Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Energy and Process Engineering

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Environmental impact of metals in Norwegian Electric and Electronic Products

Master's thesis in Nordic Master in Environmental Engineering with a specialisation in Residual Resources Engineering and Industrial Ecology
Supervisor: Johan Berg Pettersen & Anders Damgaard
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Abstract

E-waste is a rapidly growing waste stream, with a increase of 2.5 million tons every year on a global scale. Norway is the leading country in the world when it comes to generating e-waste pr capita, and have hold this spot in at least the last two decades. One of the most valuable components of e-waste, and relatively easy to recover, is metals. The environmental impact that the excavation of these metals produce is embedded within the metals, and therefore it is embedded in the electronic and electric products.

This Thesis is looking into the flow of the electronic and electric products, and the metals within, in Norway. The environmental impact that these metals have generated in the process of producing these virgin metals. Material flow analysis is used to examine the flow of the EE products and through that the flow of the metals. The lifetime and sales data of the EE products are used by this MFA to look at a period 2016-2025.

The MFA were done on 44 different EE product categories, which contains 48 different metals. A few of the 44 categories were vague in scope such as kitchen equipment and other household items. These categories were covered by an average of different EE products within the category. Out of the 48 metals that was found, only steel is not on the periodic table of elements. Only 5 of the 48 metals are found in other parts other than the printed circuit boards of the products. These 5 are steel, copper, aluminium, iron and nickel.

A LCIA is performed for the metals which shows that only a few of the metals have an impact. This was done for the following midpoint categories: *climate change*, *land use*, *material resources* and *water use*, and for the 3 endpoint categories: *ecosystem quality*, *human health* and *natural resources*.
The 5 metals that are not in PCB's have the majority of the impact throughout the different impact categories. With the exception of the midpoint category of *material resources* and the endpoint category of *natural resources*, where neodymium and praseodymium have the majority of the impact. The precious metal of silver, gold and palladium have relatively small impact in comparison to the other metals even though these are some of the most polluting metals.

Steel is found mostly in the large EE products, such as Dishwashers, ovens and washing machines. It holds a steady impact in every midpoint and endpoint category. Aluminium can be found in many of the EE product, but the biggest contribution comes from TV's and washing machines. It has the larges impact on *climate change*, *land use*, *ecosystem quality* and *human health* out of all the metals. Iron is similar to steel and can mainly be found in the larger EE product, such as refrigerators and freezers. Iron has a impact on everyone of the categories that are looked at, but in comparison with the other is has a small contribution. Neodymium is a rare earth element and it can be found in almost every EE product, but it is mainly found in speakers such as headphones, ear plugs and loudspeakers. The impact from this metal is mainly in the *material resources* and *natural resources* category.

This thesis provides knowledge on the flow of EE products in Norway, the metal composition of these EE products and the environmental impacts these metals produce in the early process of making the virgin metal. This knowledge can be used for decision making or for comparisons with other related subjects. The findings should be worked on further, to improve the robustness of the model.

1 Sammenfatning

Elektronisk affald er en hurtigt voksende affalds strøm, som stiger på global skala med 2.5 millioner tons hvert år. Norge er det land i verden hvor der bliver produceret mest affald pr. indbygger, og det har de i hvert fald været igennem de sidste to årtier. En vigtig ressource som findes i elektronisk affald er metal, hvilket også er let at genudvinde. Miljøpåvirkningen forudsaget af produktionen af disse metaller ledsager dem videre, og er derfor også en del af påvirkningen som findes i elektroniske og elektriske produkter.

Dette speciale kigger på strømmen af elektroniske og elektriske produkter, og derved også metallerne der er en del af dem, i Norge. Miljøpåvirkningerne som er genereret da metallerne blev produceret. Matrialestrømsanalyse bliver brugt til at undersøge EE produkterne, og derved også metallerne. Livstiden og salgs dataen for EE produkterne bruges som grundlag til at lave matrialestrømsanalysen for perioden 2016-2025.

Matrialestrømsanalysen blev udført på 44 forskellige EE produkt kategorier, med 48 forskellige metaller. Nogle få af de 44 produkt kategorier var vagt beskrevet, såsom "køkken udstyr" og "øvrige husholds genstande". Disse kategorier blev dækket af et gennemsnit af forskellige EE produkter som passede ind under. Ud af de 48 metaller er stål det eneste metal der ikke er at finde i det periodiske system. Kun 5 af de 48 metaller kan findes uden for printpladerne der er i elektroniske produkter. Disse metaller er stål, kobber, aluminium, jern og nikkel.

En LCIA er udført for metallerne, hvilket viser at kun nogle få af dem har en indflydelse. Dette blev gjort for de følgende midpoint kategorier: *Klima forandringer*, *arealanvendelse*, *materielle ressourcer*, og *vandforbrug*, og for de 3 endpoint kategorier: *økosystemkvalitet*, *menneskesundhed* og *naturressourcer*. De 5 metaller der ikke er i printpladerne er ansvarlige for hovedparten af påvirkningerne spredt ud på de forskellige kategorier. Undtagelsen er for midpoint kategorien *materielle ressourcer* og endpoint kategorien *naturressourcer* hvor neodymium og praseodymium er ansvarlig for hovedparten af påvirkningen. De kostbare metaller som sølv, guld og palladium har relativt lille påvirkning når der sammenlignes med de andre metaller, selv om de er kendt for at være nogle af de mest forurenende.

Stål er en del af de fleste store EE produkter, såsom opvaskemaskiner, ovne, og vaskemaskiner. Dets påvirkning er stabilt for alle midpoint og endpoint kategorier. Aluminium er en del af mange af EE produkterne, men de største bidrag af aluminium kommer fra TV og vaskemaskiner. Det har den største påvirkning i følgende kategorier *klima forandringer*, *arealanvendelse*, *økosystemkvalitet* og *menneskesundhed* når der sammenlignes med de andre metaller. Jern opføre sig i stil med stål da det hovedsagligt findes i store EE produkter, såsom køleskabe og frysere. Dets påvirking er tydeligt på tværs af alle kategorierne, men det er relativt småt sammenlignet med de andre metaller. Neodymium er en del af gruppen "sjældne jordarters metaller" og det kan findes i næsten alle EE produkter, men hovedparten af det findes i højtalere. Høretelefoner, både på og i ørene, er blandt dem med højest bidrag af neodymium. Påvirkningen fra dette metal ses mest i *materielle ressourcer* og *naturessourcer*.

Dette speciale bidrager med viden omkring strømmen af EE produkter i Norge, metal indholdet af disse EE produkter og deres miljøpåvirkninger fra produktionen af det nye metal. Denne viden kan danne grundlaget for beslutninger eller bruges til sammenligning med lignede emner. Dette emner bør arbejdes videre på for at forbedre modellen og forøge robustheden af modellen.

Preface

This Thesis is written in the spring of 2024 (Started the 10th of January 2024 and handed in on the 10th of June 2024) as the final project of the Nordic Master in Environmental Engineering with a specialisation in Residual Resources Engineering and Industrial Ecology. This master thesis is written by Mads Vingborg Andersen, master student in the joint Nordic master programme at the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU) and at the Department of Environmental and Resource Engineering at the Technical University of Denmark (DTU). This master thesis is equal to 30 ECTS points and is supervised by Johan Berg Pettersen (Associate Professor, NTNU Industrial Ecology Programme), Anders Damgaard (Associate Professor, DTU Sustain), and co-supervised by Kim Rainer Mattson (Ph.D. Candidate, NTNU Industrial Ecology Programme).

The focus for this thesis was the embedded environmental impact of the metals that is in the electronic and electrical products in Norway. Based on literature the metal contend of the most common electrical and electronic products were determined. The environmental impact from these metals were found with the life cycle assessment software Brightway 2.0 that was access through Activity-Browser. This thesis was trying to understand which metals, and what impacts these have, are found in the Norwegian Electrical and Electronics products. This was achieved by building a data base for the different products, with the metal content, the weight and the lifetime of said products.

This Thesis have been made with help and guidance from a few people of which I would like to give my thanks. I would like to thank Kim, Johan and Anders for their guidance, patience and support throughout the process. The great input for the times when I was stuck on a problem. The help they provided that gave me motivation to continue through the harder times of the project.

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2 Introduction

The increase in electronic waste (e-waste) is accelerating, with a estimate of a yearly increase of 2.5 million metric tons (Mt) globally. With 44.4 Mt generated in 2014, and 53.6 Mt in 2019, it is estimated to reach 74.7 Mt in 2030 (Forti et al., 2020). This is a rapidly growing waste stream, with a lot of potential. This potential does not come without its problems, as most of the e-waste is generated in the western world. When looking at the amount generated per capita in Europe in 2019 the number was at 16.2 kg per capita, which put it in the first place in the world. In second place Oceania with 16.1 and third was the Americas with 13.3 kg per capita. Note that the Americas is both north and south America (Forti et al., 2020). So even though Asia is the major part of the 53.6 Mt with a 24.9 Mt, it is only 5.6 kg per capita.

If the average consumer in the world was generating the same amount of electronics as the Europeans then the total would be around 125 Mt, assuming a world population at 7.76 billion people (Worldometer, 2024). There is a huge problem with this waste flow, as 82% of it has an unknown fate, and Europe is the only place with a collection and recycling rate at 42.5%. The rest is lying around 10%, with the exception being Africa at 1% (Forti et al., 2020).

When looking at Europe one country sticks out in regards to e-waste, and that country is Norway. As seen in Figure. 2 Norway has been the country with the highest e-waste per capita since 2005 and every year all the way up to 2020.

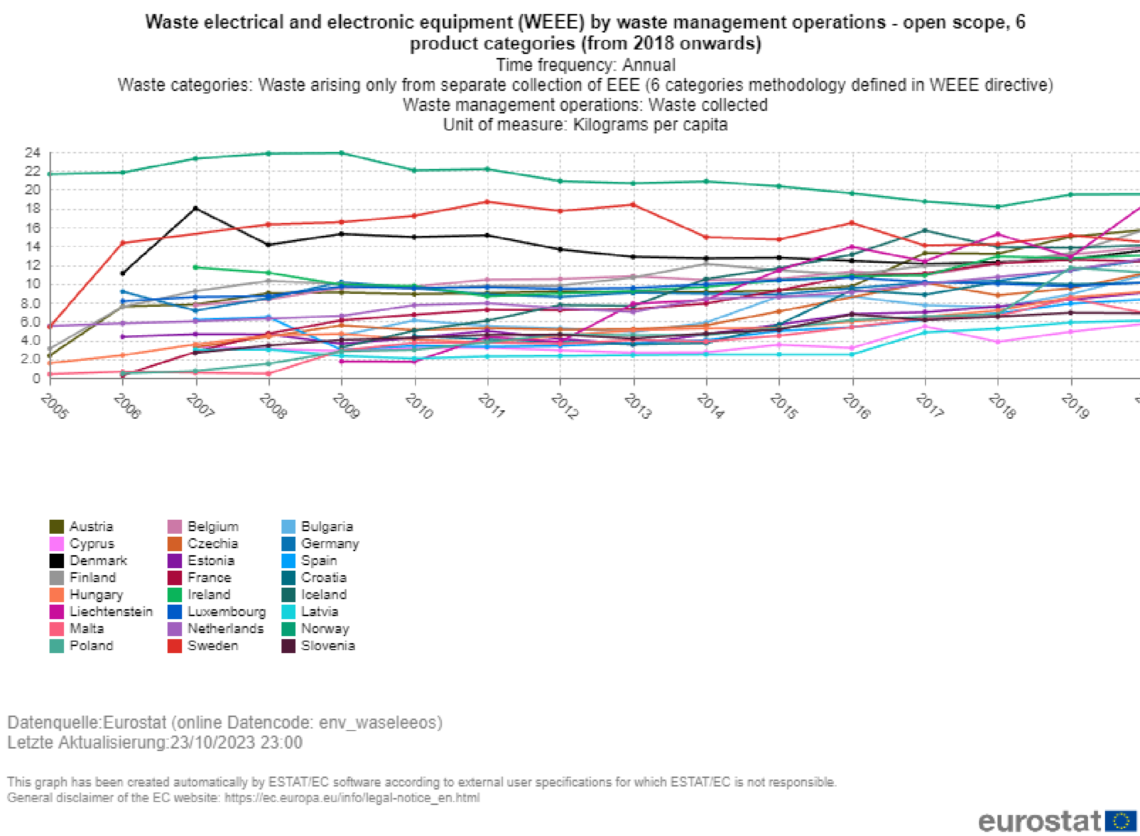

Figure 2: The countries in EU and their e-waste generation from 2005-2020 in kg per capita (eurostat, 2023)

Even though it has decreased from its peak in 2008 and 2009 where it was almost at 24 kg per capita, its lowest point in 2018 is being just about the top points of the closest countries. More concerning, but backed up by the future estimate from Forti et al., 2020, is that most of the countries have an increasing tendency in e-waste. With Liechtenstein going from one of the lowest to the second highest country in just a decade. According to Forti et al., 2020 the amount is actually higher for Norway, as it has 26 kg per capita in 2019.

When talking about electronic waste there are many different terms that are used, e-waste, WEEE and EEE. These are among the most common, and mostly describe the same thing in more or less detail. EEE is electrical and electronic equipment and WEEE being waste from electrical and electronic equipment. So if WEEE are waste from EEE and it pretty much is the same as e-waste then what is meant by e-waste? This is very different depending on what country that is looked at. In Japan there are 2 categories, "Large home appliances" and "small home appliances". In the other end there is China with 8 different categories, and close after EU with 6 categories. These categories covers many different appliances, and the United Nations University (UNU) have divided these into 54 subcategories (Kumari & Samadder, 2022).

Another perspective that fits the scope of this thesis more is to look at what electronics is being sold in Norway, and use those overall subcategories to categorize the products. The subcategories that is used in Norway by Elektronikkbransjen, 2024a in 2022 is the following; "Mobil" *Mobile*, "Stillbildekamera" *Camera*, "Store elektriske Apparater" *Large Electric Appliances*, "Småelektrisk" *Small electric*, "Lyd- og bildeprodukter" *Sound and picture system.* These subcategories covers most of the sold electronics that will end up as E-waste at one point, there is one major product that is missing form these categories which is computers. Therefore *Computers* is added on in its own way. Elektronikkbransjen is a Norwegian organization that consist of many different partners, big and small, that works together regarding everything electronic. The provide a yearly statistic for sold electronic in Norway.

One of the problems that can be seen on a global scale is the export of e-waste from developed countries to developing countries. With the problem here lying in the lack of proper handling of the e-waste. This has caused some of the places that the e-waste is transported to become extremely toxic. Ghana is one such place with a part of the capital city of Accra, named Agbogbloshie, being placed on the Blacksmith Institute's list of the world's 10 most polluted places. Other places on this list include Chernobyl, due to the radiation, and Noril'sk which is heavily polluted due to industrial mining (Biello, 2014). So even though the Blacksmith list no longer have any places in western Europe or USA, the source of the problem sites still come from the consumers in these countries.

E-waste can be very toxic if handled wrong, where Agbogbloshie is one of the best example for this. One of the methods that is used to recover the metals found in e-waste is the burning of the cables for the copper. This results in the release of heavy metals that get into the environment (Biello, 2014). When released into the environment it can find its way into our food through soil contamination. And then it can impact human health in numerous ways, with a few being skin disease, cancer and respiratory problems (Nande et al., 2023).

With all of these different problems increasing with the rising quantity of e-waste there is a need to investigate these subjects.

2.1 Research questions

RQ 1. What are the flows of electronics products and the metals within, and how does it change over the decade 2016-2025?

RQ 2. What are the impacts embedded in the metals in electronic products, and which metal and product contribute the most?

To answer RQ 1. a general overview of the electronic products that is found in Norway will be determined, based on available data. For the metal content of the different electronic devices found in the Norwegian system a literature review is performed. The lifetime for these products is then used to estimate the quantity for each product that is entering the waste system each year. This is built upon the sales numbers for electronic product in Norway.

In order to answer RQ. 2 a literature review is performed to understand the potential environmental impact that the extraction of metal can have. With this knowledge and with the help of Brightway 2.0 accessed through activity-browser the environmental impacts for the metals is found in the Ecoinvent database. This is then combined with the MFA made for RQ 1 in order to find the actual impact, and which product that have the metals with the highest contribution.

2.2 Disclaimer

This Thesis is built upon the work done in the project (Andersen, 2023) performed during the fall of 2023 in relations to the course TEP5100 at NTNU by the same author of this thesis. The project was focusing on the same subject as this thesis, but only scratched the surface. The work presented in this thesis, even though there are similarities, especially in the method section, is original and has improved upon the former work.

3 Background

In this section different subcategories of electronic waste will be presented in order to better understand and discuss the impacts of extraction and preparation of metals found in electronic waste.

3.1 Looking into the background of metal environmental impacts

The focus of this thesis is the impacts that the metals found in e-waste have had on the environment as it gets onto the market from the mining extraction. Therefore to get a rough idea if the results of this thesis are correct a review of similar reports will be performed here. To start with the periodic table in Figure 3 shows the elements that are present in e-waste with a light red color. It also visualize how much an element pollutes during the mining process with a range of colors from dark blue to red, the figure is from Bel et al., 2019.

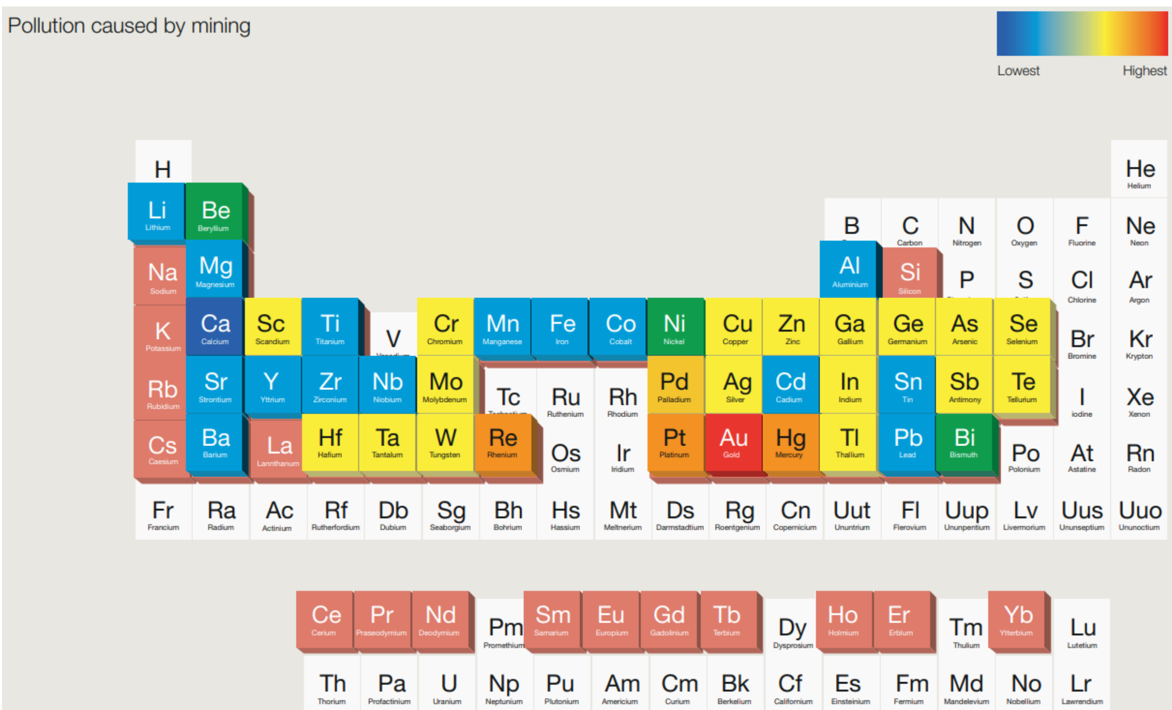

Figure 3: The periodic table and gradients of pollution from low to high caused by mining for the different elements, This figure is from (Bel et al., 2019)

According to Figure 3 the highest pollution from mining would be gold, followed by rhenium, platinum, mercury and then palladium. Due to the lack of information about what kind of pollution this figure is actually showing it can mostly be used to give an idea of which metals to look out for.

Another report has made a deep dive into the production of the metal production for 64 elements (Nuss & Eckelman, 2014). They have performed a LCA covering the cradle to gate production of these metals and have impact categories such as *global warming potential* as well as *cumulative energy demand*, *terrestrial acidification*, *freshwater eutrophication* and *human toxicity*. The *global warming potential* impacts can be seen in Figure 4 below. For the other 4 impact categories, see Figure 5 further down.

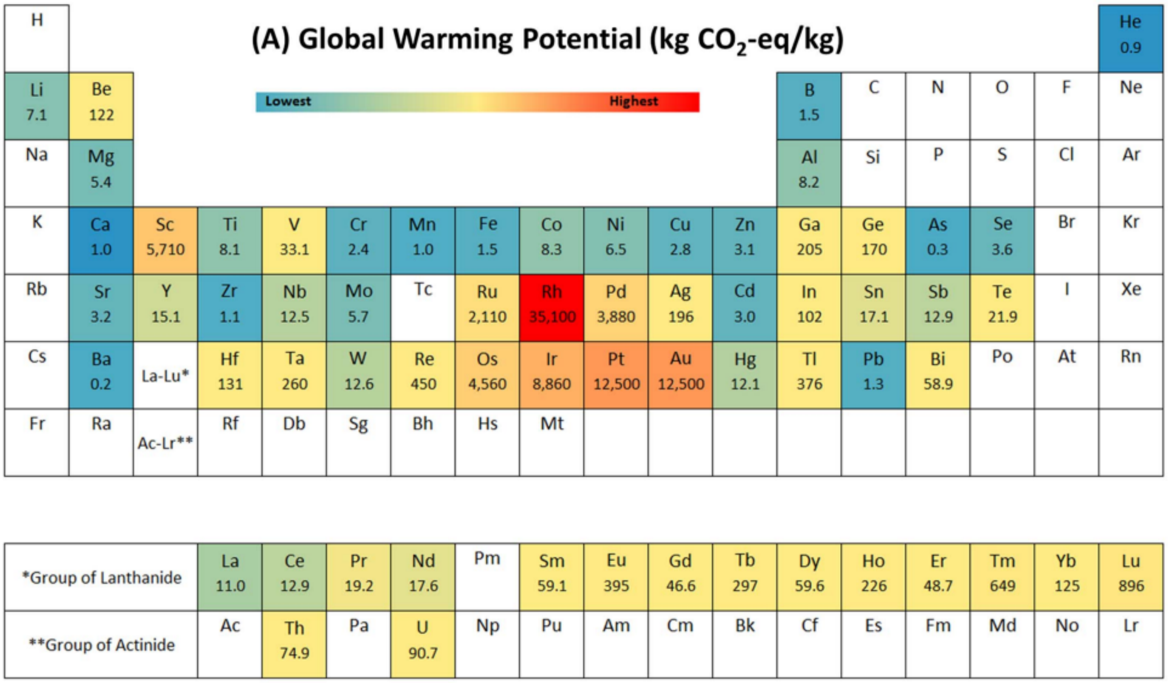

Figure 4: The *global warming potential* for 1 kg of element on the periodic table, this is from (Nuss & Eckelman, 2014).

When comparing Figure 4 with Figure 3 there are similarities but there are also some differences. Figure 4 has several other elements, and the highest potential is not the same as in Figure 3.
Here rhodium have the highest *global warming potential* with a 35,100 kg CO_2-eq for every kg of rhodium. The second closest to that is gold and platinum which each have 12,500 Kg CO_2-eq for every kg of the element. That is a huge different if compared to one of the lower ranked elements, like copper. copper is only at 2.8 Kg CO_2-eq pr.kg copper, likewise a lot of the metals have a low value.

Looking at the other 4 categories that Xavier et al., 2023 looked at in Figure 5, there are some variations between them. To begin with lets look at *cumulative energy demand*, for which the unit is MJ-eq/ kg of element. This one have the same patterns as the *global warming potential* with rhodium being the most demanding of the elements.
Looking at the *terrestrial acidification*, with the unit kg SO_2-eq/ kg Element. The pattern have changed a bit from the other 2, with nickle and copper moving up in value. rhodium is still the element with the highest value.

For the remaining two, *freshwater eutrophication* (with the unit kg P-eq pr kg element) and *human toxicity* (with the unit CTUh pr kg element), the highest ranking element is gold. Which correlate with the expectations from Figure 3. *freshwater eutrophication* pattern is otherwise pretty similar with *terrestrial acidification*. *human toxicity* have quite a few of the different elements up towards the high value, compared to the other 4 impact categories.
With these figures there is a baseline to compare the results with, and it also gives an indication of which of the impact categories are important in regards to mining metals.

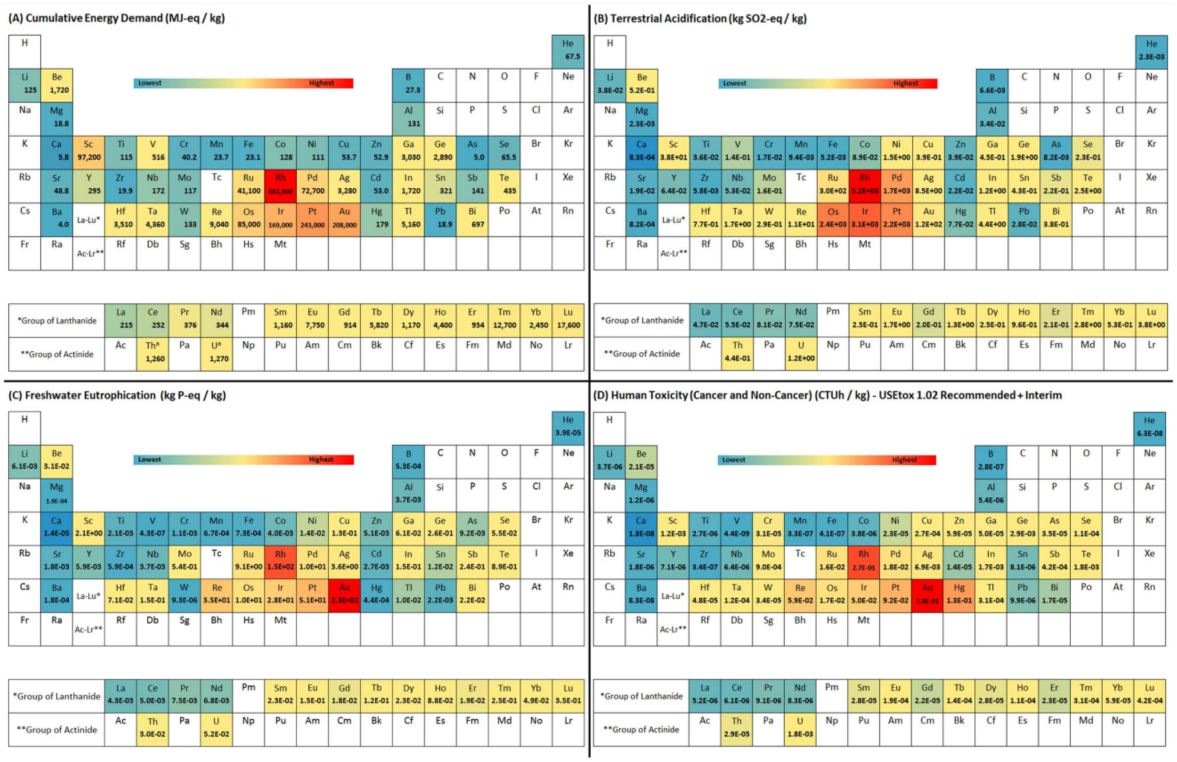

Figure 5: The different impact categories for the mining of 1 kg of element on the periodic table, this is from (Nuss & Eckelman, 2014).

3.2 The Electronic waste situation in Norway

As touched upon in the introduction Norway is the country with the highest waste generation per capita in the world. In 2019 it was at 26 kg pr capita, according to Forti et al., 2020. This is 6 kg more than what is shown on the map in Figure 6. The difference between the two sources is not known, but is speculated to be a matter of what is considered e-waste. When looking at the graph in Figure 2 then Norway is one of a few countries that have a decline in the period from 2005-2020.

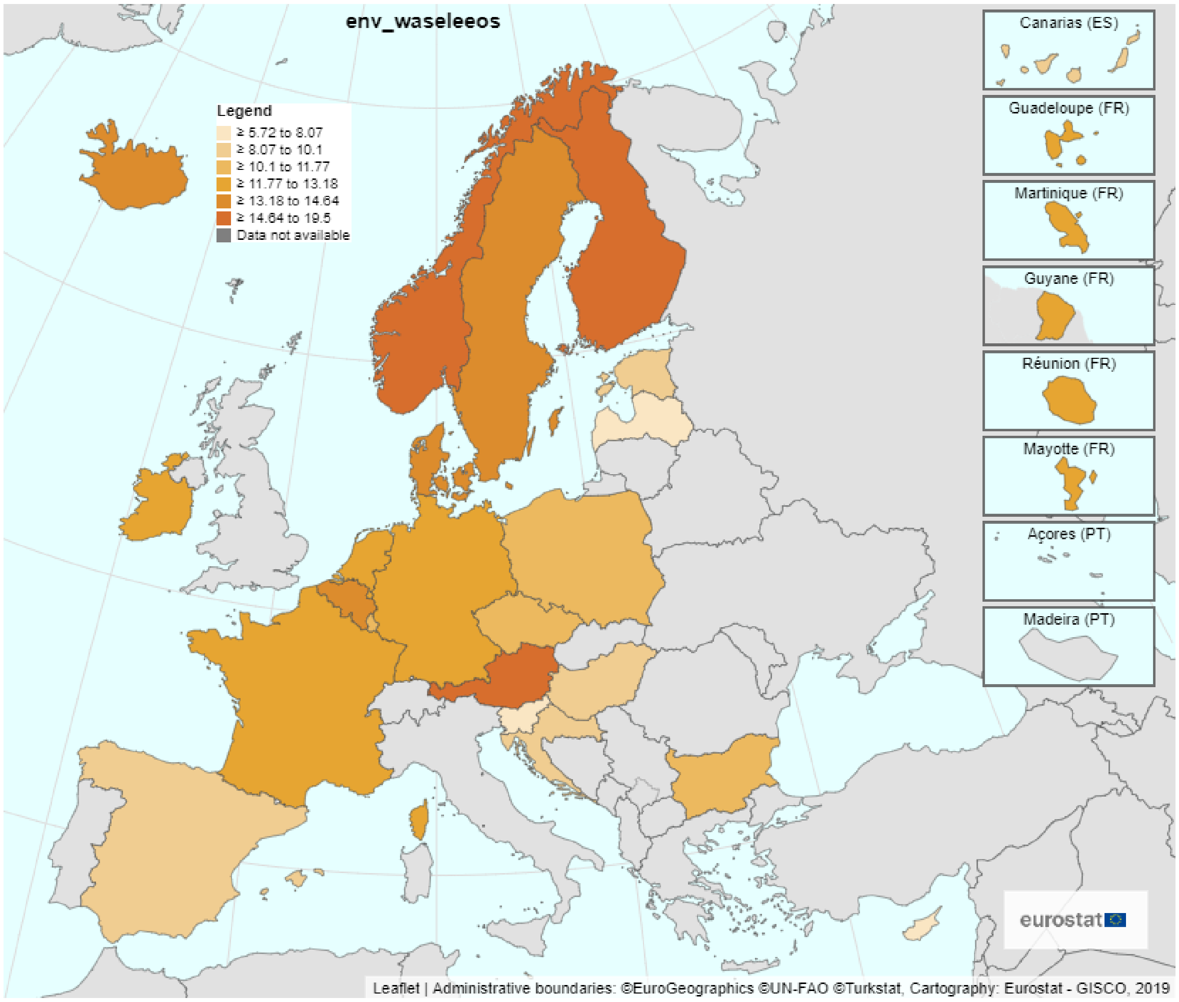

Figure 6: Europe and the e-waste generation for the different countries in 2020. Norway is the one with the highest value at 19.5 kg per capita, this is from (eurostat, 2023).

3.3 What methods/technologies are used in recycling metals today

There are different methods used to separate metals from the other materials used in electronics. here 3 of them are presented in order to understand what the difference between such methods can have on environmental impacts.
In general the e-waste is be dismantled manually, then shredded before it is separated by density or/and magnetism. This is to minimize the impurities of the final product, and to avoid a higher pollution of toxic material in later processes (Priya & Hait, 2017).

Pyrometallurgy is a thermal process that incinerate the e-waste at high temperature in order to separate the metals from the leftover materials not separated completely by earlier stages. This process will melt the metals and if the original metal is pure, such as copper from a wire then the final product will also be pure. The problem comes with different alloys, or electronic product with many different kind of metals. In these situations further separation steps are needed to achieve an end result that can be used again (Xavier et al., 2023). This makes pyrometallurgy an energy intensive process, and to add even more problems it is also recorded to have a lot of second hand emissions of toxic gasses such as: Polybrominated Dibenzodioxins (PBDD), Phenol, Biphenyl and Dibromobenzene to name a few (Priya & Hait, 2017).

Somewhat successful attempts have been made to improve on this method. It is a cleaner ultrasonic assisted pyrometallurgical metal recovery technique, which have lowered the emissions of waste and increased the yield of metals greatly. Copper and iron have been recovered with 95.2-97.5 and 97.1-98.5% respectively. Another process involving introducing vacuum have given results of 99% pure copper and 99.9% pure gold. But to achieve these results other methods are often needed, such as hydrometallurgy (Priya & Hait, 2017).

Hydrometallurgy is a process that involves either acid or base leaching agents that can dissolve the specific metal and by that separate it from the other materials from the electronic device. After the new solution is made it then undergo one or more of many separation option such as: electrodeposition, cementation or ion exchange (Xavier et al., 2023). For acid leaching the amount recovered vary depended on which metal is in question. For chromium it is 98%, for nickel it is 92%, for copper it is 85%, for iron it is 71%, for aluminium it is 44%, for zinc it is 34% and for tin it is 21%. There are 3 different recovery values for gold as it depend on the acid used, but the percent recovered are 82%, 97.5% and 98%. This method is susceptible to metal loss in the solvents if done on an industrial scale, but the energy and the environmental pollution are way lower than that of the pyrometallurgy method.

Biometallurgy is a greener and way newer option for recovering of metals from e-waste. It has similarities to the hydrometallurgy process in regards to the method of leaching the metals out of the waste. This is done with microorganisms that is able to convert the metal into it soluble state (Priya & Hait, 2017). As this is still a quite new method the recovery rates vary a lot as variations of the process is tested. Depending on the metal and the process the recovery can change between 80-96.8% for copper, 20-88.2% for aluminium, 78-92% for nickle and 74-91.6% for zinc. A factor also seems to be time as the only low value for aluminium was a test of 165 days, and the rest was 68% or over (Priya & Hait, 2017).

A comparison between these 3 methods was also done by Priya and Hait, 2017, which can be seen below in Figure 7.

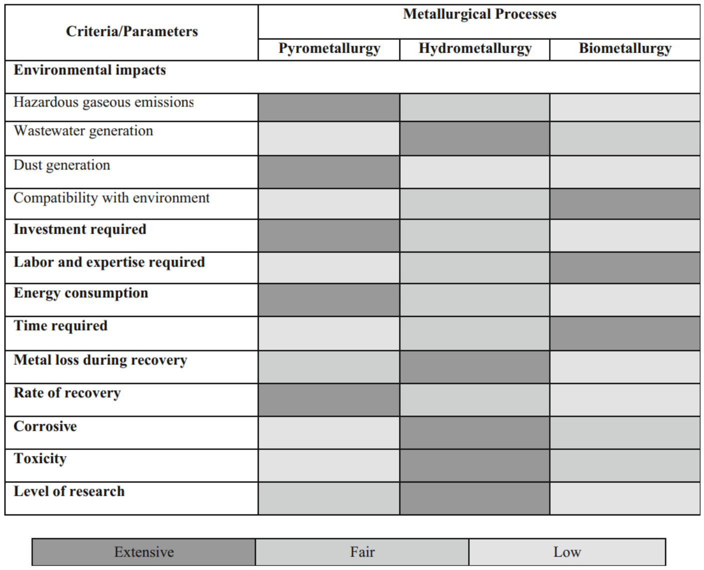

Figure 7: Compare the 3 metallurgical processes on a number of different parameters, this is from (Priya & Hait, 2017).

Here it is clear that biometallurgy have a great potential, but the level of research is still low and therefore has room for improvement. If looking at the environmental impacts between pyro- and hydrometallurgy then hydrometallurgy looks like it has the lesser overall impact. It might be the better choice until more research has been done on biometallurgy.

3.4 Metal demand and supply

When talking about recycling metals from e-waste it should be specified which metals that is talked about, as there are 94 metals in the periodic table. Not every single element that is classified as a metal is present in e-waste, and even if it is present it might be unrecoverable. Looking at the periodic table from Bel et al., 2019 gives a good overview of which metals that is used in electronics, based on which is found in e-waste. This table can be seen in Figure 8 below.

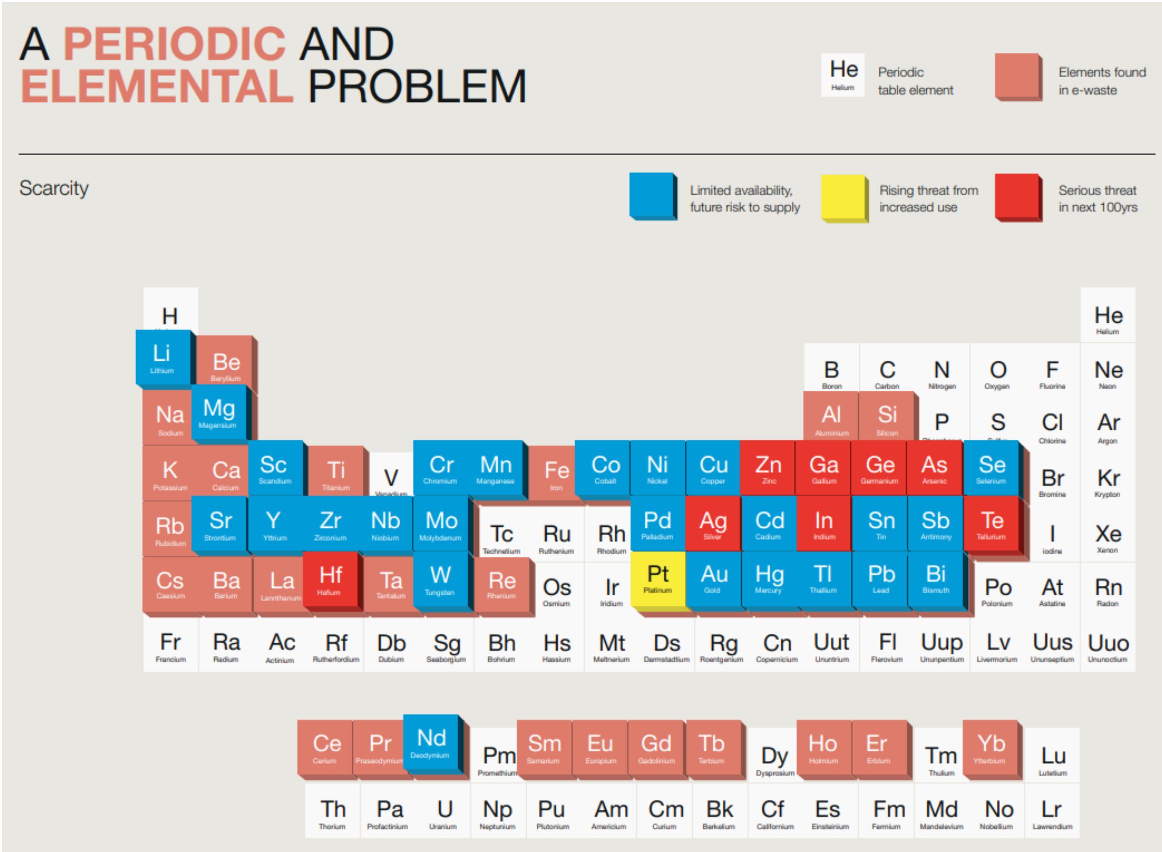

Figure 8: The periodic table with the elements that is in e-waste highlighted. The scarcity of the elements is shown as well, the table is from (Bel et al., 2019).

As shown there is quite a lot of the metals from the periodic table that are present in e-waste, along with one none metal, selenium, and a few half metals such as silicon, germanium, arsenic, antimony and tellurium. The blue markings are elements for which the supply is so limited that there is a potential future risk of using up the reserves. The one yellow, platinum, is in a rising threat as the use for this element is increasing. Then there is the elements for which the problem of running low on their reserves is within the next 100 years. This includes zinc, gallium, germanium, arsenic, silver, indium, tellurium and hafnium.

In a new report with the focus on recycling of critical raw materials (CRM) in the Nordic countries half of these have not been categorized as being critical for Europe. This is the case for indium, silver, tellurium and zinc (Bergfald et al., 2024). Other countries have categorized the 4 as CRM, indium (USA, Canada, Australia, Japan, South Korea, Russia and India), silver (Russia), tellurium (USA, Canada, Japan), zinc (USA, Canada, South Korea, Russia, South Africa). For the four remaining only gallium is getting close to being in the high risk when looking at supply of the element.
In the report Europe has defined many metals as CRM, and for simplicity they have grouped rare earth elements (REE) into two groups. Heavy and light REE (HREE and LREE respectively), with HREE being the elements from 62-71 and LREE from 57-61 in the periodic table of elements. With those two grouped then there is 26 CRM that are metals, which can be seen below in Table 1. It should be noted that the supply risk seems to have been decided based on political factors, as HREE and LREE have some of the highest scores here because the marked are controlled by China (Bergfald et al., 2024).

Table 1: The CRM that Europe have categorized in 2023. *The supply risk meter was getting near to being halfway from low to high. **The supply risk was halfway from low to high, (Bergfald et al., 2024)

Critical Raw Materials			
Aluminium	Cobalt	LREE*	Strontium
Antimony	Copper	Magnesium*	Tantalum
Arsenic	Gallium*	Manganese	Titanium
Barium	Germanium	Nickel	Tungsten
Beryllium	Hafnium	Niobium*	Vanadium
Bismuth	HREE**	Scandium	
Boron	Lithium	Silicon	

A few of the metals in Figure 8 that is shown in red (high risk of scarcity) is not mentioned in Table 1. They are however represented on other countries list of CRM, and can in the future end on the list for Europe as well. This rise in risk can be supported by the findings in (Watari et al., 2021) as they find the demand for all major metals except for lead will increase in the years to come, the report goes to the year 2100. The major metals they have looked at is iron and steel, aluminium, copper, zinc, lead and nickel. In 2100 the estimate rise in demand will be 470% for aluminium, 330% for copper, 130% for zinc and 100% for iron.

E-waste is not a homogeneous mass, but a general material content can still be assumed when looked at a large enough sample. This is another approach to see what can reasonably be recovered from e-waste, as the data found in this way is based on experiment more than theory. This is what Priya and Hait, 2017 have done, and it is presented in the Figure 9 below.

Constituents	Content (% wt/wt)	References
Metals	28.00–60.60	Widmer et al. 2005; Zhou et al. 2009
Iron and steel	8.00–50.00	Ilyas et al. 2010; Pant et al. 2012
Non-ferrous:	1.00–13.00	Pant et al. 2012; Widmer et al. 2005
Aluminum	0.75–4.70	Ilyas et al. 2010; Widmer et al. 2005
Copper	13.00–34.49	Tuncuk et al. 2012; Yamane et al. 2011
Nickel	0.0024–2.63	Yamane et al. 2011; Yang et al. 2009
Zinc	0.16–8.20	Ilyas et al. 2010; Zhang and Forssberg 1997
Lead	0.99–4.19	Iji and Yokoyama 1997
Gold	0.008–0.10	Sum 2005; Guo et al. 2009
Silver	0.20–0.33	Sum 2005; Guo et al. 2009
Plastics	20.60–23.00	Widmer et al. 2005; Zhou et al. 2009
Flame retardant	5.30	Widmer et al. 2005
Non flame retardant	15.30	Widmer et al. 2005
Glass and ceramic	2.00–33.00	Widmer et al. 2005; Yuan et al. 2007
Wood and plywood	2.60	Widmer et al. 2005
Rubber	0.90	Widmer et al. 2005
Others	4.60–16.00	Pant et al. 2012; Widmer et al. 2005

Figure 9: The different content found in e-waste, the table is from (Priya & Hait, 2017).

It can be seen that the content fraction have a large range on many of the metals, which gives some uncertainty with this method of approach. But generally a large fraction of the weight of e-waste is metal, where the largest fraction is from iron or steel. This is followed by copper and then the other fractions are beginning to overlap.

4 Methodology

In this chapter the methodologies used in the work that this thesis is based on is presented. The choices and assumptions that have been made for the model that have been built will be shown as well.

4.1 The System

The first thing is the system, that the simple material flow analysis that is used for this thesis, looks like. In Figure 10 the system can be seen, with 7 different processes included. The blue line is the system boundary for the MFA part of this thesis, which surrounds "Metal excavation and preparation for market", "Use phase of EEE" and "End of life for the EEE". The green line is the system boundary for the LCIA part of this thesis. which surrounds "Metal excavation and preparation for market", "End of Life for EEE" and "Embedded environmental impacts in the metal". This boundary exclude "Use phase of EEE" as the environmental impacts from this phase is outside the scope of this thesis. The processes which are shown in Figure 10 but not included inside the system boundary are as follows "Production of EEE", "Recycle of WEEE" and "Incineration and/or Landfill".
The production of EEE are the binding process between the process of "Metal excavation and preparation for market" and "Use phase of EEE".

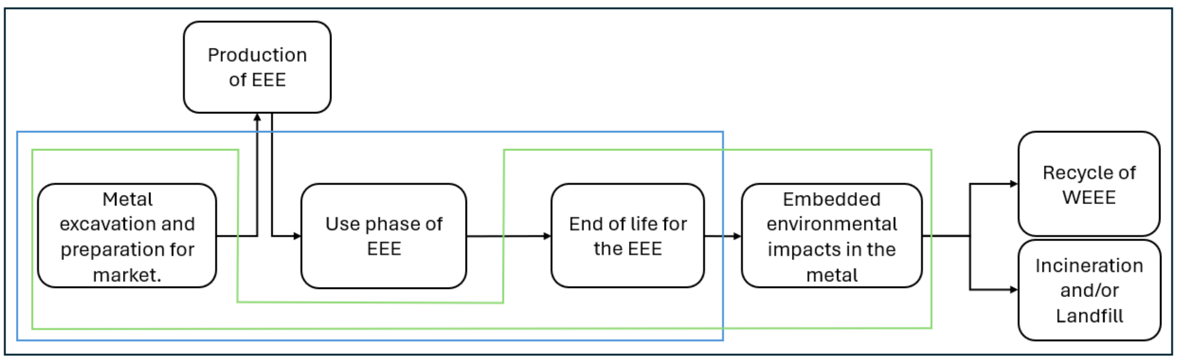

Figure 10: The system with the surrounding activities. The green line is the boundary for LCIA this thesis is working with. The Blue Line represent the MFA that includes the lifetime for the EE product in their use phase. The main focus being the end of life for EEE, with the environmental impact embedded in the metals from the point of excavation.

4.2 Building of MFA model

4.2.1 quantity of electronics

In order to find the environmental impacts from the metal an MFA model has been built based on the sales numbers found at Elektronikkbransjen, 2024a. This shows a wide array of general electronics that is bought in Norway, and there is records from 2006-2022. The records are not perfect as the focus have shifted throughout the years. Therefore a baseline for which electronics that is included in this work has been made.
The excel sheets published for the years 2016 and 2022 has been chosen for this baseline due to the fact that it covers the range for which Elektronikkbransjen have data available, and the older subcategories that no longer is collected data for is not included. With 1 exception being "Digital assistance" that only shows up for 1 year (2018), It has been excluded from the model as well due to this fact.

4.2.2 Lifetime of electronics

Knowing the quantity of electronics in the use phase in Norway, is a way to determined when the different types of electronics enters the end of life phase is needed. For this the expected lifetime for products is used as a estimate. The first problem for this is that not every piece of electronic is going to last precisely its lifetime. For the majority of the products multiple different lifetimes have been found, and the average of these lifetimes has been implemented in the model.
This is done with the mindset that the average of these lifetimes reflect the uncertainty for a product's untimely demise or its incredible long life, evened out in the greater picture.

4.2.3 Metal content of EE products.

A focused literature review was done in order to find as much data on the metal content for the different EE products. The literature review was performed on DTU Findit, a search engine available for DTU students. In Table 2 the search words used in this literature review can be seen. The search was done for every EE product that is on the sales numbers list, with a example being ”Recycle of metals from Refrigerator”. The search was not only on the products, but also focused on the most common metals that is found in EE products. This was done for the 8 metals presented in the table as well.

Table 2: Search words used in literature review to find the metal content for EE products. When ”Electric device” is in the sentence it was replaced with every EE product, and ”Metal” was substituted with the everyone of the 8 different metals also presented.

Seach words.		
BOM for ”Electric device”	”Metal” in electronics	
Bill of Materials for ”Electric devices”	”Metal” in ”electronic device”	
”Electric device” content	”Metal” in electronics	
Metal content of ”Electric device”	**Metals**	
Recycle of ”Electric device”	Copper	Steel
Recycle of materials from ”Electric device”	Gold	Aluminum
Recycle of metals from ”Electric device”	Silver	Iron
LCA for ”Electric device”	Palladium	Nickel
MFA for ”Electric device”		

The information for the metal content found with this literature review can be put into two categories, mg/kg and percent of 1 unit. This presented a new problem, comparing these two is hard if not impossible. Therefore a new search was performed, the average weight of each EE product. In some of the literature this weight for the relevant product was included, but for many of the EE product there was none.
Therefore a semi random search on online shopping sites was performed to find the average weight. It was semi random in the regard that the most common name for the EE product was used on the sites and the products that came up was chosen in no particular manner. The average weight was then estimated to be correct, based upon common knowledge. As an example if the average weight of a TV was 30 kg, then more would be added to the average in order to see if the weight would change. With the average weight for each product, combined with either a mg/kg or percent of total weight for that product. The metal content for the product can be determined, the common unit kilogram can be used going forward.
Aside from the elements found in the periodic table, steel is also looked at as it showed up in much of the data found on metal content of EE products.

4.2.4 special case: Computers

One product that is not included in the sales list from Elektronikkbransjen, 2024a, and that can be assumed to have a big impact on this case is computers. An estimate for both desktop and laptop computers was calculated based on the revenue from sales of computers in Norway, found at Elektronikkbransjen, 2024b. This revenue is for every type of computer, therefore a ratio between laptops and desktops is found on Canalys, 2023 by the graphs on this site. Out of 100 computers, 78 of them is assumed to be laptops and the other 22 is assumed to be desktops.
With the ratio and the revenue the only thing left is the spread of prices on computers, with the assumption that most of the computers are within normal price range that the average consumer is able to pay. Half of all sold computers is assumed to be an average of 600 USD. 40% is assumed to be at 1000 USD, and then the highend 10% is spread evenly between 3000 and 3500 USD. This is how the number of computers have been estimated and was only feasible to do for the years that the revenue was available, which was from 2019 to 2022 (Elektronikkbransjen, 2024b).

The MFA model for the metal in EE products is now feasible to make, by combining the above mentioned flow of metal through the Norwegian system can be calculated over a long period.

Table 3: The lifetime and the weight of the different products

Lifetime and weight of the products and its sources.				
Product	Average Lifetime (yr)	Sources	Average weight (kg)	Sources
Mobile Phone	3	(Gurumurthy & Annamalai, 2019) (Zhang et al., 2017)	0.092	(Zhang et al., 2017) (Oguchi et al., 2011) (Priya & Hait, 2018)
Tablet	5	(Ostroff, 2021)	0.521	(Apple, n.d.) (Samsung, n.d.-b) (Samsung, n.d.-a) (Amazon & Microsoft, n.d.)
Smartwatch	4	(Bingham, 2023)	0.037	(Amazon & Noise, n.d.) (Elkjøb & Apple, n.d.) (Elkjøb & Garmin, n.d.) (Ma et al., 2017)
Camera	7	(AVC-Photo-Video, 2023)	0.596	(Power & Canon, n.d.-b) (Power & Canon, n.d.-c) (Power & Sony, n.d.-g) (Power & Canon, n.d.-d) (Elkjøb & Sony, n.d.-b) (Elkjøb & Sony, n.d.-a)
Camera lenses	-	(Canon, 2018)	0.358	(Power & Canon, n.d.-g) (Power & Canon, n.d.-a) (Power & Canon, n.d.-f) (Power & Canon, n.d.-h)
VideoCamera	7	Same as Camera	0.672	(Power & Sony, n.d.-d) (Power & Sony, n.d.-c) (Power & Panasonic, n.d.-c) (Power & Sony, n.d.-e) (Power & Canon, n.d.-e)

Table 3: The lifetime and the weight of the different products

Lifetime and weight of the products and its sources.				
Chest Freezer	16	(Mr.Appliance, n.d.)	35	(Power & Senz, n.d.-a) (Power & Senz, n.d.-b) (Power & Gorenje, n.d.-c) (Power & Point, n.d.-a)
Cabinet Freezer	16	(Mr.Appliance, n.d.)	66	(Power & Samsung, n.d.-c) (Power & Samsung, n.d.-b) (Power & Point, n.d.-b) (Power & Gorenje, n.d.-a) (Power & Point, n.d.-g)
Refrigerator/ Freezer Combo	16	(Mr.Appliance, n.d.)	48	(Power & Point, n.d.-c) (Power & Bosch, n.d.-f) (Power & AEG, n.d.-a) (Power & SMEG, n.d.)
Refrigerator	10	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)	40	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)
Washing machine	13	(Huang, 2021) (Priya & Hait, 2018)	65	(Power & Samsung, n.d.-e) (Power & Samsung, n.d.-d) (Power & AEG, n.d.-c) (Power & Indesit, n.d.) (Power & AEG, n.d.-e) (Priya & Hait, 2018)
Dryer	13	(Gustafson, 2023)	48	(Power & AEG, n.d.-f) (Power & Grundig, n.d.-b) (Power & Grundig, n.d.-a) (Power & AEG, n.d.-g) (Francesca et al., 2019)
Dishwasher	7	(Gustafson, 2023)	46	(Power & Miele, n.d.-b) (Power & Siemens, n.d.-a) (Power & Miele, n.d.-c) (Power & AEG, n.d.-b) (Francesca et al., 2019)
Standalone oven	13	(Gustafson, 2023)	54	(Power & Voss, n.d.) (Power & Gorenje, n.d.-d) (Power & Gram, n.d.)
Build in oven	13	(Gustafson, 2023)	35	(Power & Gorenje, n.d.-b) (Power & Siemens, n.d.-b) (Power & AEG, n.d.-d)
Table stove	13	(Gustafson, 2023)	8.5	(Power & Haws, n.d.) (Power & Point, n.d.-f) (Power & Senz, n.d.-f)
Kitchen ventilation	15	(Hauslane, 2023)	13.3	(Power & Thermex, n.d.-a) (Power & Thermex, n.d.-b) (Power & Røroshetta, n.d.-a) (Power & Bosch, n.d.-c) (Power & Røroshetta, n.d.-b)
Minikitchen	6	Same as Microwave	14.3	Same as Microwave

Table 3: The lifetime and the weight of the different products

Lifetime and weight of the products and its sources.				
Microwave	6	(Gustafson, 2023)	14.3	(Power & Whirlpool, n.d.-b) (Power & Whirlpool, n.d.-a) (Power & Senz, n.d.-g) (Power & Samsung, n.d.-a)
Personal care	3	(Schmidt, 2021)	0.623	(Power & Point, n.d.-h) (Power & Huawei, n.d.) (Power & Babyliss, n.d.-a) (Power & Philips, n.d.-b) (Power & Oral-B, n.d.) (Power & Philips, n.d.-c) (Power & Babyliss, n.d.-b) (Power & Remington, n.d.-a)
Electric shaver	10	(ShaverShop, 2019)	0.341	(Power & Philips, n.d.-d) (Power & Braun, n.d.-b) (Power & Philips, n.d.-e) (Power & Braun, n.d.-a) (Power & Remington, n.d.-b)
Hair removal (Female)	10	Same as Electric shaver	0.623	Same as Personal care
Kitchen equipment	7	(Shield, n.d.)	4.211	(Power & Ninja, n.d.-b) (Power & Barista, n.d.) (Power & Bosch, n.d.-e) (Power & Nespresso, n.d.) (Power & Ninja, n.d.-a) (Power & OBH, n.d.-a) (Power & Brevilla, n.d.) (Power & Senseo, n.d.) (Power & BLND, n.d.) (Power & Electrolux, n.d.-a) (Power & Bosch, n.d.-d) (Power & OBH, n.d.-b)
Other household items	10	(Bobba et al., 2016)	3.822	(Power & Dyson, n.d.) (Power & Miele, n.d.-a) (Power & Bosch, n.d.-b) (Power & Ecovacs, n.d.) (Power & Roborock, n.d.) (Power & Electrolux, n.d.-b) (Power & Bosch, n.d.-a) (Power & Philips, n.d.-a) (Power & Senz, n.d.-e) (Power & Tefal, n.d.) (Power & Point, n.d.-d) (Power & Point, n.d.-e) (Power & Mill, n.d.) (Power & Senz, n.d.-d)
TV	8	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)	19.14	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)

Table 3: The lifetime and the weight of the different products

Lifetime and weight of the products and its sources.				
DVD Player	7	(ADSY, 2023) (Priya & Hait, 2018)	1.012	(Power & Panasonic, n.d.-b) (Power & Denver, n.d.) (Power & Senz, n.d.-c) (Priya & Hait, 2018)
Blu-ray Player	7	Same as DVD player	1.507	(Power & LG, n.d.) (Power & Sony, n.d.-a) (Power & Panasonic, n.d.-a)
Sound and picture system	12	Average of TV and Loudspeaker	7.20	(Power & JBL, n.d.-a) (Power & Cepter, n.d.) (Power & JBL, n.d.-b) (Power & Creative, n.d.) (Power & Yamaha, n.d.-a) (Power & Feel, n.d.) (Power & Jamo, n.d.) (Power & Logitech, n.d.) (Power & Klipsch, n.d.) (Priya & Hait, 2018)
Radio with loudspeaker	10	(Priya & Hait, 2018)	0.568	(Power & Philips, n.d.-h) (Power & Philips, n.d.-g) (Power & Philips, n.d.-f) (Priya & Hait, 2018)
Receiver/ Amplifier/ Tuner	14	333333(Priya & Hait, 2018)	7.20	Same as Sound and Picture system
Loudspeaker	13	(Audiosolace, 2022)	7.20	Same as Sound and Picture system
Wired Loudspeaker	13	Same as Loudspeaker	7.20	Same as Sound and Picture system
CD-player	3	Same as Mobile phone	0.521	(Oguchi et al., 2011)
LP player	7	Same as DVD-player	1.012	(Oguchi et al., 2011)
Travle radio	10	Same as Radio with Loudspeaker	0.568	Same as Radio with Loudspeaker
CD-player	3	Same as Mobile phone	1.012	(Oguchi et al., 2011)
MP3-player	3	Same as Mobile phone	-	-
HeadPhones	5	(Peters, 2023)	0.518	(Power & Sennheiser, n.d.) (Power & Yamaha, n.d.-c) (Power & Yamaha, n.d.-b)
Ear plugs	2	(Soundcore, 2022)	0.078	(Power & Supra, n.d.-b) (Power & Supra, n.d.-a) (Power & Razer, n.d.)

Table 3: The lifetime and the weight of the different products

Lifetime and weight of the products and its sources.				
Car Radio	10	Same as Radio with Loudspeaker	0.57	Same as Radio with Loudspeaker
Car Amplifier	8	(Martin, 2023b)	1.1	(Power & JVC, n.d.) (Power & Sony, n.d.-f) (Power & Sony, n.d.-b)
Car Loudspeakers	18	(Martin, 2023a)	7.20	Same as Loudspeaker
Computer (desktop)	5	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)	16.19	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)
Computer (laptop)	4	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018)	3.04	(Gurumurthy & Annamalai, 2019) (Priya & Hait, 2018) (Francesca et al., 2019)

4.3 Environmental impacts

To determine the environmental impacts of the metals in EE products the Ecoinvent database is used. In order to use the data found in Ecoinvent the software tool called Brightway 2.0 is used through another software called Activity-Browser.
There are many different impact categories that can be used when assessing the impacts on the environment, not every impact is equally important for every situation. the impacts that will be looked at for this case can be seen in Table 4, which is separated in midpoint impacts and endpoint impacts. The last column is the 4 elements for which no impacts categories was found in Ecoinvent.

Table 4: The impact categories that will be used for the LCIA are from ReCiPe 2016 v1.03 (H). The four elements for which there were no impact categories found is presented in the right column.

Environmental impact category		
Midpoint	Endpoint	Elements without impact categories
Climate change global warming potential (GWP1000)	Total: ecosystem quality ecosystem quality	Vanadium
Land use agricultural land occupation (LOP)	Total: human health human health	Bismuth
Material resources: metals/minerals surplus ore potential (SOP)	Total: natural resources natural resources	Calsium
Water use water consumption potential (WCP)		Thallium

The impacts categories are all with the Hierarchist perspective, due to its relevant perspective on policy principle and time-frame. The other 2 possibilities are Individualist and Egalitarian for which the first focuses on short-term interest, impact types and technological optimism. The second focuses on the long term pictures, which is beyond the scope of this thesis.
For the midpoint categories *climate change*, *land use*, *material resources* and *water use* have been chosen due to the focus these have in the public eye. For endpoint all 3 where chosen, to see how the impact of the different metals differs between them.

The other thing that will have an impact on the results is the precise process that each metal is related to in Ecoinvent. These combinations can be seen in Table 5 below. The selection for which process to choose was done based on the description found under the processes. After searching for the metal, with the name of the metal shown in Table 5, the description for every relevant result were read and the most relevant was chosen.

The processes are all at the point of "market", which means it is ready to be sold.This is done to avoid it being influenced by other factors than the process of extracting the metal from the earth and preparing it for use. They are all "GLO" which is the global market, this is to set a net standard for all the metals.
There are two general sub-categories the processes for metal can be put into. The first are for the pure metal, as an example this could be tin which also has a process named tin. The other sub-category would be for the metals that don't have a direct process, but have one that is very near what is looked at. An example for this sub-category could be cerium, for which the process are lanthanum-cerium oxide, this metal is sold in a compound with another metal.

4.3.1 The environmental impacts from metals in EE products

With the environmental impacts categories and factors found the actual impact from the metals in EE products in Norway can then be determined. This is simply done by multiplying the factor for an impact with the total mass of said metal from a product in a specific year. This is then done for every metal for every product and every year that the data is available for.
This allows a thorough analysis to see what metal in which product that have the highest impact for a specific year. It also gives the total impact for every category, and how it evolves over the years.

Table 5: The specific names found in Brightway 2.0 combined with the metals found in EE products.

Specific name for the elements found for the LCIA							
Steel	forging steel market for forging, steel GLO, kilogram	Tantalum	tantalum powder, capacitor-grade market for tantalum powder, capacitor-grade GLO, kilogram	Strontium	strontium carbonate market for strontium carbonate GLO, kilogram	Europium	europium oxide market for europium oxide GLO, kilogram
Copper	copper scrap, sorted, pressed market for copper scrap, sorted, pressed GLO, kilogram	Selenium	selenium market for selenium GLO, kilogram	Magnesium	magnesium market for magnesium GLO, kilogram	Gadolinium	gadolinium oxide market for gadolinium oxide GLO, kilogram
Aluminium	aluminium primary, cast alloy slab from continuous casting market for aluminium primary, cast alloy slab from continuous casting GLO, kilogram	Arsenic	arsine market for arsine GLO, kilogram	Titanium	titanium market for titanium GLO, kilogram	Holmium	holmium oxide market for holmium oxide GLO, kilogram
Iron	cast iron market for cast iron GLO, kilogram	Chromium	chromium market for chromium GLO, kilogram	Niobium	ferroniobium 66% Nb market for ferroniobium, 66% Nb GLO, kilogram	Lanthanum	lanthanum oxide market for lanthanum oxide GLO, kilogram
Nickel	nickel class 1 market for nickel, class 1 GLO, kilogram	Cobalt	cobalt market for cobalt GLO, kilogram	Boron	boron trifluoride market for boron trifluoride GLO, kilogram	Neodymium	neodymium oxide market for neodymium oxide GLO, kilogram
Lead	lead market for lead GLO, kilogram	Manganese	manganese market for manganese GLO, kilogram	Silver	silver market for silver GLO, kilogram	Praseodymium	praseodymium oxide market for praseodymium oxide GLO, kilogram
Tin	tin market for tin GLO, kilogram	Beryllium	beryllium market for beryllium GLO, kilogram	Gold	gold market for gold GLO, kilogram	Scandium	scandium oxide market for scandium oxide GLO, kilogram
Zinc	zinc market for zinc GLO, kilogram	Molybden	molybdenum market for molybdenum GLO, kilogram	Palladium	palladium market for palladium GLO, kilogram	Samarium	samarium oxide market for samarium oxide GLO, kilogram
Cadmium	cadmium market for cadmium GLO, kilogram	Antimony	antimony market for antimony GLO, kilogram	Cerium	lanthanum-cerium oxide market for lanthanum-cerium oxide GLO, kilogram	Thulium	thulium oxide market for thulium oxide GLO, kilogram
Barium	barium carbonate market for barium carbonate GLO, kilogram	Silicon	silicon electronics grade market for silicon, electronics grade GLO, kilogram	Dysprosium	dysprosium oxide market for dysprosium oxide GLO, kilogram	Ytterbium	ytterbium oxide market for ytterbium oxide GLO, kilogram
Gallium	gallium semiconductor-grade market for gallium, semiconductor-grade GLO, kilogram	Zirconium	zirconium oxide market for zirconium oxide GLO, kilogram	Erbium	erbium oxide market for erbium oxide GLO, kilogram	Yttrium	yttrium oxide market for yttrium oxide GLO, kilogram

5 Results and Discussion

In this chapter the results of the thesis will be presented and discussed based on the knowledge given earlier.

5.1 The Material flow analysis

5.1.1 Sales numbers and lifetime.

The first part of the MFA is the combination of the lifetime of the products and the number of sold units for the years with given data. This can be seen in Table 6 on the next page.

The lifetime of the products vary quite a lot between the EE products. Products that have an expected life time of 2-3 years include in-ear headphones and mobile phones, going through the use phase of its life cycle many times over compared with products that have between 13-16 years of expected life. This gives a variation in the delayed output for the products each year, with data going back to 2006 for some of the products (but not all of them) this is not a big problem.
After applying the lifetime for each product to the years of sold units in order to achieve the expected end of life, the results gave some large holes for different products. The full table can be seen in Appendix 7.1. The overlap for which every product have a output for a year does not happen, but the years with the most overlap is 2023, 2024 and 2025. With many of the products having data for the period of 2016-2025, which will be the primary period focused on for the variation over the years

Some of the products to take note of when it comes to lack of data are the freezers and computers. The freezers contains large quantities of steel or iron and the computers contains relatively large quantities of precious metals. This is expected to have an impact on the results of the first half of the decade that is looked at, and when they are part of the product lineup it is expected to be apparent from the results.

The objectives for digital single-lens reflex (DSLR) camera have been left out due to its lifetime being very hard to find. The common consensus for it being several decades or even longer, with these results it is pretty safe to assume that the data found on the number of sold units will not be relevant for quite some time.

The general trend for products that reach its end-of-life phase is represented by arrows in the last column. This trend does not take spikes in number of products for a single year into account, but looks at the overall change in number of units for the period. There are 18 of the products that have a downward trend, 17 that is keeping a steady stream throughout the period and 7 that is increasing in number of units. Camera lenses have been excluded due to the lifetime of the product. Wired loudspeaker is in a similar case. With the difference being that there is a lifetime for wired loudspeakers, but it is so long that the products has not reached its end-of-life phase in this decade.

Table 6: Sales numbers is combined with the lifetime of products in order to estimate the quantities of each product that will be entering the Waste system each year. The trend column shows the general trend for the product over the decade. ** Lifetime is multiple decades, and this product is therefore assumed to be the average sold unit for the available data.

Number of sold electronics that is at its end-of-life based on its average lifetime.													
Category	Product	Lifetime	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	Trend
Mobile	Mobile Phone	3	2.400.000	2.100.000	1.850.000	2.000.000	1.900.000	1.800.000	1.700.000	1.600.000	1.520.000	1.356.000	↘
	Tablet	5		500.000	950.000	700.000	613.000	500.000	500.000	523.000	546.000	514.000	→
	Smartwatch	4		320.000	720.000	760.000	900.000	1.060.000	1.210.000	1.170.000	1.200.000	1.160.000	↗
Camera	Camera	7	519.000	499.000	405.000	311.000	224.000	140.000	120.000	68.000	80.000	49.000	↘
	Camera Lenses	**	-	-	-	-	-	-	-	-	-	-	
	Videocamera	7	63.000	53.000	38.000	59.000	80.000	82.000	99.000	48.000	46.000	48.000	→
Large electric appliances	Chest Freezer	16							60.000	54.000	52.000	47.000	↘
	Cabinet Freezer	16							38.000	38.000	33.000	34.000	↘
	Refrigerator/Freezer combo	16							181.000	182.000	160.000	149.000	↘
	Refrigerator	10	92.000	85.000	77.000	77.000	89.000	93.000	93.000	105.000	97.000	94.000	→
	Washing machine	13				230.000	234.000	225.000	218.000	219.000	221.000	234.000	→
	Dryer	10	92.000	79.000	70.000	71.000	76.000	82.000	86.000	77.000	87.000	91.000	→
	Díshwasher	7	146.000	151.000	164.000	182.000	183.000	185.000	199.000	190.000	199.000	202.000	↗
	Standalone oven	13			108.000	101.000	95.000	79.000	70.000	73.000	69.000	70.000	↘
	Built in oven	13			169.000	184.000	172.000	147.000	166.000	193.000	227.000	214.000	↗
	Table stove	13			17.000	18.000	15.000	20.000	16.000	15.000	18.000	19.000	→
	Kitchen ventilation	15						130.000	129.000	118.000	112.000	101.000	↘
	Mini Kitchen	6	2.000	2.000	2.000	1.000	2.000	1.000	1.000	1.000	1.000	1.000	↘
	Microwave	6	156.000	215.000	230.000	210.000	142.000	153.000	156.000	142.000	140.000	153.000	→
Small electric	Personal care	3	677.000	664.000	643.000	657.000	620.000	613.000	540.000	680.000	670.000	633.000	→
	Electric shaver	10	138.000	130.000	111.000	123.000	129.000	142.000	140.000	125.000	134.000	131.000	→
	Hair removal (Female)	10	47.000	60.000	45.000	40.000	47.000	44.000	42.000	40.000	51.000	59.000	→
	Kitchen equipment	7	1.307.000	1.549.000	1.752.000	1.625.000	1.774.000	1.902.000	1.923.000	1.590.000	1.412.000	1.600.000	→
	Other household items	10	1.242.000	1.388.000	1.154.000	1.102.000	1.437.000	1.200.000	1.127.000	1.099.000	1.087.000	962.000	↘
Sound and picture products	TV	8	636.000	601.000	593.000	520.000	483.000	415.000	429.000	387.000	375.000	386.000	↘
	DVD Player	7	107.000	80.000	52.000	24.000	17.000	15.000	25.000	15.000	14.000	12.000	↘
	Blu-ray Player	7	76.000	98.000	140.000	150.000	122.000	70.000	70.000	50.000	44.000	30.000	↘
	Sound and picture system	12			161.000	149.000	142.000	161.000	215.000	219.000	198.000	158.000	→
	Radio with loudspeaker	10	119.000	95.000	98.000	120.000	110.000	90.000	140.000	180.000	120.000	130.000	→
	Receiver/Amplifier/Tuner	14					11.000	30.000	24.000	29.000	29.000	44.000	→
	Loudspeaker	13			76.000	68.000	36.000	92.000	83.000	88.000	112.000	100.000	↗
	Wired Loudspeaker	13											
	CD Player	3	2.000	2.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000		↘
	LP Player	7	4.000	4.000	4.000	4.000	8.000	9.000	10.000	12.000	10.000	15.000	↗
	Travel radio	10	200.000	170.000	192.000	185.000	125.000	185.000	270.000	330.000	500.000	620.000	↗
	CD Player	3	15.000	13.000	10.000	5.000	5.000	10.000	5.000	5.000	5.000	2.000	↘
	MP3 Player	3	75.000	60.000	20.000	20.000	25.000	25.000	25.000	12.000	5.000	5.000	↘
	Headphones	5				1.200.000	1.000.000	800.000	840.000	880.000	960.000	920.000	↘
	Ear plugs (from 2020)	2							1.200.000	1.000.000	980.000		↘
	Car Radio	10	255.000	220.000	174.000	223.000	238.000	225.000	220.000	210.000	200.000	220.000	→
	Car Amplifier	8	10.000	10.000	10.000	8.000	7.000	5.000	5.000	5.000	3.000	4.000	↘
	Car speaker	18								390000	459000	428000	→
Computers	Computer (desktop)	5									177.000	191.000	→
	Computer (laptop)	4								648.000	697.000	688.000	↗

5.1.2 Metal content of the EE products

Due to the considerable number of both metals and EE products that is looked at in this thesis the graph have been split into 3 separate graphs. This is done in order to be able to see the spread in weight between the metals and it is easier to compare similar products, here being the size of the product.
The first graph can be seen in Figure 11 which shows the larger products, being freezers, refrigerators, ovens, TV and computers. The amount of metal shown is for one average unit of the EE product, with the oven being the unit with the most metal followed by the upright freezer.
Many of the metals are in such small quantities that they do not show on the graphs, with the following metals being the ones that are visible: steel, copper, aluminium and iron. Steel and iron are the main contributor when it comes to quantity in these products.

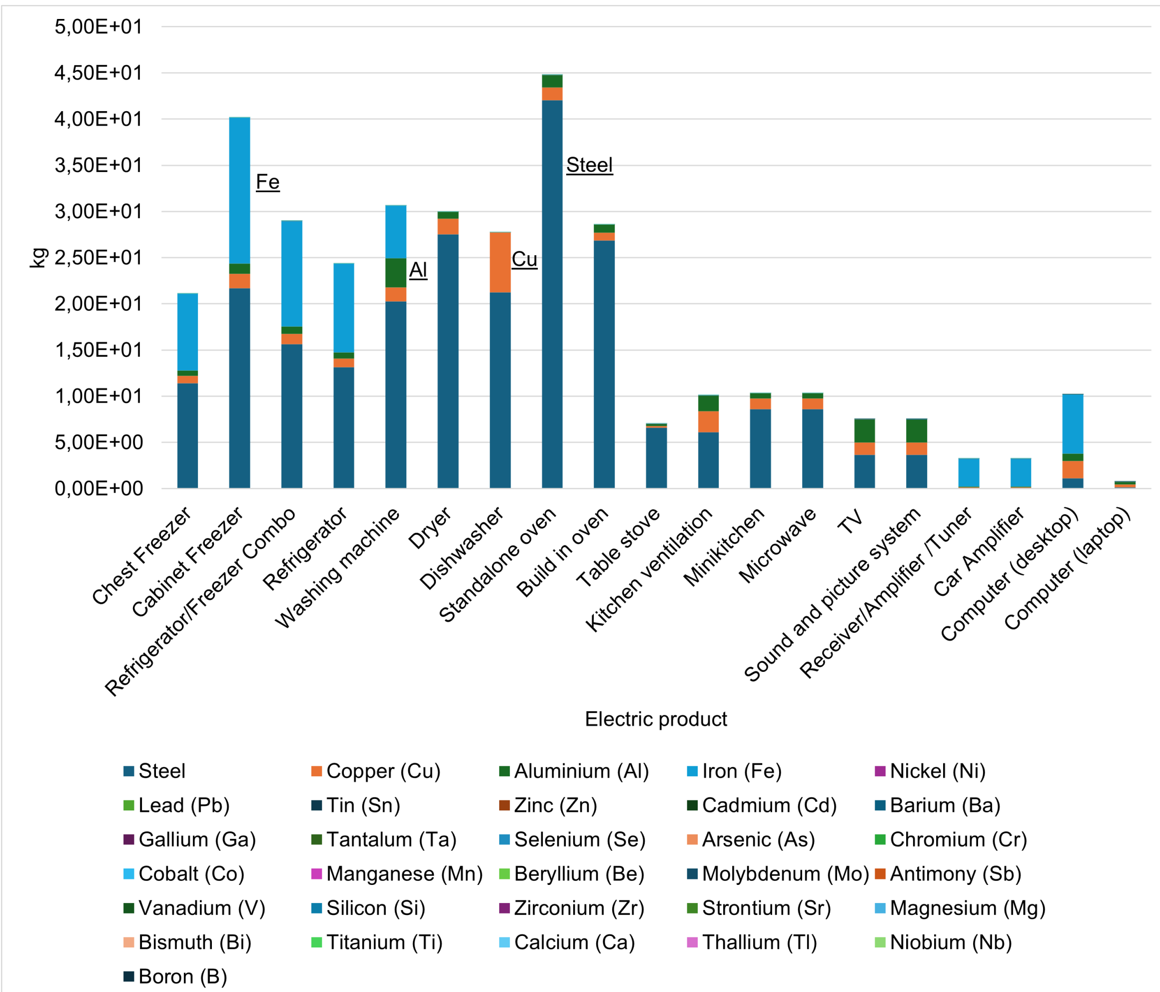

Figure 11: The metals that can be found in 1 unit of EE products, part 1

Looking at the products in Figure 12. The difference between the products is quite vast. The Y-axis is still in kg, but the values are smaller than in part 1, with every product being under 1 kg of metal in total.
There is a little more variation here than in Figure 11. The metals with the larges contribution is still steel and iron, but aluminium and copper have gotten a bigger role here. And nickel is also present

in the products from *Personal care* to *Kitchen equipment.* Another product that is noteworthy is the MP3 player which mainly consists of tin.

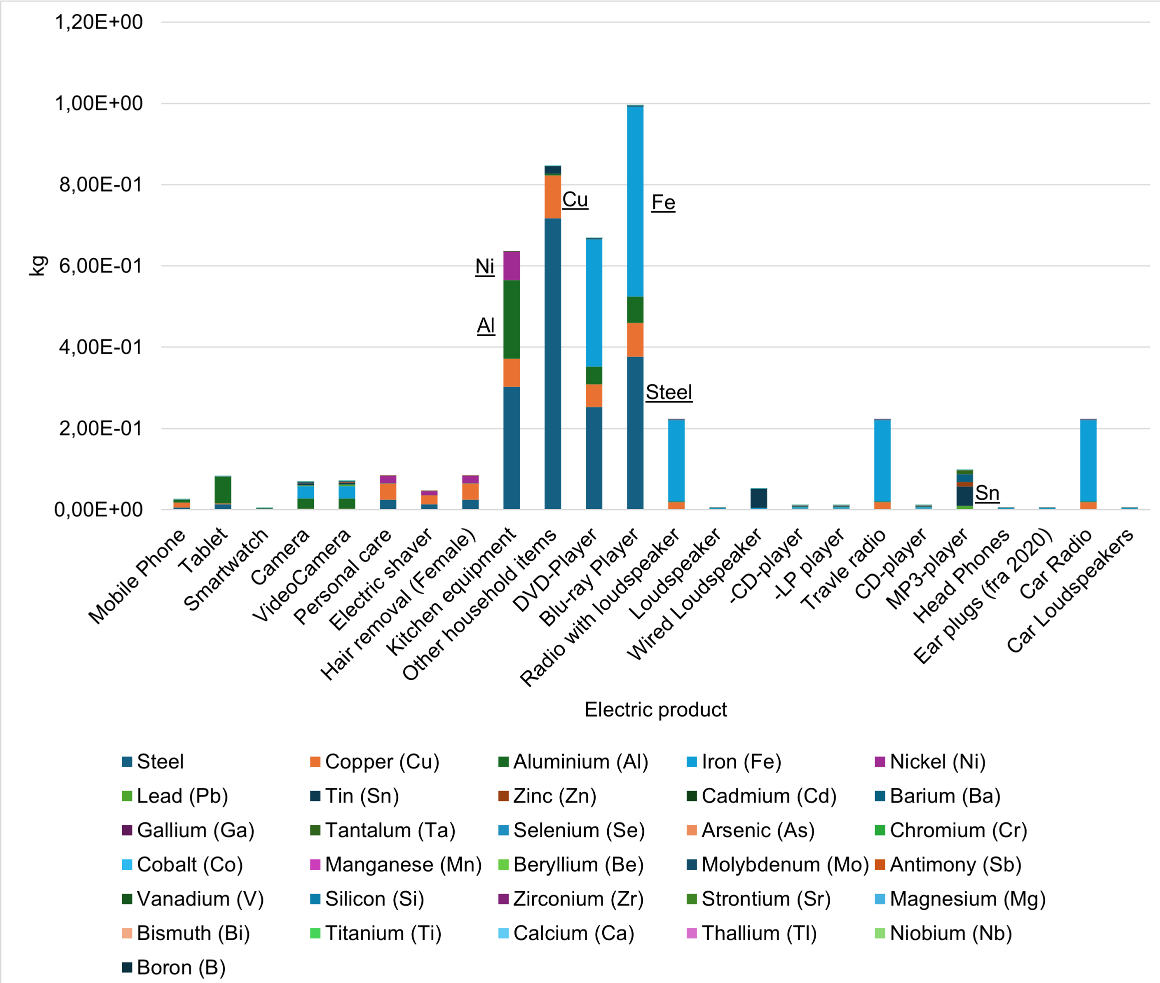

Figure 12: Shows the metals that can be found in 1 unit of EE products, part 2

For the last graph showing the metal content of the products, it is the metals that have been replaced. Here the focus is the more precious metals, along with the rare earth elements (REE) that is also common in electronics. As it can be seen in Figure 13 the quantities of these metals are quite small in a single unit of the EE products. This is to be expected as these metals are mostly used in the printed circuit boards (PCB) that are in most electronics.

The metals that have the most occurrences are silver, gold, palladium and neodymium, neodymium being a REE.These metals are most often found in sound equipment. There is almost no presence of the metals found in the larger EE products seen in Figure 11 which can be assumed to be because these products do not need the same size or complexity of PCB to perform their function.

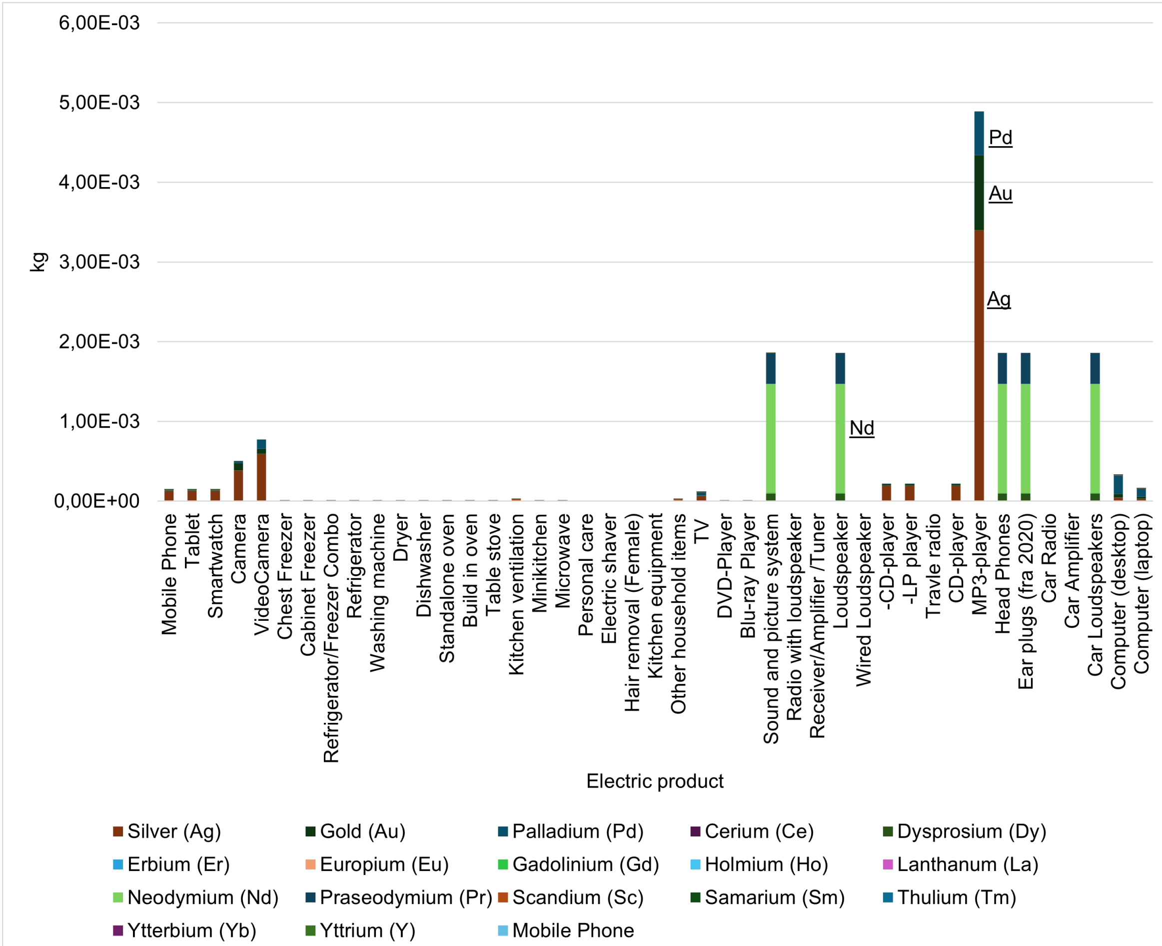

Figure 13: Shows the metals that can be found in 1 unit of EE products, part 3

With the numbers of units coming to its end of life phase and the weight of metals for each unit the general change over the decade can be calculated. This development in mass can be seen in Figure 14 below. This graph will work as a baseline for the different metals and it will help to identify metals that do not follow the norm.
Looking at the trend it can be seen that there is an increase over the years. This correspond well with what was shown in Table 6 as quite a few of the products only reach the end of life phase towards the middle of the decade. The total weight of the E-waste does almost double throughout the decade. This is due to many of the heavier EE products not being part of the end of life phase in the start of the decade.

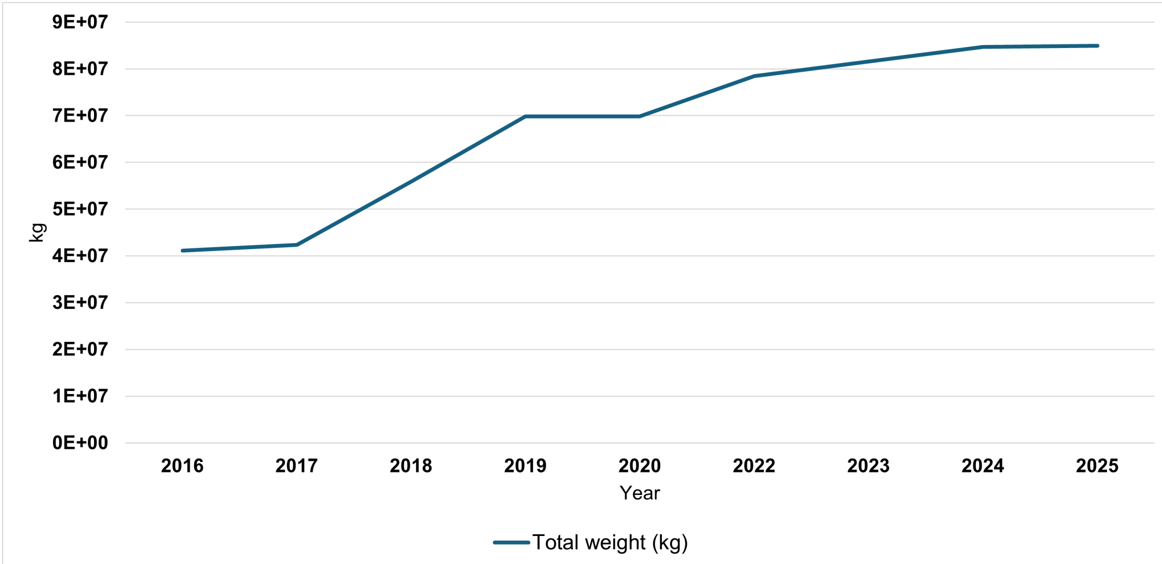

Figure 14: The total weight of the e-waste generated according to this model.

5.1.3 The changes in volume of metal for 2016-2025

With the known number of units for each EE product that is entering the waste system for the given year, and the metal content for each EE product, the total quantity of each metal can be calculated. Looking at the trend for the volume of each metal is interesting in regards to the environmental impacts of said metal. This change over the decade is presented in the 3 Figures 15, 16 and 17 below. Due to the huge difference between how much there is of each metal the graphs have been normalized in regards to the total quantity of each metal for the decade.
Noteworthy and interesting changes for each graph will be presented below the relevant graph.

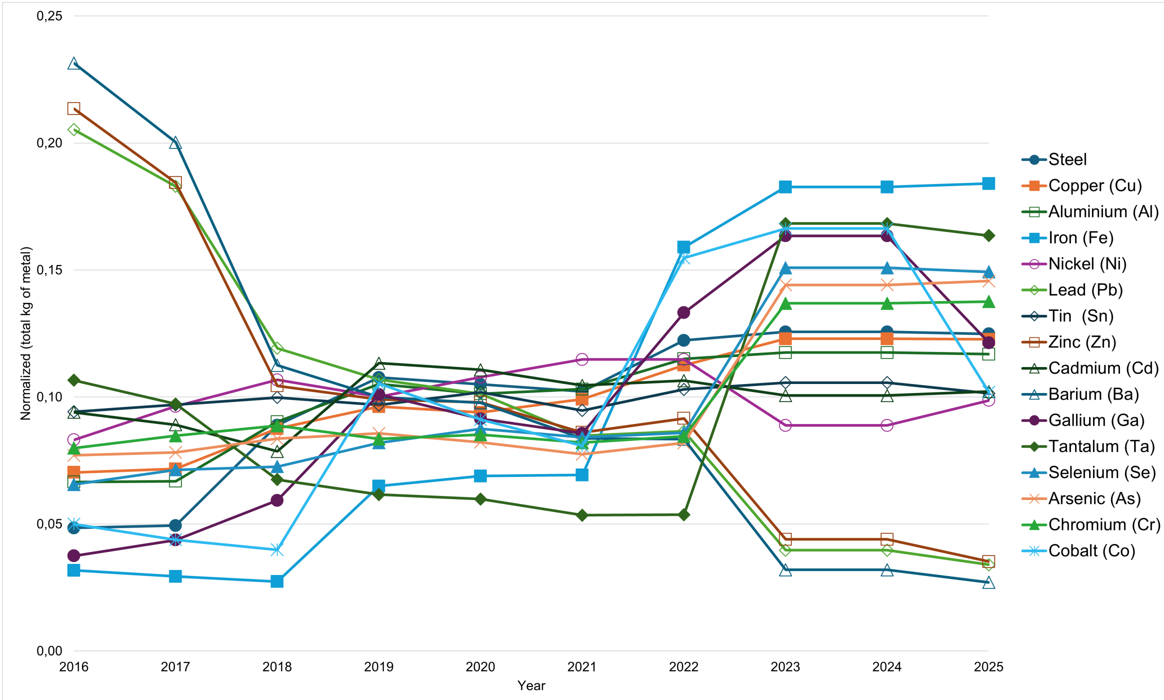

Figure 15: The change in quantity of metal over the decade, part 1.

For the metals in Figure 15 the first thing to notice is that there are 3 metals that have a decrease over the decade, these are lead, barium and zinc. This indicate that product containing these 3 elements are phasing out. On the other hand, there are 4 metals that start with a very low quantity which then quickly accelerates towards high quantities towards 2025, these being steel, cobalt, gallium and iron. This indicates that the products that contain these metals are now being sold more or new products have been introduced that includes them as well.
For the rest of the metals in this graphs it seems relatively stable throughout the decade with a little increase towards the end, with the exception of tantalum which start like most of the other metals and then have a dip until 2022 from which it surpasses its starting point. This indicates that there is a decline in the products it is used in until 2022 where a new product is introduced to the market which makes the steep increase.

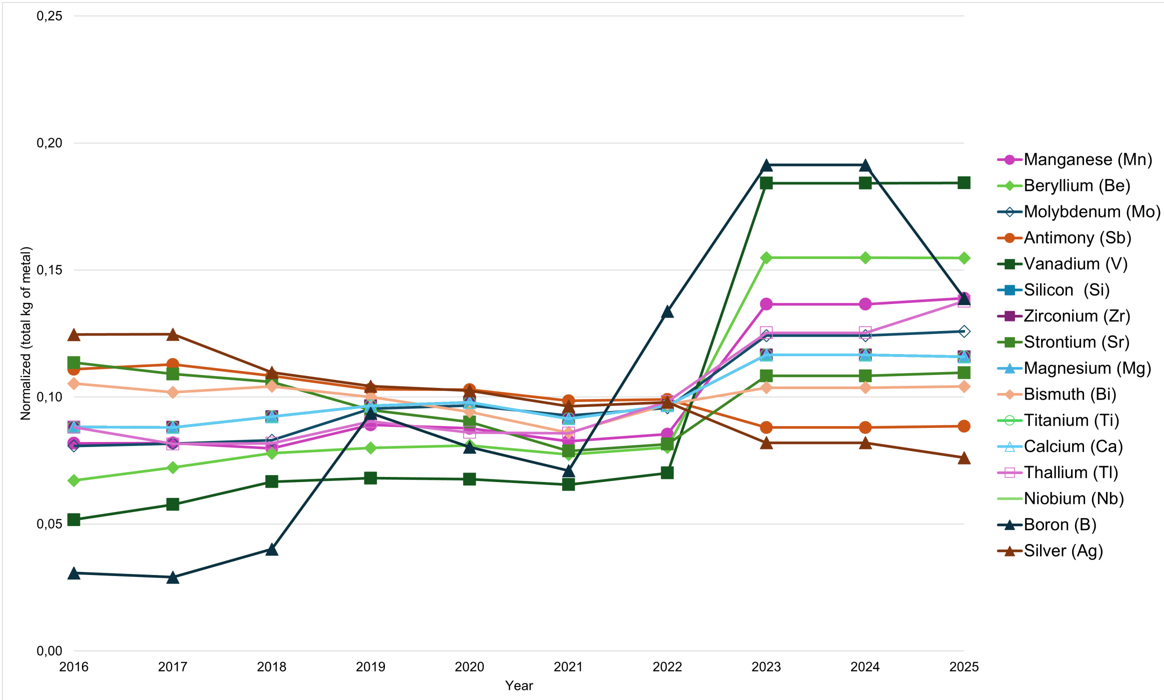

Figure 16: The change in quantity of metal over the decade, part 2.

For most of the metals in Figure 16 there is an increase in 2023, otherwise they are stable throughout. This suggest that there are more units of the EE products that reach end of life in 2023, or that new products are entering the pool. The metal with the biggest increase from the beginning to the end of the decade is boron, with an odd drop in the last year.

It is accompanied by vanadium but vanadium is stable the last 3 years. This is similar to the other metals, and likely have the same reasons for the changes. There is a metal that have a noteworthy decline, silver, which imply the decrease of products containing it.

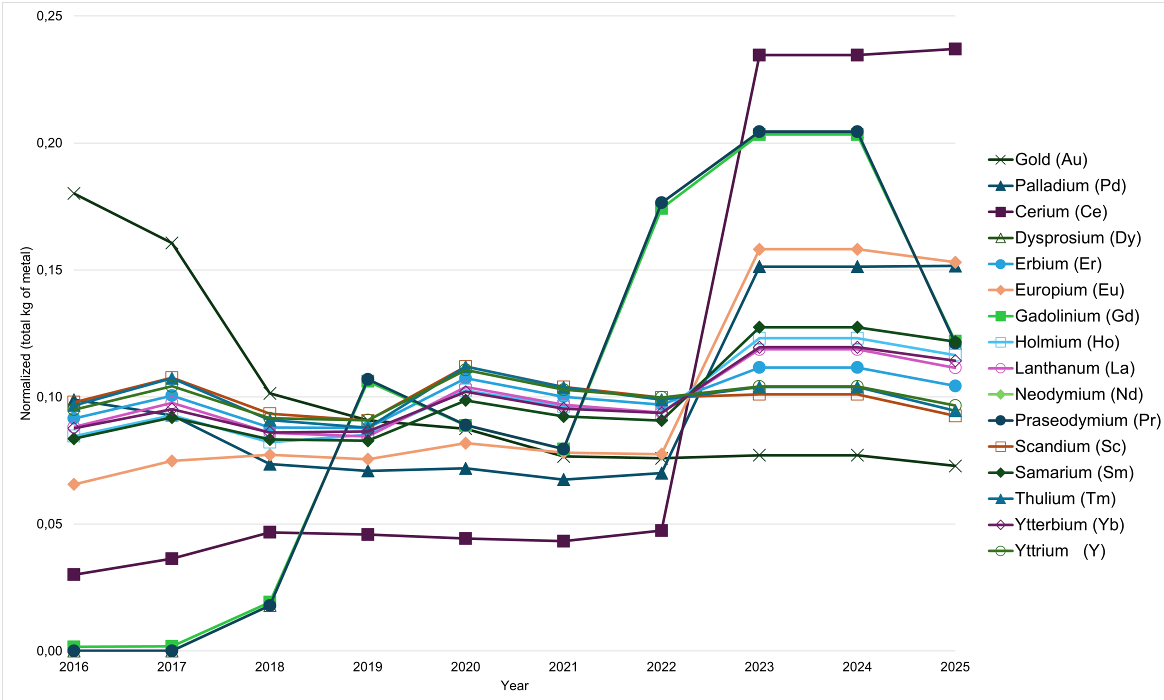

Figure 17: The change in quantity of metal over the decade, part 3.

The last metals can be seen in Figure 17, with many interesting changes presented here. First off there are quite a few that follows the same trend, making it a bit hard to see all of the details in the graph and therefore it will be describes here along with the noteworthy changes. The first interesting thing is the metals that is at zero and near zero in the start at 2016 and 2017, which then have a large increase until the year 2024 and then a drop.
These metals are: dysprosium, gadolinium, neodymium and praseodymium and they follow the same flow for the entire decade. These are the only metals that have years where they are not present at all. The sharp drop from 2024 to 2025 indicates that one or more products which have these 4 metals are no longer present. Another metal that is close in its flow is cerium, which also have a low start and then a very high increase in 2023. This imply that a product that has a high quantity of cerium is joining the pool of products in this year. The other possibility is that the quantity of these metals are relatively low, and the inclusion of new products with these metals therefore impacts the flow over the years.

5.2 Environmental impacts from the metals in Norway EE products.

In this section the different environmental impacts for the metals will be presented. The impacts are divided between midpoint and endpoint categories. There are 4 midpoint categories that is looked at here, starting with *climate change* and then going on to *land use*, *material resources* and then *water use*. These 4 impacts represents the range that metals covers, and it showcases that metals have different intensities for different impacts.
The 3 endpoint impacts are presented as well, which is *ecosystem quality*, *human health* and *natural resources*. These represent the 3 main ways that the metals in EE products in Norway can have an impact. They include every other midpoint impact that is not presented in this thesis, and therefore can give an overall picture of the impacts the metals have.

For every impact the noteworthy details will be presented below the figure. Every graph is showing the total impact from every metal for each year from 2016-2025.

5.2.1 Midpoint impacts

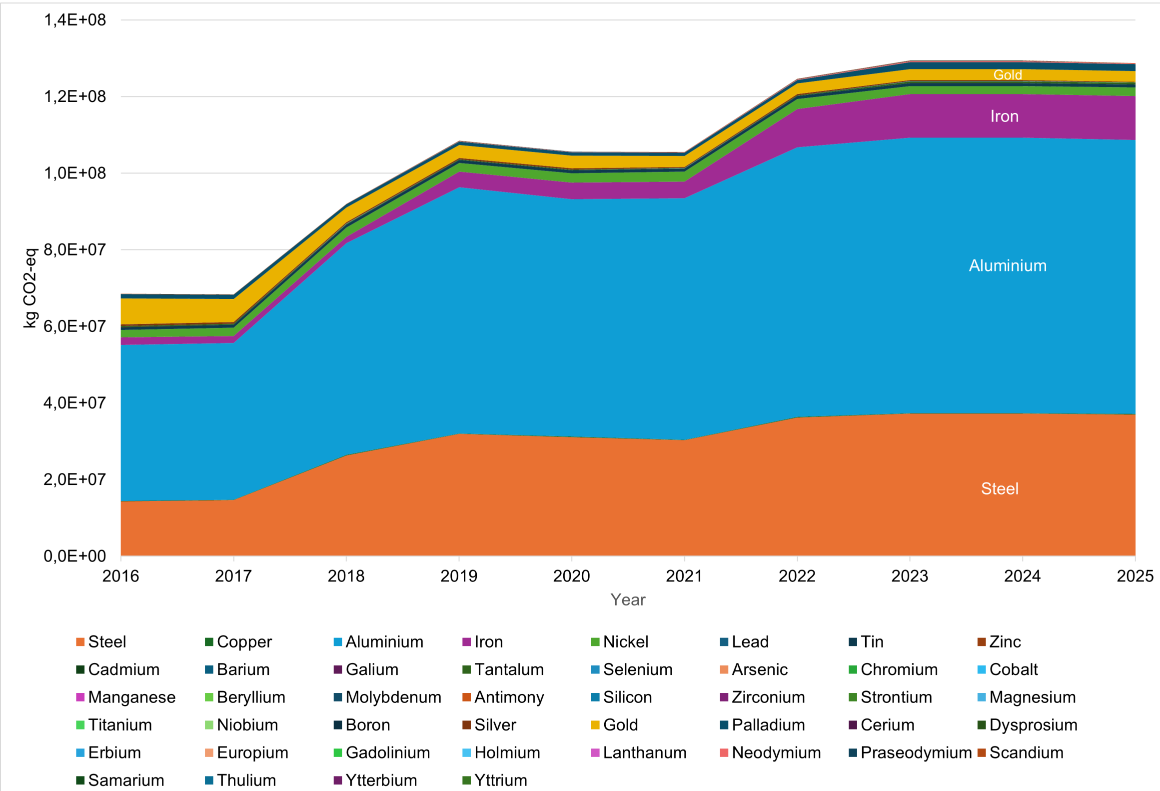

Figure 18: The climate change impact over the period from 2016-2025 for every metal found in EE products

In Figure 18 the *climate change* impact can be seen. This impact is in kg CO2-eq and is the impact used most often in decision making, regarding the environment. There is one metal that is by far the main contributor throughout the decade, and that is aluminium. The trend for most of the metals is an increase in impact, which was to be expected with the results from the Figures 15, 16 and 17. The other primary contributors to the impact are steel, iron and gold. With the highest impact being from steel and then going down in the same order. Overall there is an increase in *climate change* impact, which corresponds to the increase in EE products (see Figure 14).
The metals with the highest contribution are also the most common metals in EE products, which could lead one to the conclusion that it is just a matter of the quantity of the metal. This is not the case as can be seen in the other impacts below, though it most likely contributes to the result.

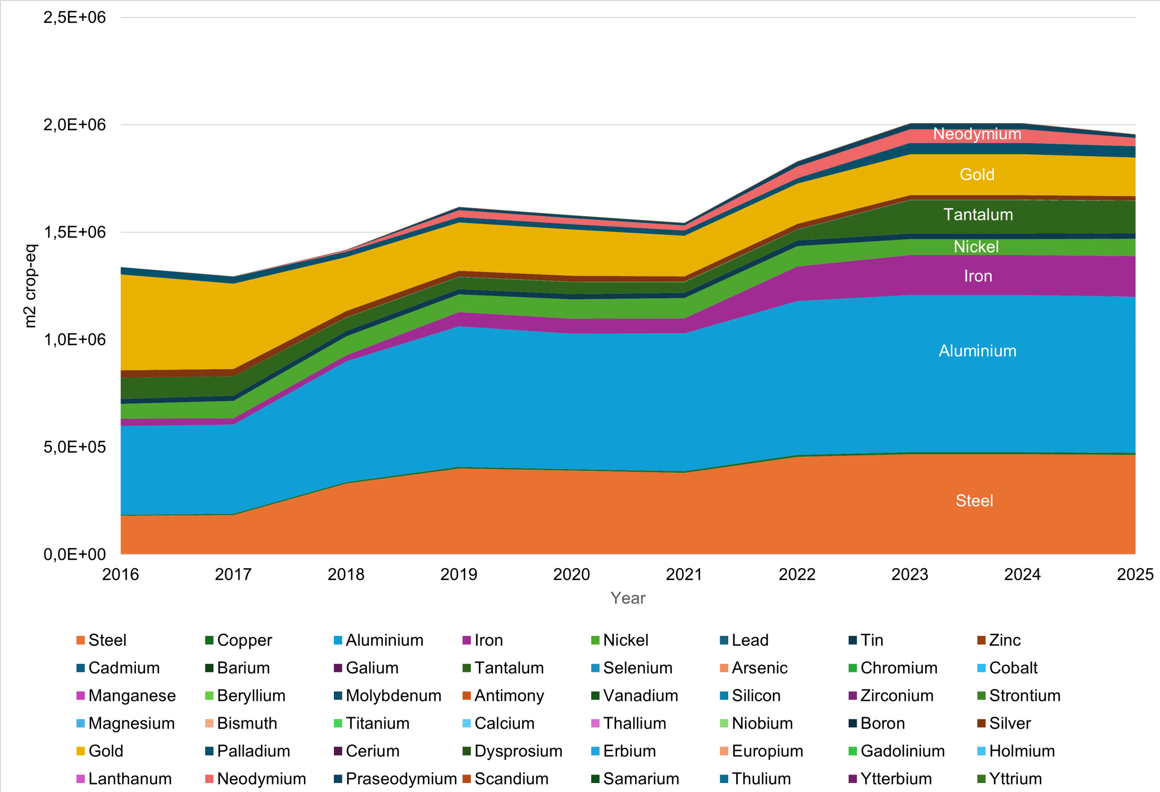

Figure 19: The land use impact over the period from 2016-2025 for every metal found in EE products

In Figure 19 the impact on *land use* can be seen. Here the picture is similar to the impact of *climate change* in Figure 18. Though there is a increase in impact from multiple other metals. This impact category is measured in m2 crop-eq, which indicates how much land is being transformed by the production of these metals.
Aluminium is the metal with the highest impact, with steel coming in second for the majority of the decade. Gold start out with the highest impact in 2016 but decreases fast after that. The other metals that have a relatively higher impact on *land use* than on *climate change* is tantalum and neodymium. Nickel is also quite impactful in this category, and iron is more or less the same as in *climate change*. Here the individual impact of the metals is showing as gold, tantalum and neodymium is nowhere near the volume of aluminium and steel.

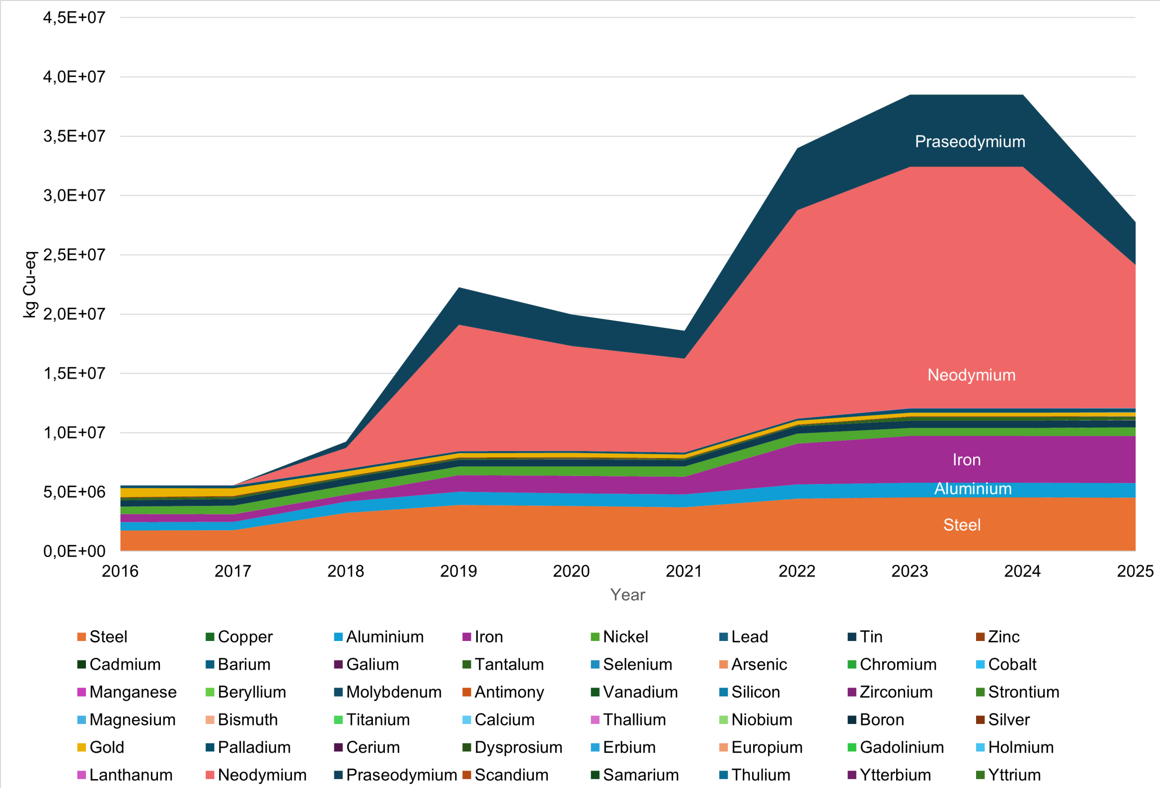

Figure 20: The material resources impact over the period from 2016-2025 for every metal found in EE products

The impact category shown in Figure 20 present the depletion of mineral resources in Cu-eq. This gives an indication of which minerals are scarce, both in a literal sense and due to the difficulty of obtaining the mineral. The impacts from the different metals are very different for this category as the most impactful is neodymium for the period that it is present.
As seen above in Figure 17 neodymium and praseodymium are not present in 2016 and 2017. Praseodymium is introduces in this category at the same time as neodymium, and for the period it is present it is the second most impactful metal. It is close with steel and iron for the second spot. Here aluminium has one of the lowest impacts that are still visible. This indicates that it is very easy to come by. This is vastly different from the prior impact categories, and is a good example of why it is important to look at the problem from different angles.

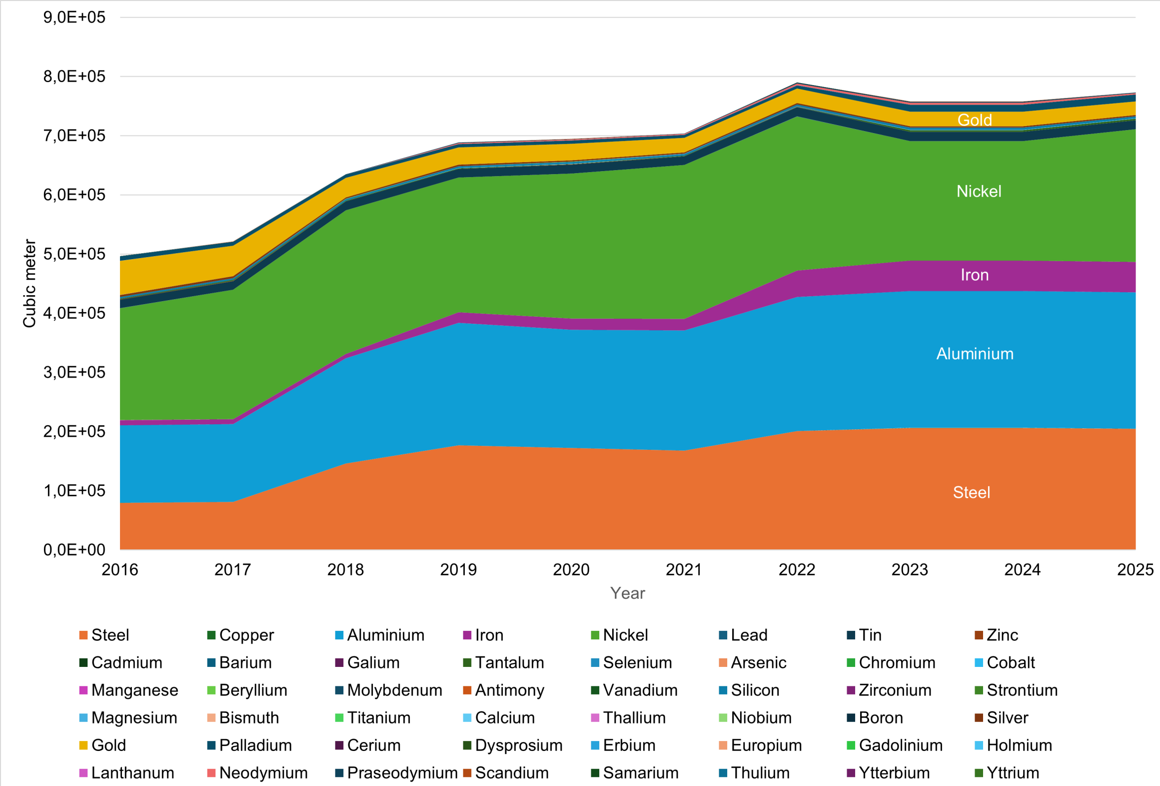

Figure 21: The water use impact over the period from 2016-2025 for every metal found in EE products

The last midpoint impact is *water use* which can be seen in Figure 21. This impact category is measured in cubic meter of water, and it is divided mostly between steel, aluminium and nickel. With gold and iron having a small presence. The production of nickel clearly uses a lot of water compared to the other metals that have showed up in all of the midpoint impact categories. There is an interesting rise in impact in 2022 where it reaches its peak before going down a little, but in 2025 it increases slightly again. This correlates to the changes in the quantity of the metal seen in Figure 15.

For the 4 midpoint categories there are a few metals that has a noticeable presence in every one of them. These are steel, aluminium, iron, nickel and gold. The relative size of their impacts vary between the different impacts, but they are visible in every one of them. Besides these neodymium has shown a large presence in the mineral depletion and a smaller presence in the land use category. Let's see if this trend continues with the endpoint impacts.

5.2.2 Endpoint impacts

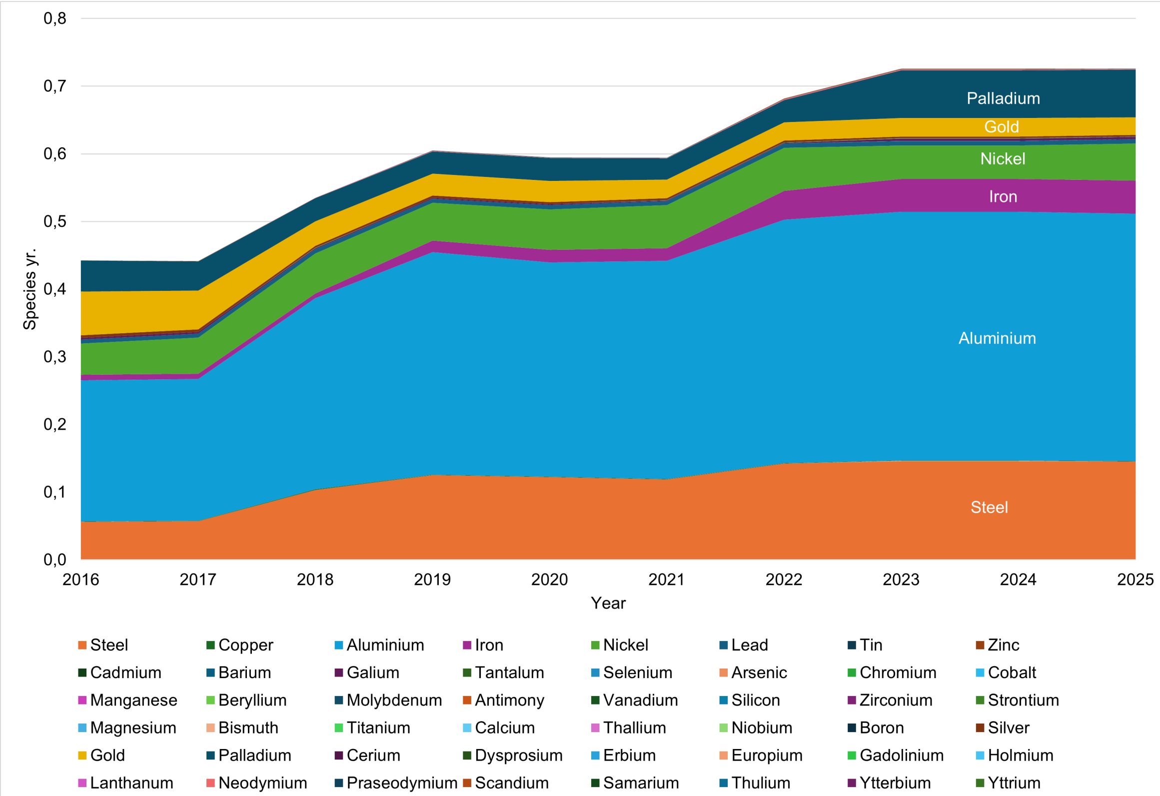

Figure 22: The ecosystem quality impact over the period from 2016 to 2025 for every metal found in EE products.

The first endpoint impact category that is presented is *ecosystem quality*, which is measured in species lost pr. year. This impact can be seen in Figure 22 above. Here aluminium has the highest impact of all the metals, with steel and palladium coming in second and third respectively. iron, nickel and gold all have a noticeable impact as well.

The impact of this category is under 1 species a year throughout the decade, which means that the metals in the Norwegian EE products is not single-handily responsible for the extermination of any species, but towards the end of the decade it is getting close with the total being just over 0.7 species a year.

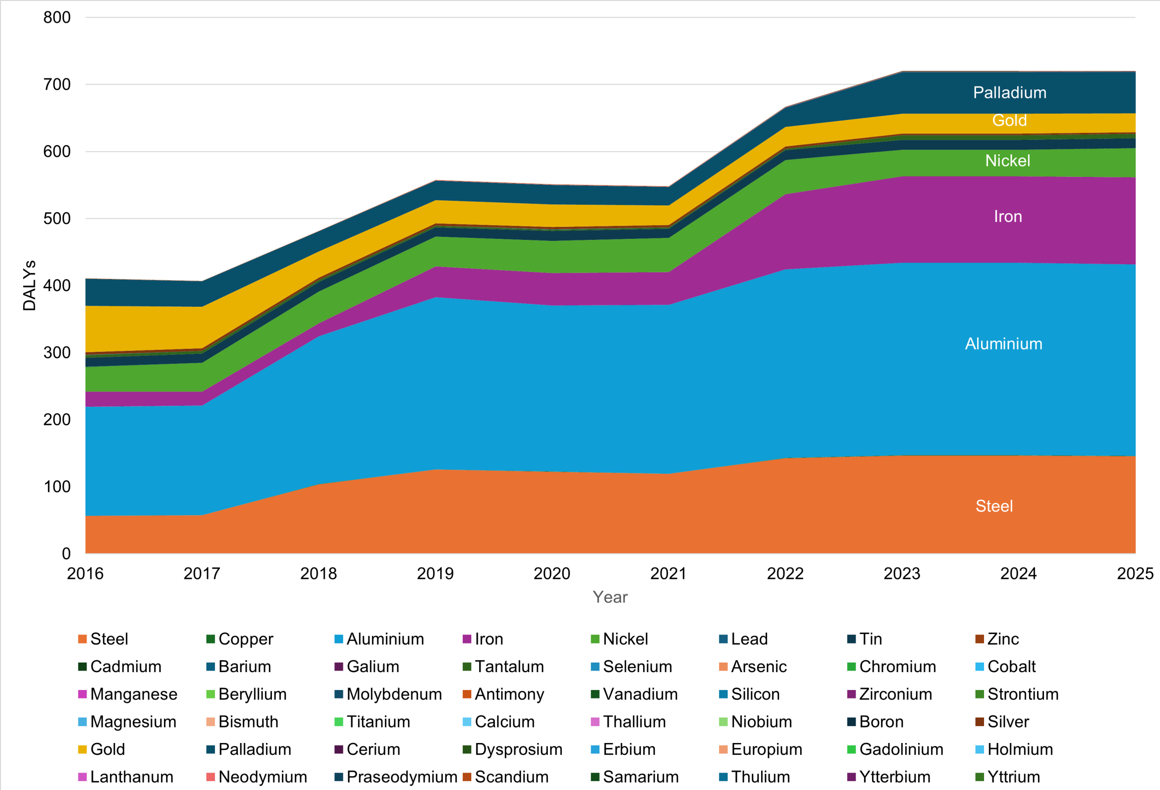

Figure 23: The human health impact over the period from 2016 to 2025 for every metal found in EE products.

The second endpoint impact that is presented is *human health* which is measured in DALYs, one DALYs equal to the loss of one healthy year. The impact for the decade can be seen in Figure 23 above. For *human health* aluminium is the main contributor followed by steel and iron, with palladium, nickel and gold following. The impact starts at 400 DALYs in 2016 and goes just over 700 from 2023 to the end of the decade.
This means that depending on which year that is looked at, between 400 and 700 years is lost due to disability, ill health or early death. This sounds like a high impact, but it is spread out over an unknown number of people which makes it hard to determine the specific meaning this has for the impacted people. The total impact is mainly from only 6 of the 48 metals that is in EE products. Which makes it easier to lower the total impact as the focus then can be on these 6 metals.

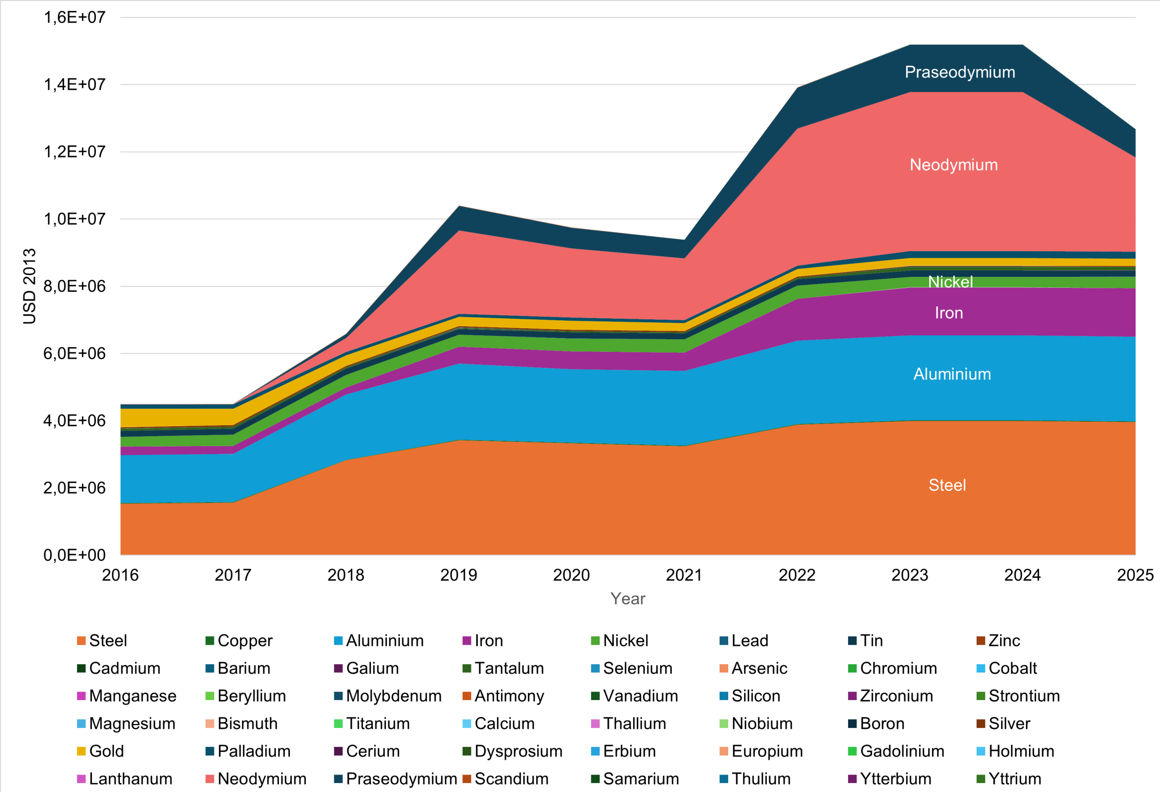

Figure 24: The natural resources impact over the period from 2016 to 2025 for every metal found in EE products.

The last endpoint impact category is *natural resources*, which is measured in US dollars pr kg of the metal. This is used to determined the scarcity of the metal, as the price of the metal will increase the more scarce it is. This is close to what can be seen in the midpoint impact category for *material resources* in Figure 20.
The metals that have the highest impacts here are steel and neodymium, followed by aluminium, iron, praseodymium and nickel. The highest total impact can be seen in the years of 2023 and 2024 which follows the trend seen for the individual metals in the 2 figures 15 and 17.

5.2.3 The products with the highest concentration of specific metals

With the environmental impacts from the metals presented in the section above, the next thing that will be looked at is some of the metals that showed up in the multiple of the midpoint and endpoint categories. steel, aluminium, iron and neodymium are the 4 metals that will be delved into in this section.

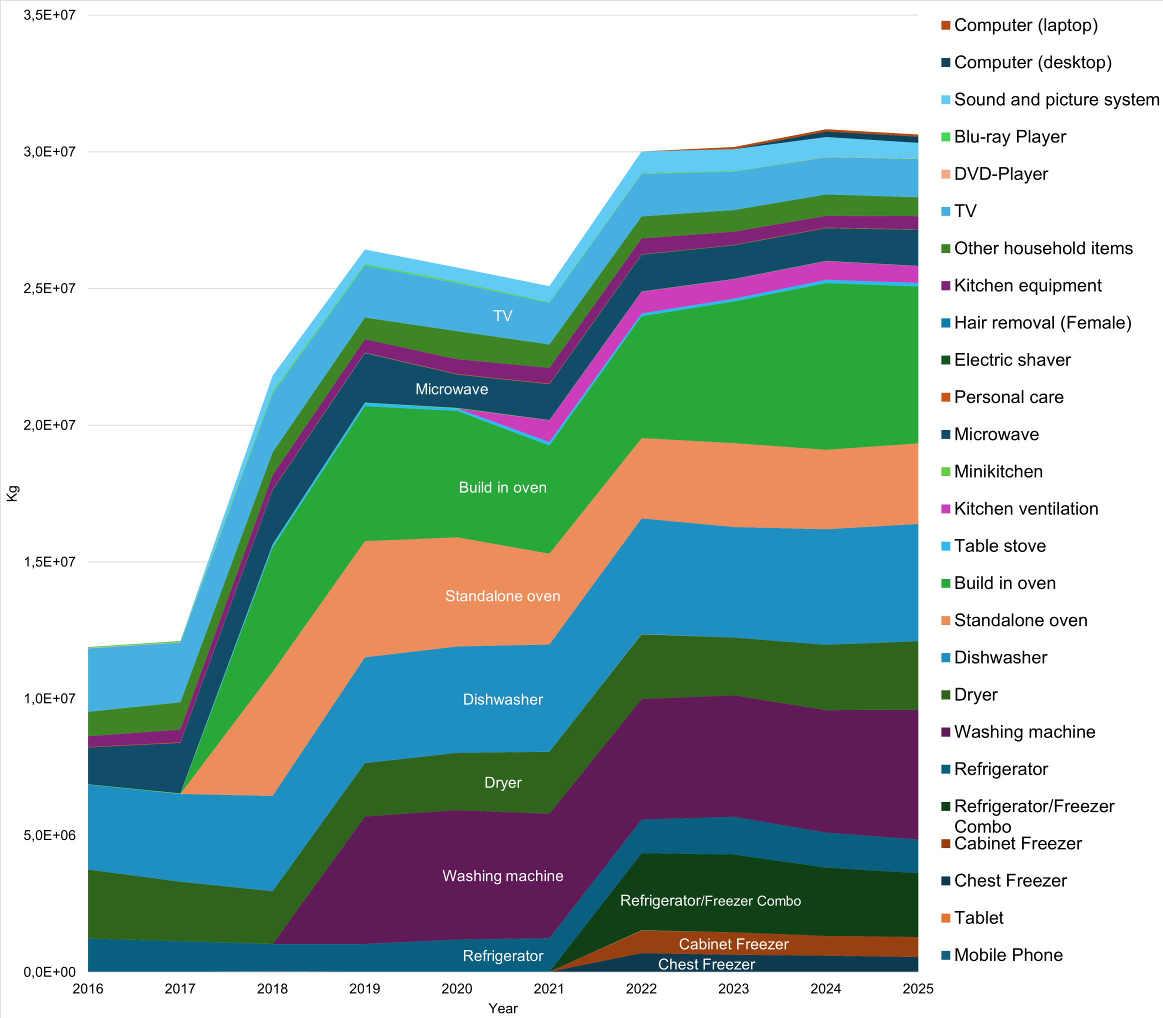

Figure 25: The highest concentrations of steel in the different product for each year from 2016-2025.

Steel is interesting as it has a solid presence for every impact category previously addressed. The different EE products that contain steel is presented in Figure 25. There are quite a few of the EE products that is not present the entire decade, such as the different kinds of freezers, the washing machine or the ovens. Steel seems to be in the larger EE products and there are not a single type of product that contains the majority of the steel.
The products with the majority of the steel are the different freezers and refrigerator, the washing machine, the cloth dryer, the dishwasher and the different kind of ovens. These are all products with a relatively long lifespan which is the reason for why most of them are showing up in the middle of the decade. Aside from these products, microwave and TV also contain a noticeable quantity of steel.

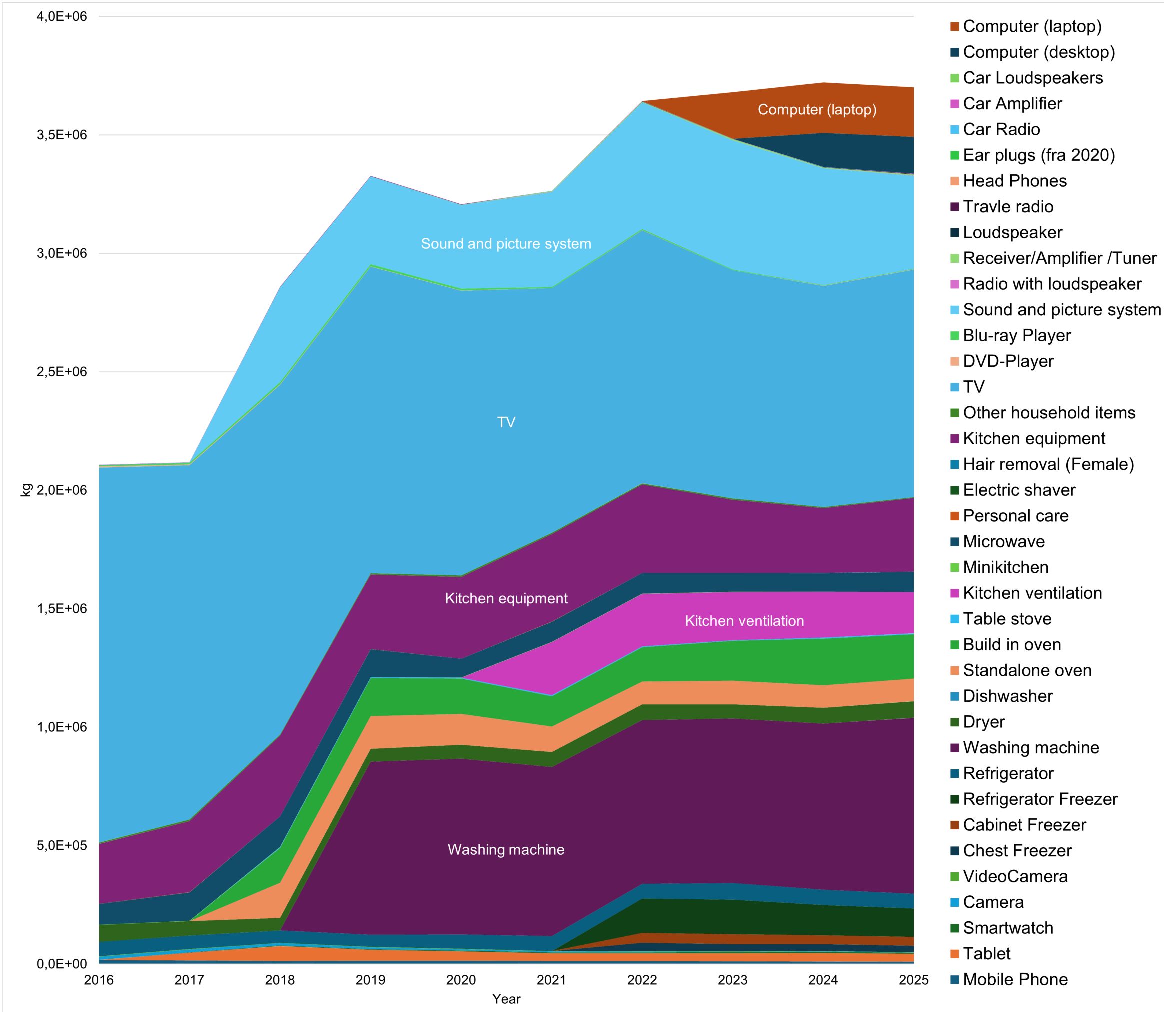

Figure 26: The highest concentrations of aluminium in the different product for each year from 2016-2025.

Aluminium is one of the metals that has a high impact in most of the environmental impact categories. Which products that contain this metal is interesting and there is some variety in the kind of product that contribute to the total volume of the aluminium.
The biggest contributor is TV's, which are present throughout the decade. When washing machines enters the end of life phase it is a close second to the TV's contribution. Other noteworthy products include kitchen ventilation, kitchen equipment, sound and picture systems and computers.
The visible green and light orange lines between washing machine and kitchen ventilation are the dryer and the two kind of ovens. There is a large difference between the products that contribute to the total volume of aluminium. As kitchen equipment provides a function that is very different from that of a TV.

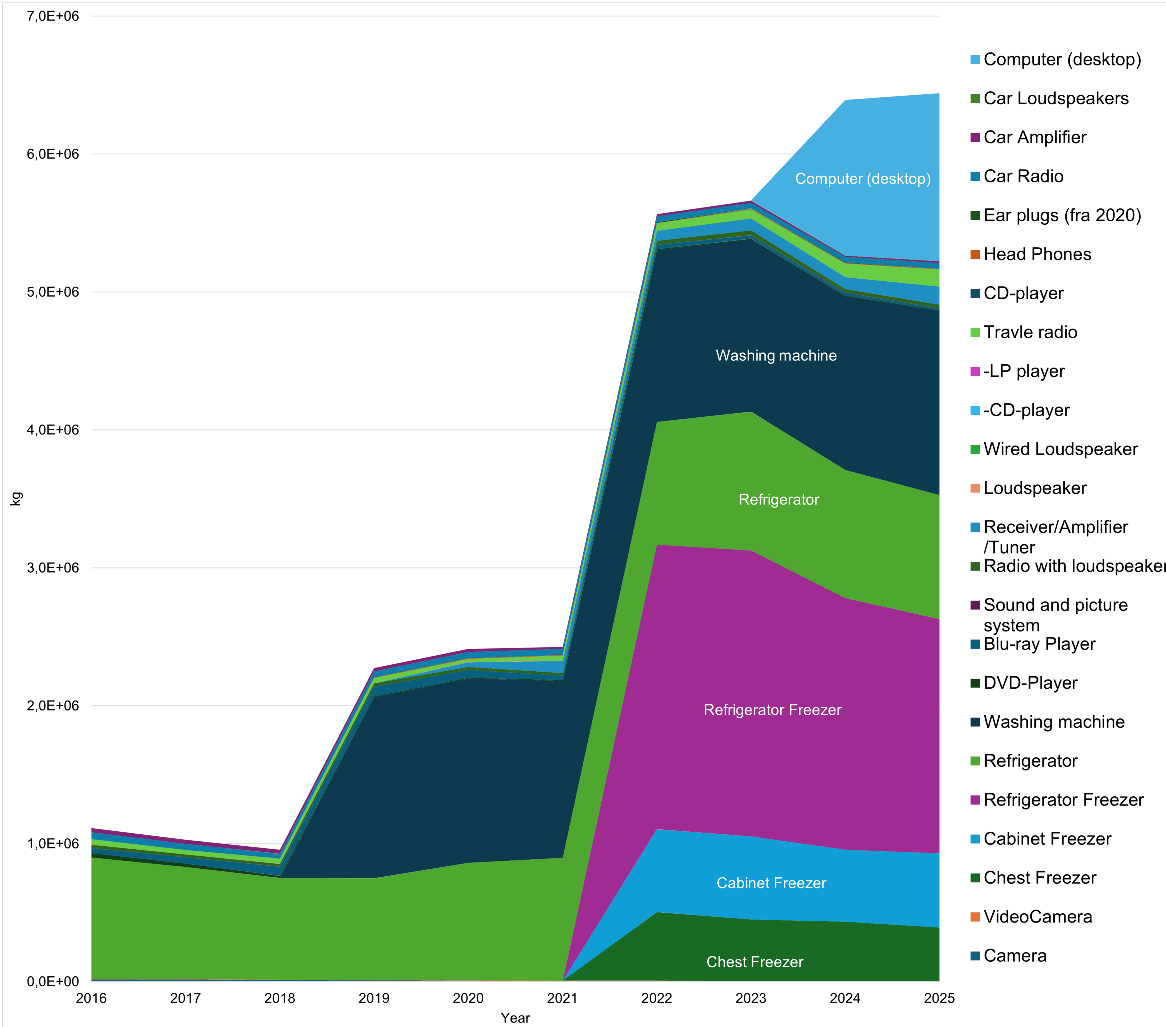

Figure 27: The highest concentrations of iron in the different product for each year from 2016-2025.

Iron is a stable part of every one of the environmental impact category, and it have the same development over the decade for every one of them. Therefore the products that have the most iron in them are looked at in Figure 27. For the products that contain iron there is a clear majority of the larger appliances. The refrigerator category is contributing throughout the decade, which is generally steady for the period.
Washing machines begins contributing in 2018, also with a pretty steady contribution. In 2021 the other kinds of refrigerator and freezer begins to contribute to the volume of iron, with the combination of refrigerator and freezer having the biggest total contribution.

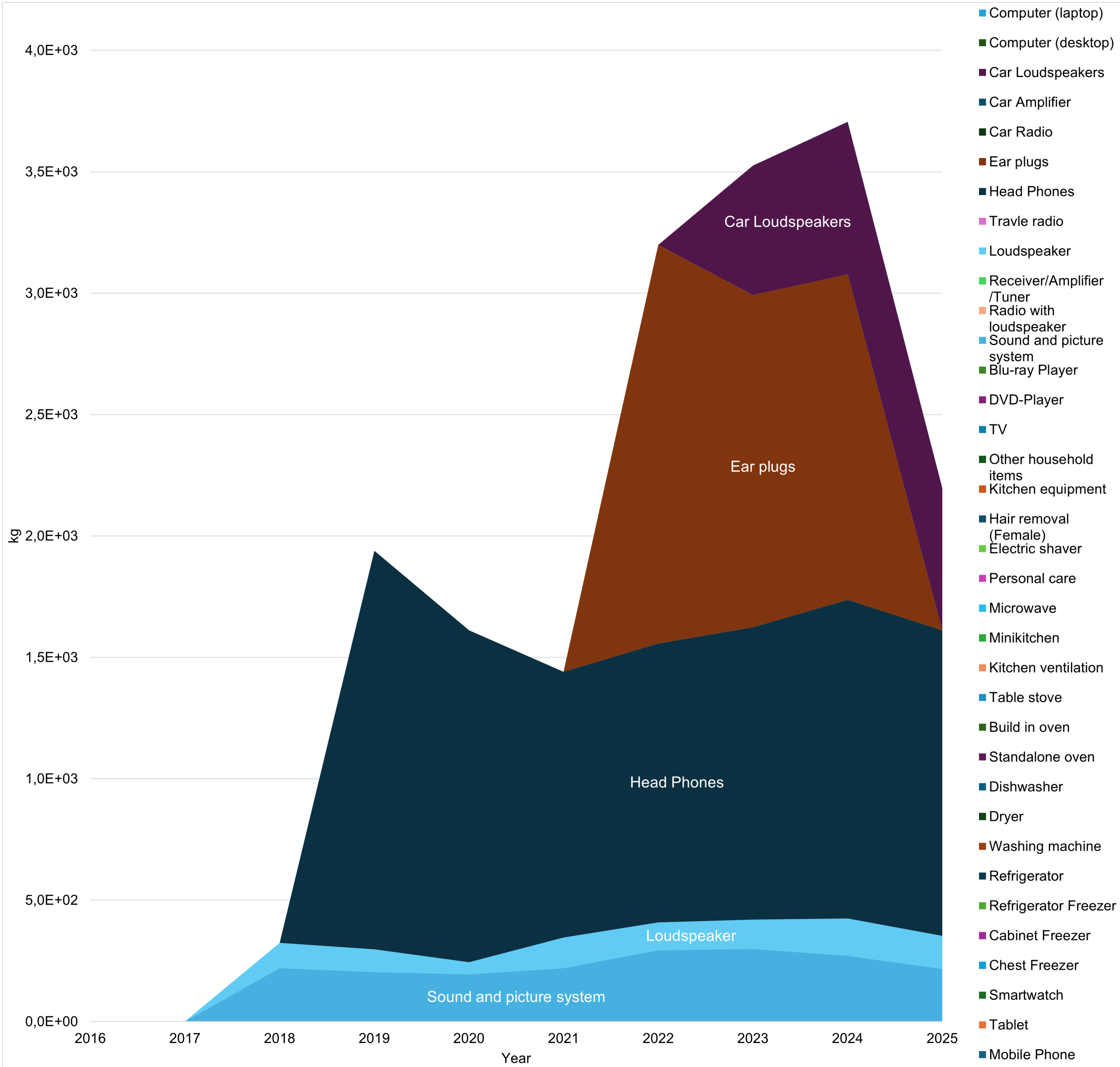

Figure 28: The highest concentrations of neodymium in the different product for each year from 2016-2025.

For the midpoint and endpoint impact category that looked at mineral scarcity it was clear that the biggest contributor was neodymium. The trend of neodymium throughout the decade correspond to what can be seen in Figure 28. The main contributors of neodymium are the electronics that produce sounds, as the only visible products are loudspeakers in different variations. Neodymium can be seen to have a presence in most modern electronics, just as most other REE's have which can be seen in Appendix 7.2, Table 13-14.
The biggest contributors are head phones and ear plugs, which are products with a short lifespan of 5 and 2 years respectively. This could be a reason for the higher contribution than the other kind of products, as people will buy new ones more often.

5.3 Answering of the research questions

For this section the result presented in the sections above will be combined to answer the 2 research questions. The various uncertainties and assumptions will be discussed as well as held up against the information gathered in the literature review.

5.3.1 Research question 1

The first question is ”What are the flows of electronic products and the metals withing, and how does it change over the decade 2016-2025?”
As the scope of this thesis focuses on the end of life of the electronic products the flows have been adjusted by the lifetime of every product. This have resulted in Table 6 where there are multiple years for different products without any data. This is due to long lifespans for the most part, as the oldest available sales data is from 2006 and there are product for which sales data does not go that far back. This does of course not mean that no E-waste is generated in these periods, just that the model does not cover this. Looking at the metals in the electronics products the flow of these are linked to the number of sold units, and therefore there will be a smaller volume in the start of the decade, compared to the end of it.
For the number of metals found in electronic waste, 48 have been documented. The vast majority of these metals are found in the printed circuit boards that is in most modern electronics. Only 5 of the metals where documented not being part of the PCB, these being steel, copper, aluminium, iron and nickel. These 5 metals are the main contributors of the metals found in electronics, which is no surprise as PCB is a relative low percent of the weight of the electronic product.

5.3.2 Research question 2

The second question is ”What are the impacts embedded in the metals in electronic products, and which metals and products contribute the most?” There are many different impacts included when looking at the process of excavating metal from the earth. The ones looked at in this thesis are chosen based on the principle that the severity of the impact a metal has changes depending on which metal or impact that is looked at. Therefore a wide variety of impacts have been chosen with this goal in mind. In the literature review different impact categories have been presented, with *global warming*, *energy demand*, *terrestrial acidification*, *freshwater eutrophication*, *human toxicity* and *metal scarcity* as the main impacts in regard to metals.
These impact categories have then been used as a base to determined which midpoint and endpoint impacts that were chosen to be applied on the metals in the Norwegian system. Four midpoint impact categories (*climate change*, *land use*, *material resources* and *water use*) along with the 3 endpoint impacts categories (*ecosystem quality*, *human health* and *natural resources*) covers the same categories that the literature review found.

With the environmental impacts determined it can be seen that the impact each metal has changes in intensity depending on which impact category is looked at. But the majority of the impacts are from the same few metals: steel, aluminium, iron, nickel and gold. Then depending on the specific impact category there are some other metals that are showing up, as a example: neodymium and praseodymium have a huge impact on the *mineral scarcity*. Nickel has a huge impact on *water use*, but a minor impact in the rest of the categories.

With these environmental impacts in mind, 4 metals have been chosen for further investigation. This is to determine which electric product are responsible for the majority of the impacts. The 4 metals are steel, aluminium, iron, and neodymium due to the consistency of the first 3 throughout every impact category. The last was chosen due to its very high impact in the *mineral scarcity* impact category.

For steel the products that contribute most to the mass of steel are the *Large Electric Appliances*, such as ovens, dishwashers, cloth dryer and washing machines. This correspond to what was found in Figure 11 that showed the mass of a single unit of each of the electronic products. There is steel in 26 of the electronic products, but the majority of the impact lies with just 5 of the products.

Continuing with aluminium which is a product that clearly have the biggest impact, TV is a major contributor throughout the decade. With washing machine contributing from 2018 as well. Looking at iron, the majority of the products is only entering the end of life phase in 2021, with the *Large Electric Appliances* having the main contribution once again. The products are, washing machine, refrigerator and freezers. Desktop computers also have a presence in the last couple of years.
For neodymium the electronics that have the majority of this metal is different kind of speakers, of one kind or another. With headphones and earplugs being the biggest contributors.

Therefore the midpoint impact of *mineral depletion* in Figure 20 and the endpoint impact in Figure 24 can be attributed to the electronics products that produce sounds, such as speakers. For aluminium the midpoint category where it were the majority of the impacts was *climate change*, but *land use* and *water use* did also have a large portion of its impact coming from aluminium. It is similar for the 3 endpoint categories, which all have aluminium presence. Here two products can take the main blame for these impacts, which are TV and Washing machines. They are not alone as there are many products that have aluminium in it, but they do stick out as the major contributors.
Iron and steel have similar trends, both within the environmental impact categories and within the products, and will as such be mentioned together here. They have a relatively big impact in both the midpoint and the endpoint categories being represented in every category. The products were the larger electrical products that use a lot of the metals due to its sizes. It is similar to the neodymium, as it is more of a overall category than one product that will take the blame for the impacts.

5.4 Further work

Further work with the this topic is possible in several ways, both in improving upon the work that is already done, or to add to it with new angles. This is what will be discussed in this section.

First the work that can be improved upon. The model is built on the statistic of sales numbers of electronic products from Elektronikkbransjen. But there are room for improvement for this. Computers are not part of the sales numbers, and were included by estimation from other sources.
There are likely other kind of electronics which are not covered by Elektronikkbransjen, and the inclusion of these electronics will make the model more robust. One such electronic which is not included in the statistic is printers. So further work with this topic could be the expansion of the electronics that are looked at.

Another way the work in this thesis could be worked with further is the range for the yearly sales of electronics, as this would improve the coverage over the years for every product. This might not be possible if the required data is not available. This will however improve with time, as Elektronikkbransjen is gathering data yearly.

In regards to adding on to the topic, or using the work from this thesis to support new work there is a clear next step. Environmental impact of recycled metals compared with the impact of virgin metals. This could be used for future decision making when it comes to improving the environment.

6 Conclusion

This thesis set out to find the flows of electric and electronic products, and the metals that these products contain. The most common EE products in Norway have been found and been categories into 6 subcategories which are *Mobile*, *Camera*, *Large Electric Appliances*, *Small electric*, *Sound and picture systems* and *Computers*. In these 6 subcategories there are 44 different kinds of EE products. Where some are being specific, like mobile phone, tablet and smartwatch which are EE products from the *Mobile* category. Others are broader in scope, like "kitchen equipment" and "other household items" which are some of the EE products from *Small electric*.

The weight of each of these EE product have been found by calculating the average of the weight of EE products for sale in Norwegian electronic stores. For some of the product there are official research reports that have provided information on the weight as well. For each of these EE products the average lifetime have been determined, and the range between products is quite wide. Ear plugs have an average lifespan of 2 years, whereas freezers have a lifespan of 16 years on average. This large difference in lifetime have proven to be a challenge for determining the flow of the products throughout a longer period of time. With the data available it was possible to make a table for the flows of EE product coming to its end-of-life phase for the years 2016-2025.

The general trend for how many products were sold in this period have been found for every type of EE product. There are 18 of the products that have a downward trend, 17 that have a steady trend, 7 that have an upward trend, and 2 which have a lifetime so high that no product have reached its end-of-life phase yet. 24 of the 44 EE products have data starting at 2016, with 2024 being the year with most products at 42 of the products.

The metals that are in the EE products have been found as well, with 48 different metals being present in these EE products. There are 5 metals that make up the majority of the metal used in EE products, which are steel, copper, aluminium, iron and nickel. The reason these metals have a much bigger presence than the rest are due to the rest mainly being found in the PCB's of the EE products. Metals found in PCB's that stand out include silver, gold and palladium which are all considered precious metals. There are many REE's found in PCB's as well with neodymium and praseodymium having the largest presence.

The metals that are the most abundant are the same metals that are responsible for the highest impact across the different environmental impact categories, with the exception of the REE's which have impact in some of the categories but the quantity of the metal is not comparable to the other mentioned metals. For midpoint categories *climate change*, *land use*, *material resources* and *water use* is looked at in this thesis. All 3 of the endpoint categories are looked at, which are *ecosystem quality*, *human health* and *natural resources*.
Steel has a clear impact on every impact category, without dominating any of them. Aluminium have the larges contribution for *climate change*, *land use*, *ecosystem quality* and *human health*. It have the smallest of the impact, when comparing the 5 metals that make up the majority in EE products, in *material resources*. Iron have a impact in every category, with the smallest impacts being for *water use* and *ecosystem quality*. In comparison to the other metals it is not the most impact full metal in any category.
Nickel have a major impact in the *water use* for which it is one of the 3 metals with the highest impacts. For the other impact categories it is one of the metals with the lowest impacts. Neodymium and praseodymium are the major impacts in *material resources*, and as a result they show a large impact in *natural resources* as well. The only other impact category where one of them, neodymium, is visible is *land use* and is is a small impact. Gold and palladium have a impact in most if the categories, but not with the same influence as the rest. They have the highest impacts in *ecosystem quality* and *human health*.

The products with most steel, aluminium, iron and neodymium have been investigated to see which product have the highest contribution on the environmental impacts.
Steel are spread out over many of the *Large Electric Appliances*, with ovens, dishwashers, cloth dryers and washing machines being some of the major contributors.These products contribute to every impact category as steel has a steady presence in every one of the categories.
Aluminium have a few major contributors such as TV's and washing machines. There are several other products that have significance impacts, such as kitchen equipment, computers and sound and picture systems. With the quantity of aluminium in these products having high impact on *climate change*, *land use*, *ecosystem quality* and *human health*.
Iron is mainly found in *Large Electric Appliances*, same as steel, within product such as refrigerators and freezers. It were found in computers as well. These products contribute in a similar way to steel. but iron did not have a major impact in any of the categories.
Neodymium is primarily found in different kind of speakers, with headphones, ear plugs and loudspeakers having the highest quantity of this metal. These product have the highest impact on *material resources* and contribute to *natural resources*.

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7 Appendices

7.1 Appendix A

This Appendix shows the sales number combined with lifetime table for the start of the available data and all the way to 2030. Table 7 can be seen on the next page. As the table clearly shows there are large gaps due to the lifetime of some of the products. This pushes some of the product end-of-life very far into the future, and some only a few years.

Table 7: Sales numbers is combined with the lifetime of products in order to estimate the quantities of each product that will be entering the Waste system each year. ** Lifetime is multiple decades, and the sales number on this product is therefore assumed to not be entering the waste system withing the timeline of the rest of the EE products.

Number of sold electronics that is at its end-of-life based on its average lifetime.																								
Category	Product	Lifetime	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Mobil	Mobiltelefoner	3	2050000	2300000	2280000	2365000	2500000	2250000	2200000	2400000	2100000	1850000	2000000	1900000	1800000	1700000	1600000	1520000	1356000					
	Nettbrett	5									500000	950000	700000	613000	500000	500000	523000	546000	514000	450000	407000			
	Smartarmbånd og smartklokker	4									320000	720000	760000	900000	1060000	1210000	1170000	1200000	1160000					
Stillbillede-kamera	kamera	7					478000	500000	550000	519000	499000	405000	311000	224000	140000	120000	68000	80000	49000	39000	29000	23000	24000	
	Objektiver	**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Videokamera	7					89000	95000	75000	63000	53000	38000	59000	80000	82000	99000	48000	46000	48000	43000	36000	37000	37000	
Store elektriske apparater	Frysebokser	16														60000	54000	52000	47000	44000	60000	57000	49000	46000
	Fryseskap	16														38000	38000	33000	34000	34000	39000	48000	47000	56000
	Kombinasjon kjøl/frys	16														181000	182000	160000	149000	140000	124000	130000	135000	138000
	Kjøleskap	10							89000	92000	85000	77000	77000	89000	93000	93000	105000	97000	94000	91000	93000	88000	88000	90000
	Vaskemaskiner	13											230000	234000	225000	218000	219000	221000	234000	234000	216000	235000	242000	217000
	Tørketromler	10							84000	92000	79000	70000	71000	76000	82000	86000	77000	87000	91000	94000	86000	85000	91000	105000
	Oppvaskmaskiner	7					181000	190000	168000	146000	151000	164000	182000	183000	185000	199000	190000	199000	202000	206000	207000	215000	201000	
	Gulvkomfyrer	13										108000	101000	95000	79000	70000	73000	69000	70000	76000	76000	78000	69000	66000
	Bygg-inn	13										169000	184000	172000	147000	166000	193000	227000	214000	213000	250000	253000	274000	267000
	Bordkomfyrer	13										17000	18000	15000	20000	16000	15000	18000	19000	25000	34000	20000	8000	4000
	Kjøkkenventilatorer	15													130000	129000	118000	112000	101000	119000	144000	129000	122000	130000
	Minikjøkken	6				2000	3000	2000	3000	2000	2000	2000	1000	2000	1000	1000	1000	1000	1000	0	0	1000		
	Mikrobølgeovner	6				150000	210000	157000	133000	156000	215000	230000	210000	142000	153000	156000	142000	140000	153000	161000	166000	155000		
Småelektrisk	Personlig pleie	3	620000	765000	766000	737000	776000	791000	733000	677000	664000	643000	657000	620000	613000	540000	680000	670000	633000					
	Barbermaskiner	10								138000	130000	111000	123000	129000	142000	140000	125000	134000	131000	126000	120000	128000	179000	171000
	Hårfjerning kvinner	10								47000	60000	45000	40000	47000	44000	42000	40000	51000	59000	50000	53000	49000	40000	30000
	Kjøkkenutstyr (Kjøkkenmaskiner,kaffetraktere, espresso, vannkokere, vaffeljern osv)	7					1301000	1515000	1292000	1307000	1549000	1752000	1625000	1774000	1902000	1923000	1590000	1412000	1600000	1501000	1800000	1925000	1280000	
	Øvrige (Strykejern støvsugere, bordvifter, varmeovner)	10								1242000	1388000	1154000	1102000	1437000	1200000	1127000	1099000	1087000	962000	1026000	997000	1062000	1181000	1134000
Lyd- og bildeprodukter	TV	8						510000	650000	636000	601000	593000	520000	483000	415000	429000	387000	375000	386000	373000	365000	430000	368000	342000
	DVD-spiller, uten kombinasjoner	7					203000	265000	200000	107000	80000	52000	24000	17000	15000	25000	15000	14000	12000	6000	6000	5000	6000	
	Blu-ray spillere	7						10000	30000	76000	98000	140000	150000	122000	70000	70000	50000	44000	30000	26000	26000	14000	15000	
	Lyd - og bildeanlegg	12										161000	149000	142000	161000	215000	219000	198000	158000	375000	260000	210000	305000	235000
	-Radiomottaker med innebygd høyttaler	10							123000	119000	95000	98000	120000	110000	90000	140000	180000	120000	130000	300000	100000	100000	100000	100000
	Reciever/forsterker/tuner	14												11000	30000	24000	29000	29000	44000	41000	41000	35000	35000	20000
	-Høyttaler	13										76000	68000	36000	92000	83000	88000	112000	100000	80000	70000	70000	70000	70000
	-Strømmende høyttaler	13																			305000	260000	370000	210000
	-CD-spiller	3	4000	3000	2000	2000	4000	3000	2000	2000	2000	1000	1000	1000	1000	1000	1000	1000						
	-Platespiller (LP)	7					2000	2000	10000	4000	4000	4000	4000	8000	9000	10000	12000	10000	15000	10000	10000	10000	10000	
	Reiseradio med kombinasjoner	10							175000	200000	170000	192000	185000	125000	185000	270000	330000	500000	620000	700000	280000	270000	200000	114000
	CD-spiller	3	40000	21000	40000	80000	30000	35000	33000	15000	13000	10000	5000	5000	10000	5000	5000	5000	2000					
	MP3-opptaker/avspiller	3	585000	400000	400000	300000	250000	230000	140000	75000	60000	20000	20000	25000	25000	25000	12000	5000	5000					
	Hodetelefoner	5											1200000	1000000	800000	840000	880000	960000	920000	800000	720000			
	Ørepropper (fra 2020)	2														1200000	1000000	980000						
	Bilradio / kombinasjoner	10							220000	255000	220000	174000	223000	238000	225000	220000	210000	200000	220000	1008000	297000	210000	198000	218000
	Forsterkere	8						12000	10000	10000	10000	10000	8000	7000	5000	5000	5000	3000	4000	4000	3000	5000	5000	0
	Høyttalere (stk.)	18															390000	459000	428000	364000	474000	501000	533000	500000
Computers	Computer (desktop)	5																177000	191000	188000	179000			
	Computer (laptop)	4															648000	697000	688000	653000				

7.2 Appendix B

This appendix shows the tables which have the metal content for 1 unit of every EE product. The unit for the metal is in kg, so it is easy to compare. Due to the number of metals that were found in EE product the table have been split up into 7 sub-tables to make it readable. The EE products will be on the left side for every sub-table, with the metals presented by their element symbol.

The colour codes that can be seen in the table is there to convey the following. If a EE product have a specific colour, that means metals that have the same colour in other products are assumed to be equal to the original EE product. As a example, looking at Table 8 Mobile Phone has a pink colour, and Tablet and Smartwatch both have there values for Pb and Sn in pink. This means the values for Pb and Sn, for both Tablet and Smartwatch, is from Mobile Phone.
This is done for products that are assumed to be very similar in either size and build or in function. A product that were chosen on size and build are Mini kitchen which were assumed to be similar to Microwave. for the function the metals are from the PCB of the product, and therefore the function of the product were prioritized for these metals in the assumption the PCB has a similar build when the product are doing similar functions.

The metals that are not found in PCB is the first 5 metals in Table 8, the rest are found in the PCB. In order to keep track of which sources contribute to these another colour code have been used. If the metals Pb and Sn in Table 8 and any of the metals in Table 9-14 are with a white background then the source is (Priya & Hait, 2018). If the background is light blue the source is (Oguchi et al., 2011), and if it is a light pink colour then the weight for the product is from (Oguchi et al., 2011) and the metal is from (Dimitrijevic et al., 2013).

After the tables with the metals, there are some tables that show the sources for the metals found in specific products. These tables are separated into 5 different tables. Table 15 present the sources for the 5 metals that EE product are mostly made of, where the rest of the tables (Table16, Table 17, Table 18, Table 19) shows the sources for the metals found in PCB's for the different EE products.

Table 8: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 1)

Product	Metals (kg pr unit)						
	Steel	Cu	Al	Fe	Ni	Pb	Sn
Mobile Phone	5,52E-03	1,17E-02	7,05E-03			7,66E-08	1,06E-03
Tablet	1,30E-02	2,40E-03	6,58E-02			7,66E-08	1,06E-03
Smartwatch			3,40E-03			7,66E-08	1,06E-03
Camera		1,79E-03	2,56E-02	3,10E-02		2,05E-03	4,70E-03
Camera lenses							
VideoCamera		1,79E-03	2,56E-02	3,10E-02		3,57E-03	4,52E-03
Chest Freezer	1,14E+01	8,14E-01	5,81E-01	8,30E+00		2,98E-08	1,87E-02
Cabinet Freezer	2,17E+01	1,55E+00	1,11E+00	1,58E+01		2,98E-08	1,87E-02
Refrigerator/ Freezer Combo	1,56E+01	1,12E+00	7,98E-01	1,14E+01		2,98E-08	1,87E-02
Refrigerator	1,32E+01	9,39E-01	6,71E-01	9,58E+00		2,98E-08	1,87E-02
Washing machine	2,03E+01	1,50E+00	3,17E+00	5,71E+00		3,43E-07	1,01E-02
Dryer	2,75E+01	1,68E+00	7,73E-01			3,43E-07	1,01E-02
Dishwasher	2,12E+01	6,52E+00				3,43E-07	1,01E-02
Standalone oven	4,20E+01	1,36E+00	1,36E+00			2,98E-08	1,87E-02
Build in oven	2,69E+01	8,71E-01	8,71E-01			2,98E-08	1,87E-02
Table stove	6,58E+00	2,13E-01	2,13E-01			2,98E-08	1,87E-02
Kitchen ventilation	6,10E+00	2,26E+00	1,72E+00			1,31E-07	1,90E-02
Minikitchen	8,62E+00	1,14E+00	5,59E-01			2,98E-08	1,87E-02
Microwave	8,62E+00	1,14E+00	5,59E-01			2,98E-08	1,87E-02
Personal care	2,47E-02	3,97E-02	5,48E-04		1,86E-02	6,42E-09	
Electric shaver	1,35E-02	2,17E-02	3,00E-04		1,02E-02	6,42E-09	
Hair removal (Female)	2,47E-02	3,97E-02	5,48E-04		1,86E-02	6,42E-09	
Kitchen equipment	3,02E-01	6,86E-02	1,94E-01		6,97E-02	6,42E-09	
Other household items	7,17E-01	1,06E-01	4,50E-03			1,31E-07	1,90E-02
TV	3,64E+00	1,37E+00	2,49E+00			7,56E-07	3,71E-02
DVD-Player	2,53E-01	5,56E-02	4,35E-02	3,14E-01		9,60E-08	3,12E-03
Blu-ray Player	3,77E-01	8,29E-02	6,48E-02	4,67E-01		9,60E-08	3,12E-03
Sound and picture system	3,64E+00	1,37E+00	2,49E+00	3,79E-03		1,71E-09	1,76E-02
Radio with loudspeaker		1,82E-02	2,84E-03	1,99E-01		8,67E-08	1,42E-03
Receiver/Amplifier/ Tuner		1,22E-01	1,22E-01	2,98E+00		1,71E-09	1,76E-02
Loudspeaker		7,02E-06	3,85E-05	3,79E-03			
Wired Loudspeaker		7,02E-06	3,85E-05	3,79E-03		1,71E-09	4,80E-02
-CD-player		2,08E-03		4,17E-03		6,32E-04	2,63E-03
-LP player		2,08E-03		4,17E-03		6,32E-04	2,63E-03
Travle radio		1,82E-02	2,84E-03	1,99E-01		8,67E-08	1,42E-03
CD-player		2,08E-03		4,17E-03		6,32E-04	2,63E-03
MP3-player						9,30E-03	4,80E-02
Head Phones		7,02E-06	3,85E-05	3,79E-03			
Ear plugs		7,02E-06	3,85E-05	3,79E-03			
Car Radio		1,82E-02	2,84E-03	1,99E-01		8,67E-08	1,42E-03
Car Amplifier		1,22E-01	1,22E-01	2,98E+00		1,71E-09	1,76E-02
Car Loudspeakers		7,02E-06	3,85E-05	3,79E-03			
Computer (desktop)	1,13E+00	1,86E+00	8,10E-01	6,38E+00		8,94E-07	4,11E-03
Computer (laptop)	1,23E-01	3,05E-01	3,05E-01			9,95E-07	7,91E-03

Table 9: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 2)

Product	Metals (kg pr unit)						
	Zn	Cd	Ba	Ga	Ta	Se	As
Mobile Phone	1,50E-08	6,18E-10	1,56E-09	4,24E-06	7,88E-05	4,19E-07	6,23E-07
Tablet	1,50E-08	6,18E-10	1,56E-09	4,24E-06	7,88E-05	4,19E-07	6,23E-07
Smartwatch	1,50E-08	6,18E-10	1,56E-09	4,24E-06	7,88E-05	4,19E-07	6,23E-07
Camera	1,06E-03	1,47E-07	1,93E-03	1,81E-06	9,52E-04	3,43E-07	4,19E-07
Camera lenses							
VideoCamera	1,55E-03	1,45E-07	2,14E-03	6,19E-06	9,52E-04	3,39E-07	4,14E-07
Chest Freezer	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Cabinet Freezer	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Refrigerator/ Freezer Combo	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Refrigerator	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Washing machine	4,78E-08	3,43E-07	1,34E-09			3,36E-06	2,29E-06
Dryer	4,78E-08	3,43E-07	1,34E-09			3,36E-06	2,29E-06
Dishwasher	4,78E-08	3,43E-07	1,34E-09			3,36E-06	2,29E-06
Standalone oven	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Build in oven	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Table stove	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Kitchen ventilation	1,49E-08	9,76E-10	4,97E-10			1,32E-06	#DIV/0!
Minikitchen	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Microwave	2,55E-08	1,20E-09	1,68E-10			5,57E-07	4,88E-07
Personal care	2,28E-10	4,80E-10	3,00E-10			1,29E-07	9,53E-08
Electric shaver	2,28E-10	4,80E-10	3,00E-10			1,29E-07	9,53E-08
Hair removal (Female)	2,28E-10	4,80E-10	3,00E-10			1,29E-07	9,53E-08
Kitchen equipment	2,28E-10	4,80E-10	3,00E-10			1,29E-07	9,53E-08
Other household items	1,49E-08	9,76E-10	4,97E-10			1,32E-06	
TV	2,37E-07	1,48E-08	1,30E-06		1,79E-04	6,69E-07	4,92E-06
DVD-Player	5,20E-10	4,03E-10	7,15E-11	1,27E-06	1,09E-05	1,47E-08	9,79E-08
Blu-ray Player	5,20E-10	4,03E-10	7,15E-11	1,27E-06	1,09E-05	1,47E-08	9,79E-08
Sound and picture system	2,94E-05	6,57E-10	3,85E-11	1,17E-05		2,50E-08	9,25E-08
Radio with loudspeaker	8,00E-10	3,83E-09	1,60E-10	7,09E-07	5,32E-07	2,19E-08	7,42E-07
Receiver/Amplifier/ Tuner	2,20E-10	6,57E-10	3,85E-11	0,00E+00		2,50E-08	9,25E-08
Loudspeaker	2,94E-05			1,17E-05			
Wired Loudspeaker	2,20E-10	6,57E-10	3,85E-11	0,00E+00	0,00E+00	2,50E-08	9,25E-08
-CD-player	1,05E-03	6,42E-08	4,53E-04		3,53E-05	1,50E-07	1,83E-07
-LP player	1,05E-03	6,42E-08	4,53E-04		3,53E-05	1,50E-07	1,83E-07
Travle radio	8,00E-10	3,83E-09	1,60E-10	7,09E-07	5,32E-07	2,19E-08	7,42E-07
CD-player	1,05E-03	6,42E-08	4,53E-04		3,53E-05	1,50E-07	1,83E-07
MP3-player	1,10E-02	1,94E-07	1,90E-02		9,60E-03	4,53E-07	5,53E-07
Head Phones	2,94E-05			1,17E-05			
Ear plugs	2,94E-05			1,17E-05			
Car Radio	8,00E-10	3,83E-09	1,60E-10	7,09E-07	5,32E-07	2,19E-08	7,42E-07
Car Amplifier	2,20E-10	6,57E-10	3,85E-11	0,00E+00	#VALUE!	2,50E-08	9,25E-08
Car Loudspeakers	2,94E-05			1,17E-05			
Computer (desktop)	4,25E-07	9,00E-09	8,15E-08	1,67E-05	1,07E-05	9,27E-06	8,47E-06
Computer (laptop)	1,70E-07	3,63E-09	4,07E-08	4,94E-06	2,87E-03	4,43E-06	5,48E-06

Table 10: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 3)

	Metals (kg pr unit)						
Product	Cr	Co	Mn	Be	Mo	Sb	V
Mobile Phone	9,45E-07	4,36E-08	4,23E-07	1,04E-09	1,74E-07	2,45E-07	1,07E-07
Tablet	9,45E-07	4,36E-08	4,23E-07	1,04E-09	1,74E-07	2,45E-07	1,07E-07
Smartwatch	9,45E-07	4,36E-08	4,23E-07	1,04E-09	1,74E-07	2,45E-07	1,07E-07
Camera	6,64E-07	1,69E-05	3,13E-06		1,45E-07	9,01E-06	
Camera lenses							
VideoCamera	6,55E-07	2,14E-05	3,09E-06		1,43E-07	8,90E-06	
Chest Freezer	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Cabinet Freezer	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Refrigerator/ Freezer Combo	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Refrigerator	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Washing machine	3,44E-09	6,51E-07	5,64E-06	2,69E-09	5,36E-06	2,01E-06	1,40E-07
Dryer	3,44E-09	6,51E-07	5,64E-06	2,69E-09	5,36E-06	2,01E-06	1,40E-07
Dishwasher	3,44E-09	6,51E-07	5,64E-06	2,69E-09	5,36E-06	2,01E-06	1,40E-07
Standalone oven	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Build in oven	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Table stove	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Kitchen ventilation	1,98E-06	2,45E-07	4,96E-07	1,01E-09	6,74E-07	1,10E-06	4,60E-08
Minikitchen	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Microwave	1,85E-06	1,11E-07	4,61E-07	8,16E-10	4,54E-07	2,82E-07	1,26E-07
Personal care	2,36E-06	2,85E-08	2,37E-07	2,40E-10	3,78E-07	2,90E-06	1,21E-08
Electric shaver	2,36E-06	2,85E-08	2,37E-07	2,40E-10	3,78E-07	2,90E-06	1,21E-08
Hair removal (Female)	2,36E-06	2,85E-08	2,37E-07	2,40E-10	3,78E-07	2,90E-06	1,21E-08
Kitchen equipment	2,36E-06	2,85E-08	2,37E-07	2,40E-10	3,78E-07	2,90E-06	1,21E-08
Other household items	1,98E-06	2,45E-07	4,96E-07	1,01E-09	6,74E-07	1,10E-06	4,60E-08
TV	9,06E-06	5,76E-07	2,96E-06	3,98E-09	3,92E-06	3,94E-06	1,57E-07
DVD-Player	3,84E-07	3,39E-08	1,42E-07	1,24E-10	1,00E-07	1,30E-06	4,94E-09
Blu-ray Player	3,84E-07	3,39E-08	1,42E-07	1,24E-10	1,00E-07	1,30E-06	4,94E-09
Sound and picture system	1,92E-07	2,59E-05	4,42E-08	8,80E-11	2,42E-08	2,20E-06	3,14E-09
Radio with loudspeaker	6,62E-07	7,89E-08	6,08E-07	3,00E-10	4,48E-07	6,13E-07	4,25E-08
Receiver/Amplifier/ Tuner	1,92E-07	1,64E-08	4,42E-08	8,80E-11	2,42E-08	2,20E-06	3,14E-09
Loudspeaker		2,59E-05					
Wired Loudspeaker	1,92E-07	1,64E-08	4,42E-08	8,80E-11	2,42E-08	2,20E-06	3,14E-09
-CD-player	2,90E-07	4,21E-06	1,37E-06		6,32E-08	3,94E-06	
-LP player	2,90E-07	4,21E-06	1,37E-06		6,32E-08	3,94E-06	
Travle radio	6,62E-07	7,89E-08	6,08E-07	3,00E-10	4,48E-07	6,13E-07	4,25E-08
CD-player	2,90E-07	4,21E-06	1,37E-06		6,32E-08	3,94E-06	
MP3-player	8,75E-07	1,50E-04	4,12E-06		1,91E-07	1,19E-05	
Head Phones		2,59E-05					
Ear plugs		2,59E-05					
Car Radio	6,62E-07	7,89E-08	6,08E-07	3,00E-10	4,48E-07	6,13E-07	4,25E-08
Car Amplifier	1,92E-07	1,64E-08	4,42E-08	8,80E-11	2,42E-08	2,20E-06	3,14E-09
Car Loudspeakers		2,59E-05					
Computer (desktop)	1,77E-05	1,05E-06	1,82E-05	2,03E-08	2,05E-06	4,95E-07	2,31E-06
Computer (laptop)	1,37E-05	4,15E-07	3,39E-06	8,00E-09	3,14E-06	7,68E-07	1,12E-06

Table 11: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 4)

	Metals (kg pr unit)						
Product	Si	Zr	Sr	Mg	Bi	Ti	Ca
Mobile Phone	2,06E-06	2,95E-07	1,30E-05	2,52E-06	1,33E-05	2,88E-06	1,72E-05
Tablet	2,06E-06	2,95E-07	1,30E-05	2,52E-06	1,33E-05	2,88E-06	1,72E-05
Smartwatch	2,06E-06	2,95E-07	1,30E-05	2,52E-06	1,33E-05	2,88E-06	1,72E-05
Camera	8,18E-06	1,17E-06	5,30E-05	1,00E-05	2,77E-05	1,14E-05	6,84E-05
Camera lenses							
VideoCamera	8,08E-06	1,16E-06	7,26E-05	9,89E-06	2,85E-05	1,13E-05	6,75E-05
Chest Freezer	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Cabinet Freezer	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Refrigerator/ Freezer Combo	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Refrigerator	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Washing machine	7,51E-05	1,08E-05	9,96E-06	9,20E-05	5,64E-05	1,05E-04	6,28E-04
Dryer	7,51E-05	1,08E-05	9,96E-06	9,20E-05	5,64E-05	1,05E-04	6,28E-04
Dishwasher	7,51E-05	1,08E-05	9,96E-06	9,20E-05	5,64E-05	1,05E-04	6,28E-04
Standalone oven	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Build in oven	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Table stove	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Kitchen ventilation	2,43E-05	3,49E-06	2,60E-05	2,98E-05	#VALUE!	3,40E-05	2,03E-04
Minikitchen	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Microwave	1,53E-05	2,19E-06	1,15E-05	1,87E-05	1,08E-04	2,14E-05	1,28E-04
Personal care							
Electric shaver							
Hair removal (Female)							
Kitchen equipment							
Other household items	2,43E-05	3,49E-06	2,60E-05	2,98E-05		3,40E-05	2,03E-04
TV	1,22E-04	1,75E-05	8,97E-04	1,49E-04	3,41E-04	1,70E-04	1,02E-03
DVD-Player	9,62E-06	1,38E-06	5,67E-05	1,18E-05	1,20E-05	1,35E-05	8,04E-05
Blu-ray Player	9,62E-06	1,38E-06	5,67E-05	1,18E-05	1,20E-05	1,35E-05	8,04E-05
Sound and picture system	5,42E-05	7,78E-06	1,12E-05	6,64E-05		7,59E-05	4,53E-04
Radio with loudspeaker	4,01E-06	5,75E-07	7,09E-06	4,91E-06	1,36E-05	5,61E-06	3,35E-05
Receiver/Amplifier/ Tuner	5,42E-05	7,78E-06	1,12E-05	6,64E-05		7,59E-05	4,53E-04
Loudspeaker							
Wired Loudspeaker	5,42E-05	7,78E-06	1,12E-05	6,64E-05		7,59E-05	4,53E-04
-CD-player	3,57E-06	5,13E-07	1,21E-05	4,38E-06	5,79E-05	5,00E-06	2,99E-05
-LP player	3,57E-06	5,13E-07	1,21E-05	4,38E-06	5,79E-05	5,00E-06	2,99E-05
Travle radio	4,01E-06	5,75E-07	7,09E-06	4,91E-06	1,36E-05	5,61E-06	3,35E-05
CD-player	3,57E-06	5,13E-07	1,21E-05	4,38E-06	5,79E-05	5,00E-06	2,99E-05
MP3-player	1,08E-05	1,55E-06	3,40E-04	1,32E-05	6,60E-04	1,51E-05	9,02E-05
Head Phones							
Ear plugs							
Car Radio	4,01E-06	5,75E-07	7,09E-06	4,91E-06	1,36E-05	5,61E-06	3,35E-05
Car Amplifier	5,42E-05	7,78E-06	1,12E-05	6,64E-05		7,59E-05	4,53E-04
Car Loudspeakers							
Computer (desktop)	1,03E-04	1,48E-05	5,78E-04	1,27E-04	7,61E-05	1,45E-04	8,64E-04
Computer (laptop)	3,36E-05	4,81E-06	1,88E-04	4,11E-05	5,93E-05	4,70E-05	2,81E-04

Table 12: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 5)

	Metals (kg pr unit)						
Product	Tl	Nb	B	Ag	Au	Pd	Ce
Mobile Phone	2,21E-10			1,30E-04	3,88E-06	9,09E-06	4,06E-08
Tablet	2,21E-10			1,30E-04	3,88E-06	9,09E-06	4,06E-08
Smartwatch	2,21E-10			1,30E-04	3,88E-06	9,09E-06	4,06E-08
Camera				3,85E-04	9,40E-05	2,41E-05	
Camera lenses							
VideoCamera				5,95E-04	6,30E-05	1,15E-04	
Chest Freezer	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Cabinet Freezer	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Refrigerator/ Freezer Combo	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Refrigerator	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Washing machine	1,34E-08			1,34E-06	7,23E-07		#DIV/0!
Dryer	1,34E-08			1,34E-06	7,23E-07		#DIV/0!
Dishwasher	1,34E-08			1,34E-06	7,23E-07		#DIV/0!
Standalone oven	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Build in oven	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Table stove	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Kitchen ventilation	1,68E-09			6,24E-07	6,32E-08		#DIV/0!
Minikitchen	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Microwave	2,96E-09			5,54E-06	1,37E-07		4,62E-08
Personal care	1,68E-09						#DIV/0!
Electric shaver	1,68E-09						#DIV/0!
Hair removal (Female)	1,68E-09						#DIV/0!
Kitchen equipment	1,68E-09						#DIV/0!
Other household items	1,68E-09			6,24E-07	6,32E-08		#DIV/0!
TV	1,71E-08	2,78E-06	5,59E-05	6,61E-05	6,41E-06	3,59E-05	
DVD-Player	7,67E-10			7,28E-07	7,56E-08	2,83E-06	1,37E-08
Blu-ray Player	7,67E-10			7,28E-07	7,56E-08	2,83E-06	1,37E-08
Sound and picture system	9,08E-10	2,78E-06	5,59E-05	6,33E-10	4,74E-09		
Radio with loudspeaker	3,92E-08			4,71E-07	4,01E-08	2,01E-06	
Receiver/Amplifier/ Tuner	9,08E-10			6,33E-10	4,74E-09		
Loudspeaker		2,78E-06	5,59E-05				
Wired Loudspeaker	9,08E-10			6,33E-10	4,74E-09		
-CD-player				1,95E-04	1,95E-05	5,26E-07	
-LP player				1,95E-04	1,95E-05	5,26E-07	
Travle radio	3,92E-08			4,71E-07	4,01E-08	2,01E-06	
CD-player				1,95E-04	1,95E-05	5,26E-07	
MP3-player				3,40E-03	9,40E-04	5,50E-04	
Head Phones		2,78E-06	5,59E-05				
Ear plugs		2,78E-06	5,59E-05				
Car Radio	3,92E-08			4,71E-07	4,01E-08	2,01E-06	
Car Amplifier	9,08E-10			6,33E-10	4,74E-09		
Car Loudspeakers		2,78E-06	5,59E-05				
Computer (desktop)	3,15E-09	2,78E-06	5,59E-05	4,60E-05	4,60E-05	2,28E-04	1,75E-06
Computer (laptop)	1,01E-08	2,78E-06	5,59E-05	2,81E-05	2,81E-05	9,89E-05	5,60E-07

Table 13: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 6)

	Metals (kg pr unit)						
Product	Dy	Er	Eu	Gd	Ho	La	Nd
Mobile Phone	2,15E-09	8,26E-10	2,85E-08	1,21E-08	4,55E-10	2,50E-08	2,19E-08
Tablet	2,15E-09	8,26E-10	2,85E-08	1,21E-08	4,55E-10	2,50E-08	2,19E-08
Smartwatch	2,15E-09	8,26E-10	2,85E-08	1,21E-08	4,55E-10	2,50E-08	2,19E-08
Camera							
Camera lenses							
VideoCamera							
Chest Freezer	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Cabinet Freezer	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Refrigerator/ Freezer Combo	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Refrigerator	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Washing machine	2,96E-08	1,08E-08	9,14E-09	1,45E-08	6,88E-09	1,27E-07	6,72E-08
Dryer	2,96E-08	1,08E-08	9,14E-09	1,45E-08	6,88E-09	1,27E-07	6,72E-08
Dishwasher	2,96E-08	1,08E-08	9,14E-09	1,45E-08	6,88E-09	1,27E-07	6,72E-08
Standalone oven	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Build in oven	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Table stove	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Kitchen ventilation	6,15E-08	4,15E-08	5,05E-08	7,50E-08	1,40E-08	7,95E-07	3,80E-07
Minikitchen	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Microwave	3,52E-09	1,76E-09	1,18E-09	8,32E-09	5,76E-10	4,44E-08	2,42E-08
Personal care	8,40E-10	3,72E-10	1,26E-09	2,46E-09	1,20E-10	5,10E-09	4,26E-09
Electric shaver	8,40E-10	3,72E-10	1,26E-09	2,46E-09	1,20E-10	5,10E-09	4,26E-09
Hair removal (Female)	8,40E-10	3,72E-10	1,26E-09	2,46E-09	1,20E-10	5,10E-09	4,26E-09
Kitchen equipment	8,40E-10	3,72E-10	1,26E-09	2,46E-09	1,20E-10	5,10E-09	4,26E-09
Other household items	6,15E-08	4,15E-08	5,05E-08	7,50E-08	1,40E-08	7,95E-07	3,80E-07
TV	8,19E-09	8,30E-09	2,50E-08	1,10E-08	2,39E-09	1,04E-07	6,65E-08
DVD-Player	3,19E-10	2,28E-10	3,32E-09	6,83E-10	6,83E-11	3,80E-09	1,69E-09
Blu-ray Player	3,19E-10	2,28E-10	3,32E-09	6,83E-10	6,83E-11	3,80E-09	1,69E-09
Sound and picture system	9,71E-05	2,20E-10	2,39E-10	6,43E-06	6,05E-11	2,53E-09	1,37E-03
Radio with loudspeaker	1,90E-09	1,10E-09	9,70E-10	1,20E-09	3,60E-10	1,17E-08	9,80E-09
Receiver/Amplifier/ Tuner	3,11E-10	2,20E-10	2,39E-10	5,23E-10	6,05E-11	2,53E-09	1,51E-09
Loudspeaker	9,71E-05			6,43E-06			1,37E-03
Wired Loudspeaker	3,11E-10	2,20E-10	2,39E-10	5,23E-10	6,05E-11	2,53E-09	1,51E-09
-CD-player							
-LP player							
Travle radio	1,90E-09	1,10E-09	9,70E-10	1,20E-09	3,60E-10	1,17E-08	9,80E-09
CD-player							
MP3-player							
Head Phones	9,71E-05			6,43E-06			1,37E-03
Ear plugs	9,71E-05			6,43E-06			1,37E-03
Car Radio	1,90E-09	1,10E-09	9,70E-10	1,20E-09	3,60E-10	1,17E-08	9,80E-09
Car Amplifier	3,11E-10	2,20E-10	2,39E-10	5,23E-10	6,05E-11	2,53E-09	1,51E-09
Car Loudspeakers	9,71E-05			6,43E-06			1,37E-03
Computer (desktop)	5,18E-08	2,93E-08	2,16E-07	3,17E-07	9,45E-09	1,06E-06	4,21E-07
Computer (laptop)	3,43E-08	1,11E-08	2,28E-07	1,51E-07	1,01E-08	2,80E-07	1,53E-07

Table 14: The metal content of 1 unit of EE product for every metal found for this thesis. (Part 7)

	Metals (kg pr unit)					
Product	Pr	Sc	Sm	Tm	Yb	Y
Mobile Phone	3,58E-09	3,96E-07	2,47E-09	1,17E-10	8,45E-10	1,43E-08
Tablet	3,58E-09	3,96E-07	2,47E-09	1,17E-10	8,45E-10	1,43E-08
Smartwatch	3,58E-09	3,96E-07	2,47E-09	1,17E-10	8,45E-10	1,43E-08
Camera						
Camera lenses						
VideoCamera						
Chest Freezer	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Cabinet Freezer	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Refrigerator/ Freezer Combo	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Refrigerator	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Washing machine	2,69E-08	2,83E-06	1,29E-08	1,34E-09	8,60E-09	1,48E-07
Dryer	2,69E-08	2,83E-06	1,29E-08	1,34E-09	8,60E-09	1,48E-07
Dishwasher	2,69E-08	2,83E-06	1,29E-08	1,34E-09	8,60E-09	1,48E-07
Standalone oven	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Build in oven	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Table stove	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Kitchen ventilation	1,46E-07	2,28E-05	4,95E-08	2,10E-08	2,30E-08	6,30E-07
Minikitchen	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Microwave	8,24E-09	3,09E-07	4,80E-09	2,56E-10	1,76E-09	3,19E-08
Personal care	1,30E-09	2,74E-07	8,52E-10	8,40E-11	6,00E-10	3,84E-09
Electric shaver	1,30E-09	2,74E-07	8,52E-10	8,40E-11	6,00E-10	3,84E-09
Hair removal (Female)	1,30E-09	2,74E-07	8,52E-10	8,40E-11	6,00E-10	3,84E-09
Kitchen equipment	1,30E-09	2,74E-07	8,52E-10	8,40E-11	6,00E-10	3,84E-09
Other household items	1,46E-07	2,28E-05	4,95E-08	2,10E-08	2,30E-08	6,30E-07
TV	3,41E-08	5,54E-06	1,27E-08	1,48E-09	9,33E-09	1,54E-07
DVD-Player	6,18E-10	1,33E-07	3,61E-10	3,90E-11	2,60E-10	1,46E-08
Blu-ray Player	6,18E-10	1,33E-07	3,61E-10	3,90E-11	2,60E-10	1,46E-08
Sound and picture system	3,90E-04	1,11E-07	3,16E-10	2,48E-11	1,95E-10	1,57E-09
Radio with loudspeaker	3,90E-09	1,53E-07	1,90E-09	1,50E-10	1,10E-09	9,70E-09
Receiver/Amplifier/ Tuner	7,78E-10	1,11E-07	3,16E-10	2,48E-11	1,95E-10	1,57E-09
Loudspeaker	3,90E-04					
Wired Loudspeaker	7,78E-10	1,11E-07	3,16E-10	2,48E-11	1,95E-10	1,57E-09
-CD-player						
-LP player						
Travle radio	3,90E-09	1,53E-07	1,90E-09	1,50E-10	1,10E-09	9,70E-09
CD-player						
MP3-player						
Head Phones	3,90E-04					
Ear plugs	3,90E-04					
Car Radio	3,90E-09	1,53E-07	1,90E-09	1,50E-10	1,10E-09	9,70E-09
Car Amplifier	7,78E-10	1,11E-07	3,16E-10	2,48E-11	1,95E-10	1,57E-09
Car Loudspeakers	3,90E-04					
Computer (desktop)	1,67E-07	5,06E-06	8,89E-08	9,11E-09	3,15E-08	4,58E-07
Computer (laptop)	4,64E-08	1,84E-06	3,50E-08	1,61E-09	1,21E-08	1,21E-08

Table 15: Source for metals values, Steel - Tin for every EE Product

Sources for the metals in the EE products	
Product	Steel Cu Al Fe Ni
Mobile Phone	(Fornalczyk et al., 2013),(Wordpress, 2015d), (Zhang et al., 2017),(Baxter et al., 2016)
Tablet	(Arduin, 2019),(Babbitt et al., 2020)
Smartwatch	(Ma et al., 2017)
Camera	(Oguchi et al., 2011)
VideoCamera	(Oguchi et al., 2011)
Chest Freezer	(Wordpress, 2014),(Wordpress, 2014),(Baxter et al., 2016),(Oguchi et al., 2011)
Cabinet Freezer	(Wordpress, 2014),(Wordpress, 2014),(Baxter et al., 2016),(Oguchi et al., 2011)
Refrigerator/Freezer Combo	(Wordpress, 2014),(Wordpress, 2014),(Baxter et al., 2016),(Oguchi et al., 2011)
Refrigerator	(Wordpress, 2014),(Wordpress, 2014),(Baxter et al., 2016),(Oguchi et al., 2011)
Washing machine	(Francesca et al., 2019)
Dryer	(Francesca et al., 2019)
Dishwasher	(Francesca et al., 2019)
Standalone oven	(Francesca et al., 2019)
Build in oven	(Francesca et al., 2019)
Table stove	(Francesca et al., 2019)
Kitchen ventilation	(Wordpress, 2015a)
Minikitchen	(Wordpress, 2015c),(Truttmann & Rechberger, 2006)
Microwave	(Wordpress, 2015c),(Truttmann & Rechberger, 2006)
Personal care	(Li et al., 2010),(Ashby, 2009)
Electric shaver	(Li et al., 2010),(Ashby, 2009)
Hair removal (Female)	(Li et al., 2010),(Ashby, 2009)
Kitchen equipment	(Ashby, 2009)
Other household items	(Bobba et al., 2016)
TV	(Fornalczyk et al., 2013),(Zhang et al., 2017), (Baxter et al., 2016),(Truttmann & Rechberger, 2006)
DVD Player	(Fornalczyk et al., 2013),(Truttmann & Rechberger, 2006)
Blu-ray Player	(Fornalczyk et al., 2013),(Truttmann & Rechberger, 2006)
Sound and picture system	(Fornalczyk et al., 2013),(Zhang et al., 2017),(Baxter et al., 2016), (Truttmann & Rechberger, 2006),(Lixandru et al., 2017)
Radio with loudspeaker	(Oguchi et al., 2011)
Receiver/Amplifier/Tuner	(Oguchi et al., 2011)
Loudspeaker	(Lixandru et al., 2017)
Wired Loudspeaker	(Lixandru et al., 2017)
CD Player	(Oguchi et al., 2011)
LP Player	(Oguchi et al., 2011)
Travle Radio	(Oguchi et al., 2011)
CD Player	(Oguchi et al., 2011)
MP3 Player	-
Head Phones	(Lixandru et al., 2017)
Ear Plugs	(Lixandru et al., 2017)
Car Radio	(Oguchi et al., 2011)
Car Amplifier	(Oguchi et al., 2011)
Car Loudspeaker	(Lixandru et al., 2017)
Computer (Desktop)	(Fornalczyk et al., 2013),(Wordpress, 2015b),(Sodhi & Reimer, 2001), (Zhang et al., 2017),(Oguchi et al., 2011)
Computer (Laptop)	(Francesca et al., 2019)

Table 16: Source for metals values, Pb-Bi for EE Product: Mobile Phone - Other Household items

	Sources for the metals in the EE products																				
Product	Pb	Sn	Zn	Cd	Ba	Ga	Ta	Se	As	Cr	Co	Mn	Be	Mo	Sb	V	Si	Zr	Sr	Mg	Bi
Mobile Phone	(Oguchi et al., 2011),(Priya & Hait, 2018)																				
Tablet	(Oguchi et al., 2011),(Priya & Hait, 2018)																				
Smartwatch	(Oguchi et al., 2011),(Priya & Hait, 2018)																				
Camera	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
VideoCamera	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Chest Freezer	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Cabinet Freezer	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Refrigerator/Freezer Combo	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Refrigerator	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Washing machine	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Dryer	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Dishwasher	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Standalone oven	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Build in oven	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Table stove	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Kitchen ventilation	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Minikitchen	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Microwave	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Personal care	(Priya & Hait, 2018)																				
Electric shaver	(Priya & Hait, 2018)																				
air removal (Female)	(Priya & Hait, 2018)																				
Kitchen equipment	(Priya & Hait, 2018)																				
Other household items	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				

Table 17: Source for metals values, Pb-Bi for EE Product: TV - Computer (Laptop)

	Sources for the metals in the EE products																				
Product	Pb	Sn	Zn	Cd	Ba	Ga	Ta	Se	As	Cr	Co	Mn	Be	Mo	Sb	V	Si	Zr	Sr	Mg	Bi
TV	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
DVD Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Blu-ray Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Sound and picture system	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018),(Lixandru et al., 2017)																				
Radio with loudspeaker	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Receiver/Amplifier/Tuner	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Loudspeaker	(Lixandru et al., 2017)																				
Wired Loudspeaker	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
CD Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																				
LP Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																				
Travle Radio	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
CD Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																				
MP3 Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																				
Head Phones	(Lixandru et al., 2017)																				
Ear Plugs	(Lixandru et al., 2017)																				
Car Radio	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Car Amplifier	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Car Loudspeaker	(Lixandru et al., 2017)																				
Computer (Desktop)	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				
Computer (Laptop)	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																				

Table 18: Source for metals values, Ti-Y for EE Product: Mobile Phone - Other Household items.

<table>
<tr><th></th><th colspan="22">Sources for the metals in the EE products</th></tr>
<tr><th>Product</th><th>Ti</th><th>Ca</th><th>Tl</th><th>Nb</th><th>B</th><th>Ag</th><th>Au</th><th>Pd</th><th>Ce</th><th>Dy</th><th>Er</th><th>Eu</th><th>Gd</th><th>Ho</th><th>La</th><th>Nd</th><th>Pr</th><th>Sc</th><th>Sm</th><th>Tm</th><th>Yb</th><th>Y</th></tr>
<tr><td>Mobile Phone</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Tablet</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Smartwatch</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Camera</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013)</td></tr>
<tr><td>VideoCamera</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013)</td></tr>
<tr><td>Chest Freezer</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Cabinet Freezer</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Refrigerator/Freezer Combo</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Refrigerator</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Washing machine</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Dryer</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Dishwasher</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Standalone oven</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Build in oven</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Table stove</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Kitchen ventilation</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Minikitchen</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Microwave</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
<tr><td>Personal care</td><td colspan="22">(Priya & Hait, 2018)</td></tr>
<tr><td>Electric shaver</td><td colspan="22">(Priya & Hait, 2018)</td></tr>
<tr><td>Hair removal (Female)</td><td colspan="22">(Priya & Hait, 2018)</td></tr>
<tr><td>Kitchen equipment</td><td colspan="22">(Priya & Hait, 2018)</td></tr>
<tr><td>Other household items</td><td colspan="22">(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)</td></tr>
</table>

Table 19: Source for metals values, Ti-Y for EE Product: TV - Computer (Laptop).

	Sources for the metals in the EE products																					
Product	Ti	Ca	Tl	Nb	B	Ag	Au	Pd	Ce	Dy	Er	Eu	Gd	Ho	La	Nd	Pr	Sc	Sm	Tm	Yb	Y
TV	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
DVD Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Blu-ray Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Sound and picture system	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018),(Lixandru et al., 2017)																					
Radio with loudspeaker	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Receiver/Amplifier/Tuner	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Loudspeaker	(Lixandru et al., 2017)																					
Wired Loudspeaker	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
CD Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																					
LP Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																					
Travle Radio	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
CD Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																					
MP3 Player	(Oguchi et al., 2011),(Dimitrijevic et al., 2013)																					
Head Phones	(Lixandru et al., 2017)																					
Ear Plugs	(Lixandru et al., 2017)																					
Car Radio	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Car Amplifier	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Car Loudspeaker	(Lixandru et al., 2017)																					
Computer (Desktop)	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					
Computer (Laptop)	(Oguchi et al., 2011),(Dimitrijevic et al., 2013),(Priya & Hait, 2018)																					

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