			1.875
PA (Nylon)			1.625
PVC			18.750
Polyethylene-high-density			8.625

Material	Common use in smartphones	Content per smartphone (g) (Based on Manhart et al. 2016)	Content per smartphone (g) (Based on Andrae 2016)
Polyester (e.g. polyethylene terephthalate)			2.875
Polycarbonate			2.625
Polypropylene			1.313
Polyurethane			1.625
Epoxy			20.000
Fiberglass			43.750
Glass			33.750
Others	(glass, ceramic, semiconductors)	99.29	
Total		160	225.56

Table 7. Examples of material composition in ICT products: I-II notebooks (laptops), IX – cell Phones, X - smart phones, XIV – tablets (Cucchiella, D'Adamo et al. 2015).

Materials composition.

Products	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Materials	g/unit													
Aluminium			67			242	130	130	12	2.9	1370	441	441	
Antimony	0.77	0.77	14	0.71	0.71					0.084				0.154
Arsenic	0.01	0.01												0.002
Barium	2.5	2.5				1								0.49
Beryllium										0.003				
Cadmium			0.2								0.407			
Cerium	< 0.001	< 0.001		0.005	< 0.001		< 0.001	< 0.001						< 0.001
Chromium	0.07	0.07	0.03											0.014
Cobalt	0.065	0.065							3.8	6.3				0.013
Copper	135	135	656	824	824	952			26	14	78	15	15	27
Dysprosium	0.06	0.06										0.06		0.012
Europium	< 0.001	< 0.001		0.008	< 0.001		0.001	< 0.001						< 0.001
Ferrite						483								
Gadolinium	< 0.001	< 0.001		< 0.001	0.002		< 0.001	0.002						< 0.001
Gallium		0.0016			0.005		0.003	0.003			0.119			
Glass			15760	162	216	6845	590	590		10.6	6915			
Gold	0.22	0.22		0.11	0.11	0.31	0.2	0.2	0.024	0.038		0.005	0.005	0.044
Indium	0.04	0.04		0.003	0.003		0.079	0.082			0.119			0.008
Lanthanum	< 0.001			0.007			< 0.001							< 0.001
Lead	5.3	5.3	1319			464	16		1	0.6				1.1
Mercury	< 0.001	< 0.001					< 0.001	0.004	1					< 0.001
Molybdenum	0.04	0.04					0.633	0.633			0.295			0.008
Neodymium	2.1	2.1								0.05		1		0.427
Nickel	3.6	3.6				199			1	1.5				0.722
Palladium	0.04	0.04		0.044	0.044		0.04	0.04	0.009	0.015		0.003	0.003	0.008
Plastics			8755	612	573	2481	1780	1780	63	60	1172	44	44	
Platinum	0.004	0.004								0.004				
Praseodymium	0.274	0.274		< 0.001			< 0.001			0.01		0.145		0.055
Selenium											0.119			
Silicon									5		226			
Silver	0.25	0.25		0.45	0.45	1.25	0.52	0.52	1	0.244		0.031	0.031	0.05
Steel/Iron			2088			3322	2530	2530	11	8		62	62	
Tantalum	1.7	1.7												
Tellurium											0.406			
Terbium	< 0.001			0.002			< 0.001							< 0.001
Tin			32	18	18	20	24	24	1	1	0.116			
Titanium							0.633	0.633						
Tungsten							0.633	0.633						
Vanadium						1								
Yttrium	0.002	0.002		0.11	0.005	1	0.016	< 0.001						< 0.001
Zinc	0.004	0.004	8.6						4	1	0.4			< 0.001
# of critical raw materials	14	13	1	10	8	1	10	7	2	8	2	4	1	14
# of precious metals	4	4	0	3	3	2	3	3	3	4	0	3	3	3

I=LCD Notebooks; II=LED Notebooks; III=CRT TVs; IV=LCD TVs; V=LED TVs; VI=CRT Monitors; VII=LCD Monitors; VIII=LED Monitors; IX=Cell Phones; X=Smart phones; XI=PV Panels; XII=HDDs; XIII=SSDs; XIV=Tablets.

Other small electronics, such as home appliances contain more "conventional" materials, e.g. 25- 80% of bulky metals (iron, copper, steel) and up to 6-60 % of plastics (Table 8).

Table 8. Average material composition (%) of small home appliances groups (based on information from (Magalini F., Kuehr R. et al. 2017)

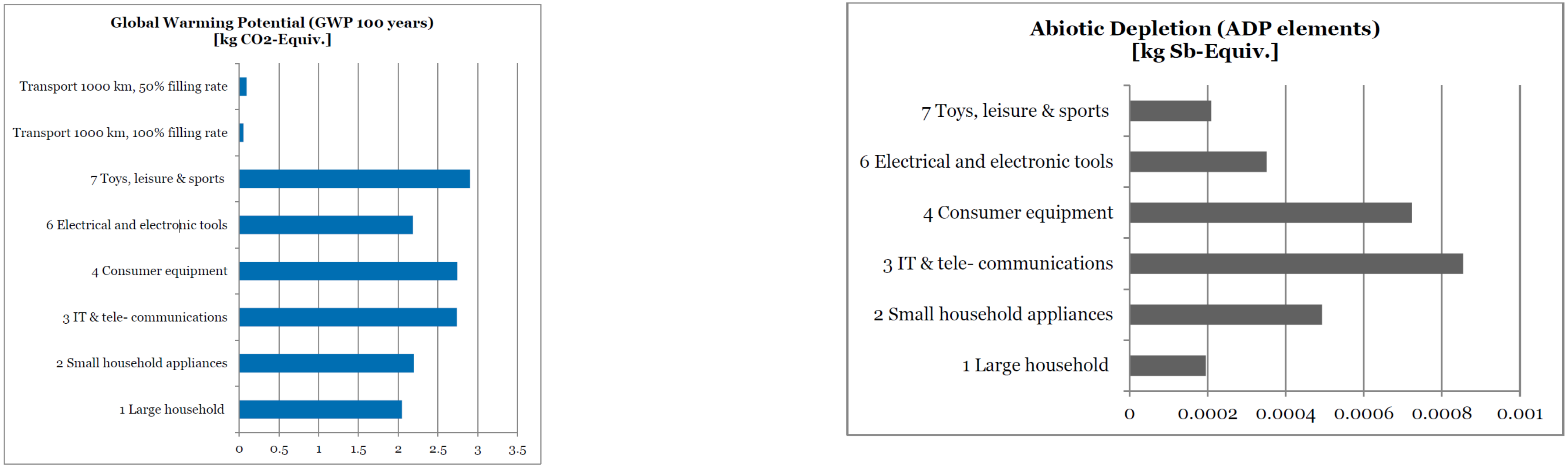
Materials	Food processing	Hot water ketlle	Microwaves	Personal care	Vacuum cleaner	Other small household appliances
Total share of metals	***52.1***	***60.4***	***80.8***	***51.8***	***25.5***	***59.62***
Aluminium	11.5	4.3	0.47	4.0	5.1	10.2
Coper	6.2	4.6	12.5	20	3.5	3
Coper +Aluminium	2.1	0.13	0.1	0.38	0.05	0.05
Stainless steel	6.7	1.8	0.92	6.3	4.2	0.87
Steel	25.6	49.6	66.8	21.1	12.6	45.5
Total share of plastics	***32.33***	***18.62***	***5.9***	***30.3***	***60.7***	***16.9***
Acrylonitrile Butadiene Styrene	0.45	2.9	1.5	3.2	10.8	5.8
Polystyrene	-	-	0.09	1	-	-
Polyamide	1.5	1.1	-	4.9	-	-
Polycarbonate	-	0.04	0.05	0.2	-	-
Polyethylene	-	0.02	0.03	0.28	-	-
Polypropylene	6	7.4	0.59	2.6	5.1	1.4
PVC	0.18	0.26	0.63	0.12	2	0.3
Other Plastics	24.2	6.9	3.1	18.0	42.8	9.4
Glass	1.3	7.6	6.4	0.53	-	-
Concrete	-	-	-	0.02	-	-
Electronics	1.4	3.3	2.4	1.3	0.21	0.26
Other	12.9	10	4.6	16	13.8	23.6

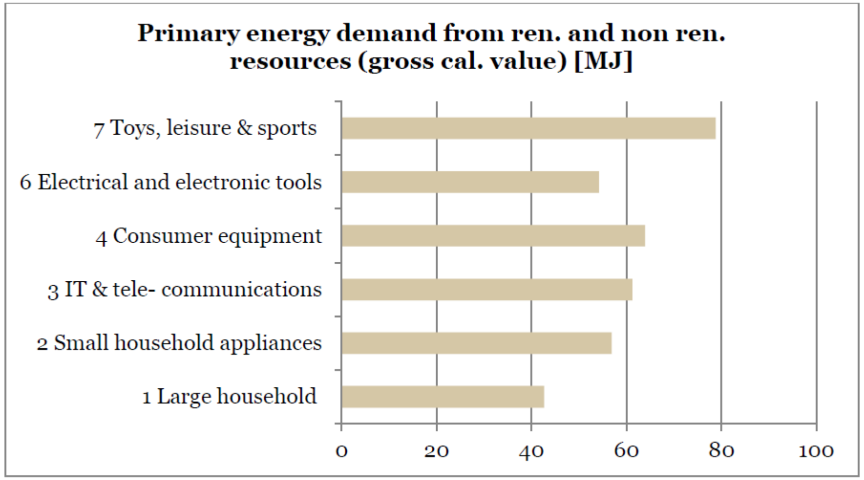
Typically, ICT related product groups compared to "simple" households' appliances are more valuable from economic or the environmental point of view **per product**. However, due to the fact that ICT waste is usually smaller in size and tend to be more dispersed, the benefits of recycling between those two groups is not always clear and depend on waste volumes and collection and recycling efficiencies.

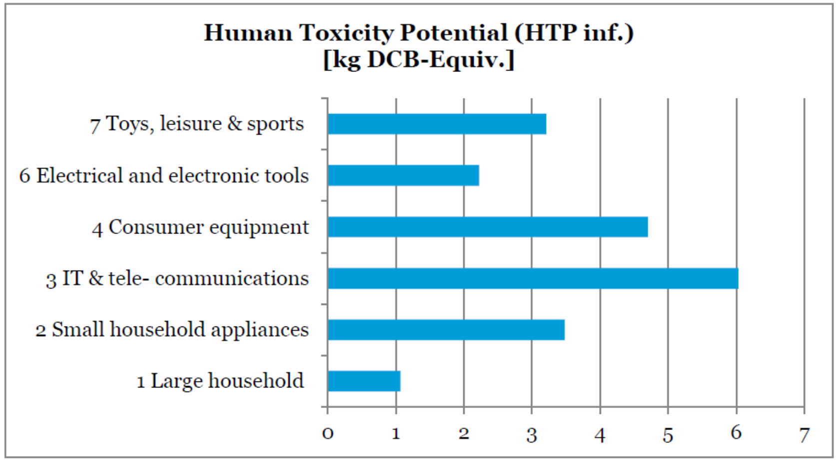
An IVLs study of 2015 (Ivert L. K., Raadal H.L. et al. 2015) looked at the potential environmental impacts of material production for various EEE fractions in different EEE categories to gauge the potential environmental savings from their recycling (Figure 6). Recycled materials can replace virgin materials, which often gives environmental savings. The potential GWP benefit of recycling was found to be much greater and negative effects of emissions from extra transportation were negligible, although it should of course be made as efficient as possible. The largest environmental impacts were found in ICT products for abiotic depletion and toxicological impact categories, dominated by the lifecycle of silver and copper. Toys, leisure and sports equipment were found to have high environmental impacts, mainly due to high content of plastics of fossil origin and high energy intensities. The study clearly showed there are clear potential savings from recycling, although several shortcomings could be pointed out:

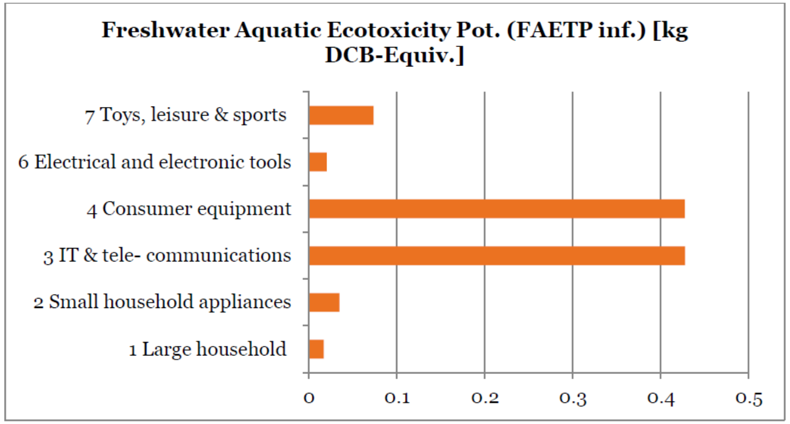
- The study was based on an older WEEE classification (changed according to new version of WEEE directive since August 14th in 2018);
- Some environmentally "charged" elements such as gold and other precious metals were not included in ICT compositional analyses, which may have resulted in an underestimation of some environmental benefits (of recycling), such as e.g. GWP;
- The study merely analysed the fact of the presence of materials in WEEE, which in reality does not mean that they are recycled (some materials are not feasible to recycle today).

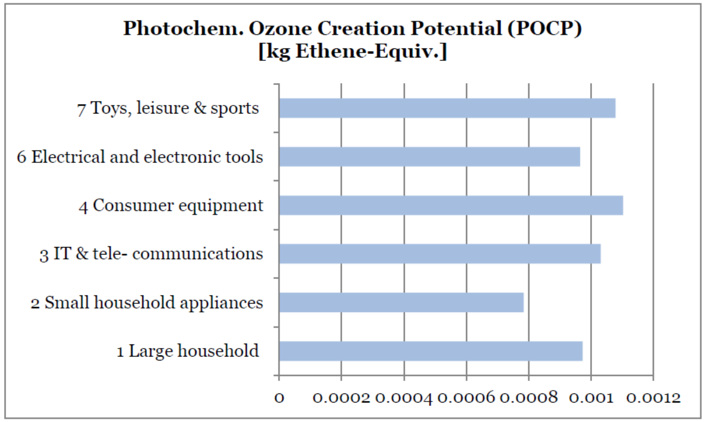
Figure 6. Potential environmental impact from material production of one kg of the respective EEE fractions. For GWP category EEE compared to 1000 km transport of one kg WEEE (Ivert L. K., Raadal H.L. et al. 2015)




Primary energy demand from ren. and non ren. resources (gross cal. value) [MJ]
7 Toys, leisure & sports
6 Electrical and electronic tools
4 Consumer equipment
3 IT & tele- communications
2 Small household appliances
1 Large household
0
20
40
60
80
100


Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]
7 Toys, leisure & sports
6 Electrical and electronic tools
4 Consumer equipment
3 IT & tele- communications
2 Small household appliances
1 Large household
0
1
2
3
4
5
6
7


Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.) [kg DCB-Equiv.]
7 Toys, leisure & sports
6 Electrical and electronic tools
4 Consumer equipment
3 IT & tele- communications
2 Small household appliances
1 Large household
0
0.1
0.2
0.3
0.4
0.5


Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]
7 Toys, leisure & sports
6 Electrical and electronic tools
4 Consumer equipment
3 IT & tele- communications
2 Small household appliances
1 Large household
0
0.0002
0.0004
0.0006
0.0008
0.001
0.0012

Currently, WEEE recycling in Sweden (as well as many other countries) still focuses mainly on precious materials and bulk materials (Figure 7). Partly technically and mainly economically it is not feasible to recycle a range of critical materials such as rare earth elements (REE). However, many precious metals (e.g., gold, palladium, silver) and other bulk ferrous and non-ferrous metals (e.g., iron, steel alloys, copper and aluminium) have significant environmental benefits if their recycling replaces virgin uses.

Diverse elektronik

Material	Hantering	%
Järn	Materialåtervinning	40%
Koppar	Materialåtervinning	5%
Aluminium	Materialåtervinning	4%
Plast	Materialåtervinning	18%
Silver	Materialåtervinning	0,012%
Guld	Materialåtervinning	0,001%
Paladium	Materialåtervinning	0,0005%
Övriga metaller	Materialåtervinning	10%
Övriga brännbara material	Energiutvinning	10%
Ej återvinningsbara eller brännbara material	Deponi	13%
Total		100%

Figure 7. Material composition of separately collected category "diverse electronics" and its recycling according to El-Kretsen; small and ICT electronics are likely to end up as "diverse" (data by El-Kretsen (2019)).

Material recycling of precious and rare metals can give significant economic benefits, for which reason they are indeed recycled. Table 9 illustrates average market prices around 2019 for different metals alongside their estimated quantities in different products. The total value of recyclable metals present in 1 mlj pieces of electronic device may vary between 20 and 70 bil. kr in smartphones and up to 120 bil. kr in the laptop computers.

Publications detailing the content of critical and precious metals in different kinds of EEE show significant differences in the reported values, which means that at best the information should be used as an estimate of the magnitude of the amounts in different product groups. The differences could be explained by product diversity in a group, ways to measure the material content (e.g., experimental vs. theoretical) and that material content changes with time (higher concentrations in older products)(Bakas, Herczeg et al. 2016). Therefore, the materials' content of critical metals in different product groups presented here should be seen only as indicative.

One of current and future challenges to increase the recycling of precious metals in WEEE is the diminishing concentrations of precious metals on a per product level. Technological advancements (e.g. ever thinner conductive interconnects in microchips or thinner contact layers on printed circuit boards (PCBs)) allow reducing the intensities of rare/precious metals per product. However, with the increasing consumption of EEE the use of environmentally sensitive materials in EEEs is still going to increase, albeit the decreasing concentrations, which impedes recycling(Jilvero, Sjölin et al. 2017).

Therefore, the economic effect of recycling depends on WEEE collection efficiencies, reduction of losses in waste management chains, recycling efficiencies, quality of recycled materials and price levels of virgin materials.

Table 9. Illustration of the value of metals (SEK) per 1 million pieces of EEE devices.

Materials	Average price, kr/kg (4)	Smartphone (1)	Smartphone (2)	Smartphone (3)	Simple phone (3)	Tablets (3)	LCD notebooks (3)	Notebooks (3)
Iron (steel) (Fe)	3	2,213	40,874	2,0122	2,7668	0	0	0
Aluminium (Al)	21	462,384	18,1160	60,456	250,163	0	0	0
Copper (Cu)	56	851,054	2,040,391	788,013	1,463,453	1,519,740	7,598,699	7,598,699
Silver (Ag)	4925	152,6776	975,166	1,201,720	4,925,083	246,254	1,231,271	1,231,271
Gold (Au)	425624	12,768,733	51,500,558	16,173,729	10,214,987	18,727,476	93,637,378	93,637,378
Palladium (Pd)	456026	4,560,262	15,504,890	6,840,393	4,104,236	3,648,210	18,241,048	18,241,048
Total, kr		**20,171,423**	**70,243,039**	**25,084,434**	**20,985,590**	**24,141,679**	**120,708,395**	**120,708,395**

Data estimated based on data reported in: (1) Manhart et al. 2016, (2) Andrae 2016, (3) Cucchiella, D'Adamo et al. (2015)(4) U.S. Geological Survey (2020)

Table 10. Illustration of composition (g) of different materials in ICT products.

Materials	Smartphone (1)	Smartphone (2)	Smartphone (3)	Simple phone (3)	Tablets (3)	LCD notebooks (3)	Notebooks (3)
Iron (steel) (Fe)	0.88	16.25	8.00	11	0	0	0
Aluminium (Al)	22.18	8.69	2.90	12	0	0	0
Copper (Cu)	15.12	36.25	14.00	26	27	135	135
Silver (Ag)	0.31	0.20	0.24	1	0.05	0.25	0.25
Gold (Au)	0.03	0.12	0.04	0.024	0.044	0.22	0.22
Palladium (Pd)	0.01	0.03	0.02	0.009	0.008	0.04	0.04
Total weight, g	**160**	**230**	**120**	**80**	**500**	**3,500**	**3,500**

Data sources (1) Manhart et al. 2016, (2) Andrae 2016, (3) Cucchiella, D'Adamo et al. (2015)

3.1.2.2 Incineration

Although, we were not able to identify reliable information on the environmental impacts of WEEE incineration, it is clear that it generates more **environmental burdens** than benefits. To the benefits belong the energy content of plastics and the benefits from the recovery of easily recoverable ferrous metals, although their value and quality is generally low. Other metals in WEEE (often toxic) remain in the ashes and can pose several environmental and health risks.

3.2 Increased recycling vs stock storage by households

A deposit system can likely facilitate an increased collection of electronics that are kept by households. The exact quantities of WEEE kept in disused product stocks is not certain. Statistics are not existent except for some anecdotal evidences from few case studies based on surveys or material balances (see chapter 1). It is rather evident that storing small valuable electronics at home past their technical or practical use time is quite common, which implies a delay before older EEE reach waste management systems or are being lost with other waste streams.

The longer the stocks are kept idle, the fewer possibilities there are to reuse old products before they could be directed to remanufacturing or recycling. Material recyclers might potentially find more value in older product stocks due to higher content of valuable materials. However, product reuse has more environmental benefits than recycling and might bring even economic benefits. In addition, stockpiling of WEEE by households can create certain risks, such as potential leakages or fires caused by old batteries or releases of harmful substances present in old plastics. From these two perspectives policy instrument, which would accelerate the forwarding of disused EEE to reuse, remanufacturing or recycling, might be beneficial.

Another debatable question is whether or not a delay of WEEE in household stocks is actually beneficial for the extraction of rare materials, given the current lack of technologies, volumes or economic feasibility. Future waste management systems are likely to be more material efficient including better sorting and fewer losses in waste management chains. At the moment this remains a rhetorical question not supported by rigorous research or robust empirical evidences.

3.3 Increased reuse vs in stocks

This section shortly discusses the potential impacts of increased collection and domestic reuse vs recycling. If the alternative is incineration (reuse vs incineration) the benefits of reuse would be unquestionable (see the section "increased recycling vs incineration").

3.3.1 Current situation

The quantities of small electronics in household storage and suitable for reuse are at large unknown. So far, our insight suggests that about 20% of the Swedish population keeps about 2 million of disused mobile phones at home in a more or less permanent stock. These are largely still suitable for a second life.

More accurate estimates would need a more precise information about the age, functionality and quantities (units or weight) in different categories. Purchasing data (on the basis of physical units or new or extended subscription) are likely to be available through market research. Data about annual collections by large re-users, such a e.g. Inrego, which stand for significant a market shares of reuse/remanufacturing services might also be useful for more precise estimates of stocks vs. re-use. Data from other large waste management players, such as e.g. El-Kretsen, could help estimate the number of disused EEE falling into waste management schemes. Additional information could be gathered from case studies with large send-hand players, such as e.g. Blocket, Swappie or Tradera, who handle a certain share of aftersales in the consumer-to-consumer market segment.

The frame and scope limitations of assessment did not allow any deeper data mining along these lines. Nevertheless, we think our suggestions are valuable for future evaluations.

3.3.2 Benefits of re-use vs recycling

As presented in previous section, the lifecycles of many small technology-rich EEE products are energy-, material-, and pollution-intensive (Figure 8). Still functional, not too old and high-quality EEE products have the greatest potential for reuse, especially those with high potential for technological obsolescence, e.g., IT and telecommunication products. An extension of the lifetime of such products by reuse can potentially bring much more significant environmental benefits than recycling.

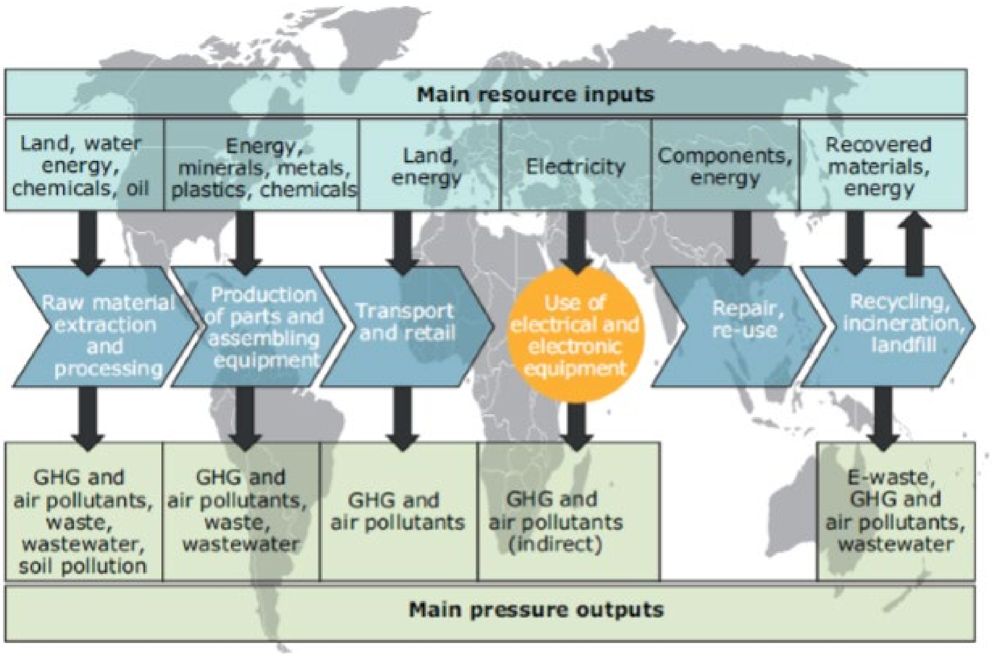


Figure 8. An overview of the main resource inputs and pressure outputs of electrical and electronic equipment value chain. Source: (Bachér, Dams et al. 2020)

Reuse usually can bring environmental benefits by replacing virgin materials and delaying waste stages. A negative side of energy using products might be energy efficiency in the use stage (for new products), which for some product groups is still improving at noticeable rates. For small hand-held EEE this is probably less of an issue (compare a mobile phone to a refrigerator). A re-use can delay additional material extraction and waste, but it should be weighted against the environmental costs of return and preparations for reuse (Figure 9).

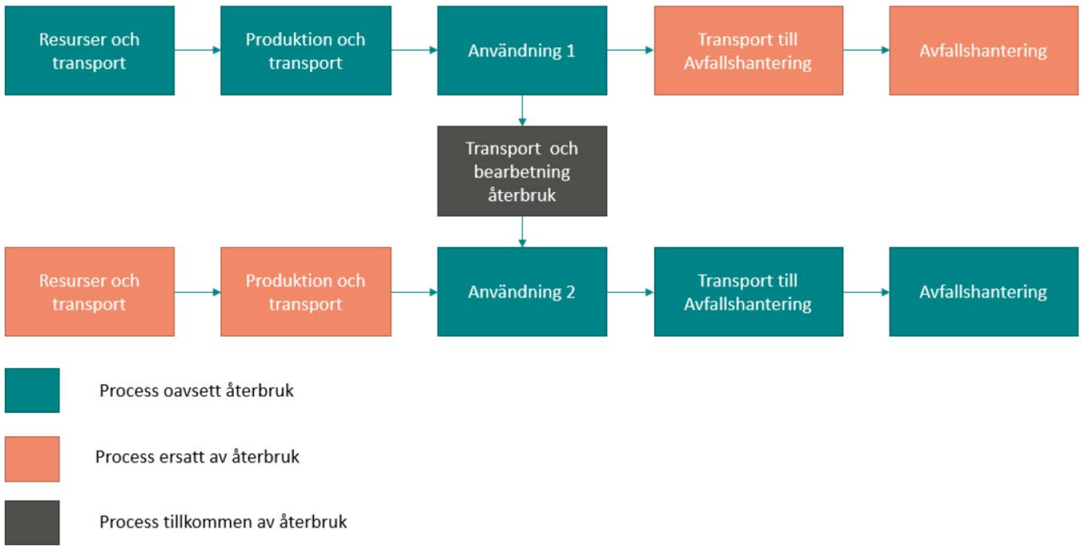


Figure 9. Schematic description of reuse and stages of life-cycle that could potentially be replaced by re-use (Wranne 2020).

The significant environmental impacts of producing highly integrated ICT products are in the material extraction, material purification and manufacturing stages. More energy intensive EEE might also have environmental hot spots in the use phase (compare a laptop and a stationary computer). The end-of-life impacts of ICT and other EEE products is probably least known as the impacts are contextual (depends on sorting, collection rates and management practices including re-use, remanufacturing and recycling rates as well as regulations for waste management practices).

Box 3. Example of life cycle stages of a smartphone

Material extraction and manufacturing stages of the lifecycle of **smartphones** accounts for 35–92% of the total GHG emissions. Especially GHG intensive is the manufacturing of integrated circuits, LCD screens and printed circuit boards. The use phase of EEE is largely linked to electricity consumption, which can contribute to about 10–49% of the total GHG emissions over their lifecycle. The distribution phase (transports) is responsible for just 3–17, regardless of the global nature of production (Bachér, Dams et al. 2020). These indicative examples are relevant also to Sweden, except perhaps for use phase, where the relatively greener electricity mix might have a lower share of GHG emissions.

Although a second-hand product reduces the environmental impacts of a new product (materials, energy, emissions and waste), it may require additional environmental burdens in the return and reconditioning chains (e.g. storing, repairing, refreshing, transportation, remanufacturing, spare parts, etc.). However, from the climate change perspective these burdens tend to be relatively lower than the savings of avoided production (Figure 10). At the same time, the savings from reuse can vary greatly between different EEE groups. Manhart et al. (2016) showed a range of estimated GHG emissions between 16 and 110 kg-CO2-eq. over the lifetime of different smartphone models (Bachér, Dams et al. 2020). An IVL study (Wranne 2020), estimated average CO2 savings from reuse of different typical IT products - 55kg-CO_2-eq per smartphone, 95 kg per tablet, 280 kg per notebook and 470 kg per desktop (Figure 10). Despite wide variations of savings between different products and product groups, the benefits of reuse (especially for IT products) vs recycling are tangible (recycling can give climate savings in a range of 2-2.5 kg of GWP per kg (Figure 6) and (Ivert L. K., Raadal H.L. et al. 2015).

Sub category	Avoided total (sum) (kg CO2-eq)	New production	Transport from new production	Refurbishment	Transport to and from refurbishment	Waste handling	Transport to waste handling	Weight (kg)
Notebook (average all sub categories)	280	280	1,2	-0,4	-0,5	1,6	0,1	1,6
Notebook: Screen below 14 inch	250	250	1,1	-0,4	-0,4	1,5	0,1	1,4
Notebook: Screen 14+ inch	300	300	1,5	-0,4	-0,6	1,6	0,1	2,1
Notebook: Hybrid	280	280	1,0	-0,4	-0,4	1,6	0,1	1,2
AIO (average all sub categories) (All-in-one desktop)	470	460	4,4	-0,4	-1,7	10,0	0,4	8,4
AIO: Screen below 24 inch	420	410	3,8	-0,4	-1,4	7,3	0,3	7,0
AIO: Screen 24+ inch	520	500	5,1	-0,4	-1,9	14,0	0,5	9,8
Desktop (average all sub categories)	470	460	4,3	-0,4	-1,6	9,1	0,4	8,2
Desktop: USDT (Ultra Small DeskTop)	290	290	1,6	-0,4	-0,6	3,4	0,1	2,4
Desktop: SFF (Small Form Factor)	380	370	3,6	-0,4	-1,3	8,7	0,3	6,7
Desktop: Tower	750	730	7,7	-0,4	-2,9	15,0	0,7	15,0
Monitor (average all sub categories)	520	510	5,6	-0,4	-2,1	8,4	0,5	11,0
Monitor: Screen below 33 inch	440	430	3,6	-0,4	-1,3	6,4	0,3	6,6
Monitor: Screen 33+ inch	620	600	7,5	-0,4	-2,8	10,0	0,7	15,0
Printer: Desk	180	170	12,0	-0,4	-4,7	0,0	1,2	26,0
Server: Rack	400	390	13,0	-0,4	-4,8	0,0	1,2	26,0
Handheld (average all sub categories)	98	97	0,7	-0,4	-0,3	0,7	0,0	0,4
Handheld: Tablet-big	140	140	0,8	-0,4	-0,3	1,0	0,0	0,7
Handheld: Smartphone	55	55	0,5	-0,4	-0,2	0,5	0,0	0,2
Handheld: Tablet-Small	95	94	0,6	-0,4	-0,2	0,7	0,0	0,3
Projectors: mid size	21	20	1,4	-0,4	-0,5	0,0	0,1	2,0
Network equipment (average all sub categories)	340	330	6,8	-0,4	-2,6	2,6	0,7	14,0
Network equipment: Small	8,7	9	0,7	-0,4	-0,3	0,1	0,0	0,5
Network equipment: Rack mounted (blade)	200	200	3,2	-0,4	-1,2	1,6	0,3	5,9
Network equipment: Rack mounted (large)	800	780	17,0	-0,4	-6,2	6,3	1,7	35,0
Components (average all sub categories)	22	22	0,1	0,0	0,0	0,2	0,0	0,2
Components: SSD	94	93	0,0	0,0	0,0	0,7	0,0	0,1
Components: HDD	71	70	0,4	0,0	0,0	0,6	0,0	0,8
Components: RAM memory	5,1	5	0,0	0,0	0,0	0,0	0,0	0,0
Components: Processor	50	50	0,0	0,0	0,0	0,4	0,0	0,0
Components: Laptop battery	7,9	8	0,2	0,0	0,0	0,1	0,0	0,3
Components: Laptop screen	61	60	0,1	0,0	0,0	0,5	0,0	0,1
Components: Tablet screen	32	32	0,1	0,0	0,0	0,3	0,0	0,2
Components: Smartphone screen	14	14	0,0	0,0	0,0	0,1	0,0	0,1
Components: Keyboard	3,7	3	0,4	0,0	0,0	0,0	0,0	0,8
Components: Power adaptor, laptop	3,5	3	0,1	0,0	0,0	0,0	0,0	0,2
Components: Docking station	8,4	8	0,4	0,0	0,0	0,1	0,0	0,8
Components: Network card	1,9	2	0,1	0,0	0,0	0,0	0,0	0,2
Components: Fan	0,3	0	0,0	0,0	0,0	0,0	0,0	0,0
Components: DVD	3,4	3	0,1	0,0	0,0	0,0	0,0	0,2
Components: Mouse pad	0,1	0	0,1	0,0	0,0	0,0	0,0	0,1
Components: Smartphone/tablet charger	1,3	1	0,1	0,0	0,0	0,0	0,0	0,1

Figure 10. Environmental benefits of re-use of IT products (Wranne 2020)

Other benefits than GHG savings can be expected from higher order waste management solutions for EEE . According to Wranne (2020), laptops, smartphones and some DIY tools have high waste footprints compared to other products due to high material intensities in material extraction, the use of precious and critical materials as well as high energy requirement. Moreover, ICT products with high level of component integration contribute to large energy intensities in manufacturing due to high purity input materials and clear room environments. In this respect a reuse of functional products avoids new production and the associated impacts in several impact categories.

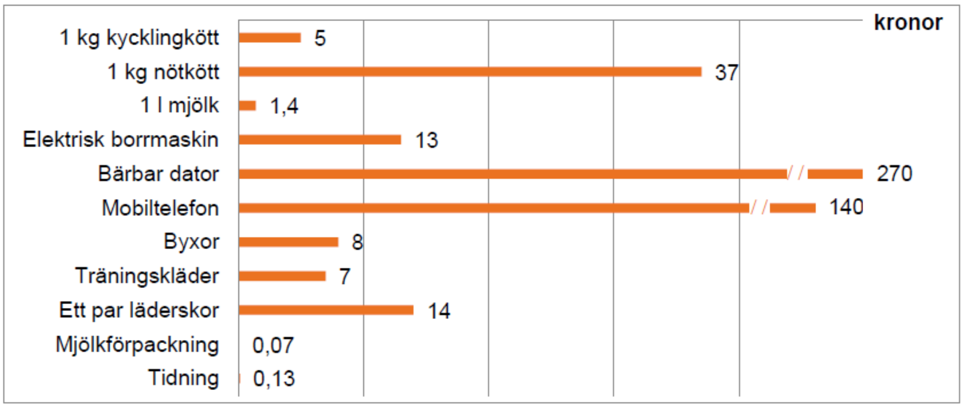


Figure 11. Environmental impacts (climate costs, waste footprint) of three electronic products (drilling machine, laptop and smartphone) in comparison to other daily life products (Laurenti and Stenmarck 2015)

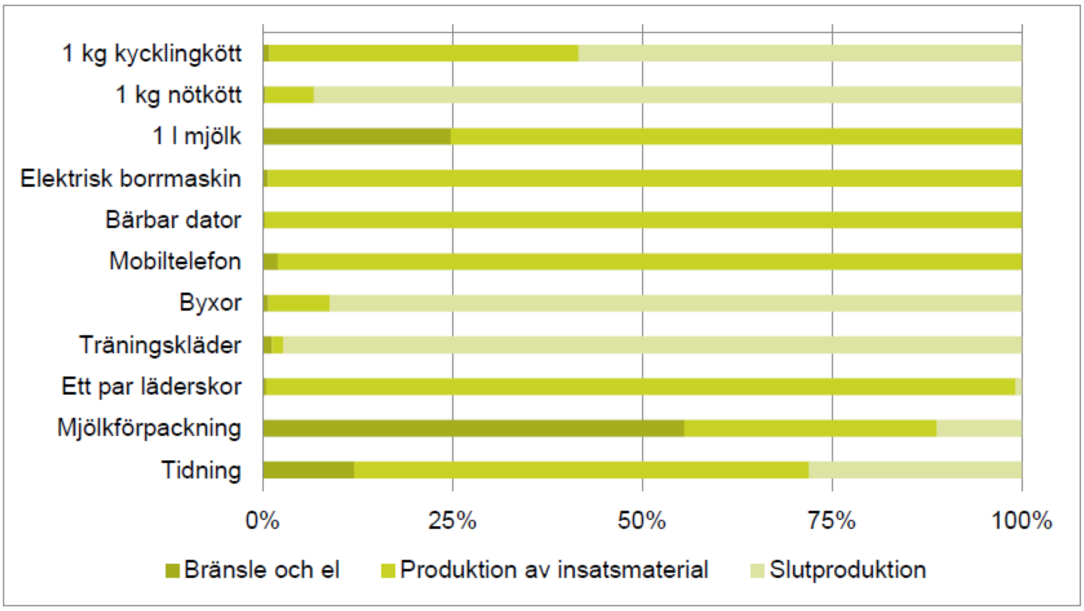


Figure 12. The proportion of the contribution of various production steps to waste footprints of several consumer products (Laurenti and Stenmarck 2015).

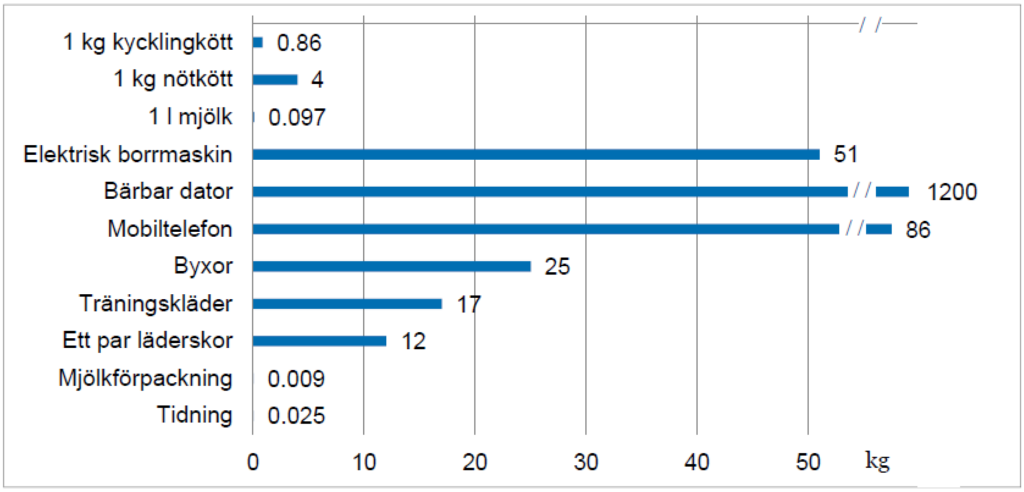


Figure 13. Waste footprints of various consumer products(Laurenti and Stenmarck 2015)

Previous examples were based on assumptions that reuse fully replaces the production of new products. In practice, the expected benefits depend on: (1) how much longer the life of product is extended; (2) to what degree the reuse replaces new consumption, and (3) where the reuse takes place (impacts in Sweden could be different from those in other countries).

Generally, literature on practical possibilities to extend products' lifespans and the environmental benefits of reuse is scarce in terms of quantitative estimates. However, the available evidence at least qualitatively points to that lifetime extension for most EEE (especially in the ICT group) should be supported as much as possible, since material extraction and manufacturing have large environmental intensities.

A review study reported that smartphones can be used anywhere between 7 and 20 years (Bachér, Dams et al. 2020). To illustrate, a 1-year lifetime extension of all smartphones in Europe would save about 2.1 million tonnes CO2-eqv. per year by 2030. Just a 30% improvement would be equivalent of taking about 1 million cars off the roads for a year. Extending a smartphone's lifetime by 4.5 years could halve its climate impacts (Bachér, Dams et al. 2020).

Other small electrical devices

In most of the previous examples, it was implied that the use phase of 2nd life products would be equal to use phase of a new product's impacts. This is perhaps truer for handheld (low energy devices), but less relevant for energy-intensive products, especially in product groups where energy efficiency improvements are significant. For such products, lifetime extension imposes trade-offs with the impacts from energy use (Bachér, Dams et al. 2020). In countries like Sweden or Norway with fairly green electricity mixes, this is less of an issue, but it still should be taken into account.

4 Conclusions

This study has been assigned by the Swedish Government to investigate the potential of a deposit-refund system for small electric and electronics equipment (EEE) including ICT electronics. The study focusses on the reusability of electronics kept in stocks and the potential environmental impact of circular solutions vs alternatives (incineration and in stocks).

Reusability in stocks

The amount of small unused electronics kept in stock at home is a delayed or lost opportunity to remanufacture or reuse them. Overall, data on the quantities of electronics kept in stocks in Sweden is limited and fragmented, which makes it unreliable so far.

An international study projected around of 100 million pieces of small IT and 808 million of other small electronics that is potentially kept by the Swedish households in 2020. However, the study has some shortcomings, e.g. informal and partly formal exports were not included in the modelling, and the accounts over the stocks also refer to the products in use. A recent Swedish survey shows that potentially there are around 2 million pieces of unused functional mobile phones under 4-year-old kept by the Swedish households.

The reuse potential of unused electronics kept at home would depend on products' durability and their obsolescence as perceived by the consumers (i.e. consumers' attitudes and preferences). The available information describing the lifetime often refers to the time until products are discarded as waste, which discounts the time they are kept idling household stocks. There is little consensus in the literature over the average designed lifetime and the durability of electronics and information. For unused electronics kept in stocks, the greatest potential for reuse is when the products are still within their designed lifetimes. With time, the potential for reuse decreases due to technological obsolescence and changing consumer preferences. Idling products (e.g. mobile phones) usually have low intrinsic value for their owners given there are better alternatives available in the market.

The potential for reusing dysfunctional EEE in household stocks in Sweden is probably low. It is low especially for items of low economic value (e.g. old toys) or ICT electronics beyond their designed lifetimes. EEE that are still functional and technically performing, have a much higher reuse potential, but it depends on a product group. For some rapidly aging products, e.g. smartphones, tablets and laptops, their quality, brand and make might play a positive role in their reusability. At the moment, there is little publicly available oversight over which product categories and especially brands and makes that are more prone for reuse.

Environmental impacts

In this study, three product waste management options are qualitatively compared from the environmental point of view - increased recycling vs incineration, increased recycling vs storage at household and increased domestic reuse vs recycling.

It was estimated that yearly around 8,000 tonnes of small electronics enter incineration as a part of mixed households waste flow. This figure not very accurate as it could also include electronics which are out of the focus of this study.

If the waste management system would be more effective in diverting the WEEE flows towards higher recycling and material recovery rates (especially the "exotic" metals), we could expect tangible environmental and economic benefits compared to incineration. The magnitude and nature of the benefits depend on the quantity of collected electronics, composition, and the effectiveness and the efficiency of sorting and recycling.

Overall, our qualitative literature review shows that the extension of the lifespans of small EEE by domestic reuse could potentially bring environmental benefits in comparison to other current alternatives. This is particularly relevant for the ICT products with typically high environmental lifecycle related environmental burdens. The absolute savings from reuse can vary greatly between EEE groups and even within the same product group.

However, drawing definite conclusions about the impacts of increased collection and current recycling vs keeping WEEE in stocks is difficult as depends mainly on future behaviour and management of end-of-life electronics.

Limitations

The study revealed that information about the relevant waste and product streams is very fragmented and the existing knowledge gaps could be only filled with empirical research, such as e.g., consumer surveys or interviews with practitioners, which were not possible in the frame of the project. Current study is based on a few Swedish and foreign examples, which facilitated a more theoretical discussion of the potential impacts, trends and tendencies, rather than empirics-based evidences.

Electronics is a highly dynamic sector with large potential differences in environmental impacts both between and within single product groups. These depend on producers, product characteristics, quality, age and consumer behaviour, issues which were not always possible to consider in this study.

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