PROSPECTING THE URBAN MINES OF AMSTERDAM

Interdisciplinary Project Groups

Industrial Ecology

Date: June 15th, 2016

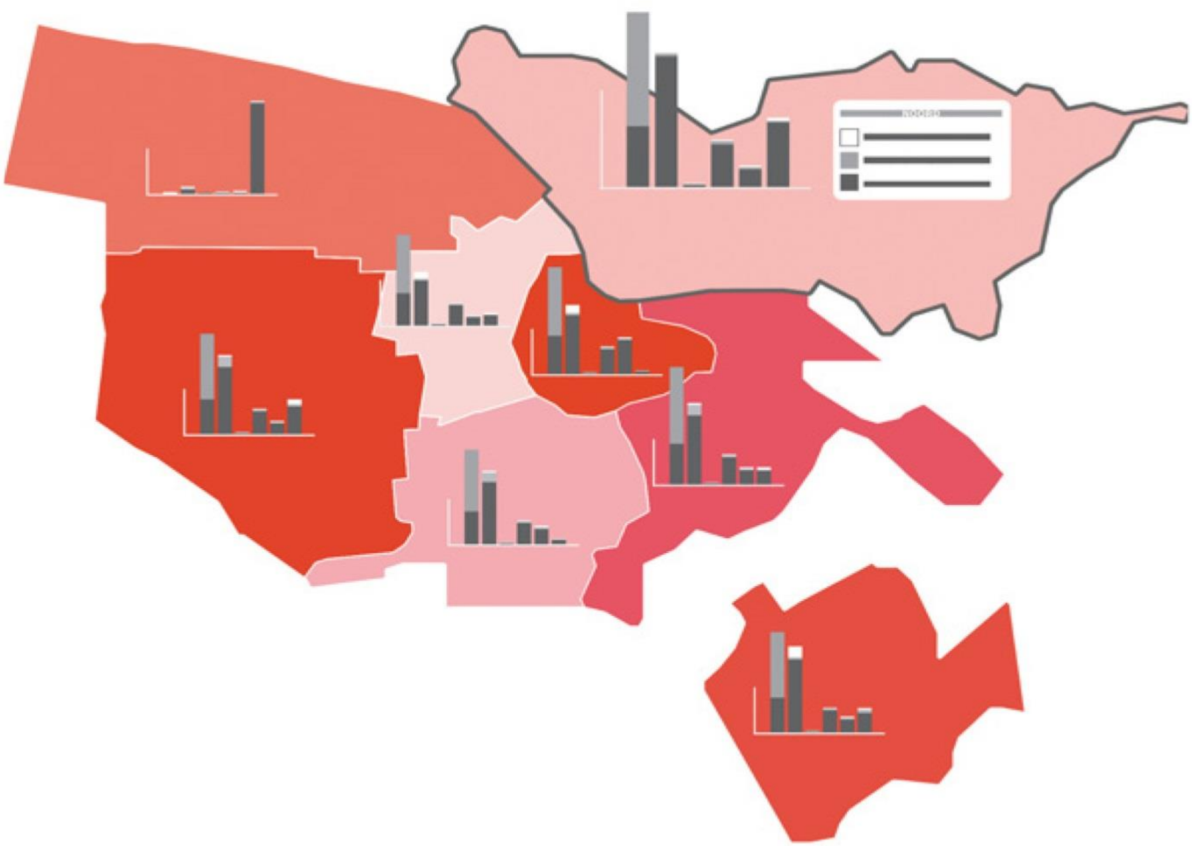

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Table of Contents

Executive summary

Amsterdam has put the circular economy on their agenda, called their 'Agenda Duurzaamheid'. A circular economy is a way to lead a city, country or entire continent towards a more resource efficient, competitive and low carbon economy. The circular economy creates local jobs, new business opportunities and allows for more social cohesion. From an environmental point of view, the circular economy will lower carbon emissions, save energy and will avert irreversible depletion of resources. The term 'circular economy' is an umbrella term for multiple concepts, one of which is urban mining. This is a new approach towards recycling, where anthropogenic materials from the urban environment are systematically reused. Just like it is done for any type of mine, before starting any activity considering physical material extraction, the mine has to be prospected first. However, such stock estimations and assessments for the urban mine in Amsterdam have not been researched and documented yet. 'Prospecting the Urban Mines of Amsterdam' (PUMA) is a project fulfilling this purpose. The project is conducted by a research partnership between Amsterdam Institute for Advances Metropolitan Solutions (AMS), Delft University of Technology, Leiden University, Waag Society and Metabolic. The main focus is looking specifically at the possibilities of Amsterdam on urban mining. As a complementary study, this research performed by an interdisciplinary project group consisting of Industrial Ecology master students focuses on urban mining for in-use products in the urban environment of Amsterdam not related to buildings. With copper, aluminum and iron & steel being the highest contributors to metals used in the urban environment, the PUMA project focuses on these three metals only (van der Voet & Huele , 2016).

Other studies assessing stocks in several areas find very different metal amounts per capita for various reasons. Firstly, the studies are conducted for very different areas. Scopes range from a city to an area and even globally. Also, the use of metals in a society is correlated with development of the society (Zhang et al. 2014). Additionally, there is no standard method to estimate stocks yet, different methods and scopes give different results. Therefore, a study specifically for Amsterdam is necessary. The aim of this study is to quantify the stock these metals, create a 'geological' map of their availability (where and in what form these metals van be found) and assess the pattern of stock becoming available. The study only focuses on non-building sources of metals and is complementary to a similar study focused only on buildings as the main source. With this information, it is possible to estimate the economic and environmental advantages of the circular economy of metals for Amsterdam. The report can then aid Amsterdam to structure the pathway towards a future circular economy of metals.

The main question of this study is:

What is the quantity, quality, accessibility and economic value of the urban mine of Amsterdam for iron, copper and aluminum not related to buildings?

The following sub questions are investigated to answer the main question:

- What is the quantity of copper, aluminum and iron & steel from in-use sources in the urban environment in Amsterdam, buildings not included?

- What is the quality of the copper, aluminum and iron & steel in the urban environment in Amsterdam? In other words, what are the sources (i.e. products and non-building constructions) of the metals?
- What is the accessibility of the found copper, aluminum and iron & steel? In other words, when do the sources of the metals become available to exploit according to the life expectancy of the sources?
- What is the economic value of the urban mine and which sources have the highest economic potential?

The geographical boundaries of Amsterdam have been used as the physical boundaries for this study. Buildings are not taken into account because this is part of another study. Private infrastructure or service connections are not taken into account, and neither are products that are not movable, like fences, kitchen blocs, HVAC and solar panels. Products that are movable, like ovens, lighting and electronics, are taken into account in the household and commercial appliances categories of this study.

Methods

The area of focus is the city of Amsterdam and its 8 districts: Amsterdam Centrum, West, Zuid, Oost, Noord, Zuidoost, Nieuw West and Westpoort (Gemeente Amsterdam, 2016). Buildings were not taken into account because this is part of another study. Private infrastructure or service connections have not been taken into account, and neither are products that are not movable, like fences, kitchen blocs, HVAC and solar panels. Products that are movable, like ovens, lighting and electronics, have been taken into account in the household and commercial appliances categories of this study.

In this study, a bottom-up approach was used. This method is commonly used to estimate stocks and provide clear spatial boundaries to a certain stock (region, city or country). Here, this method was used to make the results spatially explicit and detailed. The aim of this study is also to provide a very transparent way of achieving stock estimations, which is not the case in much of the scientific literature.
As a bottom-up study is very location specific, ideally data would be collected by hand for the area in question. However, for this study, direct and indirect data was used to make estimations for the city of Amsterdam. Results will therefore be rough but in the right magnitude and should give a correct idea of the scale of metal stocks in the city, non-related to buildings.

In words, the method will follow these concise steps:

- Estimating the amount of a certain product in Amsterdam (those containing metals), and in what region/location;
- Researching the average weight of that product;
- Assessing the metal content of that product, in the form of a percentage;
- Multiplying the three steps above provides the total stock of the metal calculated for in that specific product in all of Amsterdam.

In order to estimate iron, copper and aluminum stocks in all non-building related products in Amsterdam, an inventory of all possible products was made, then separated into the following categories:

Transportation is defined as carriers of people and goods, that provide mobility. The main products in this category are trams, cars, buses, bicycles and scooters.

Infrastructure is defined as all services that facilitate transportation. This includes bridges, tunnels, streetlights, underground pipes and cables (sewage and water), tram rails.

Industrial appliances including industrial machinery and tools for agriculture, construction and warehousing.

Commercial good includes products for commercial use, such as restaurant equipment and hotel beds.

Household electronics and appliances includes all equipment for personal use, that might be found in households. This includes for example, refrigerators, washing machines, desktop computers, and several more.

Public goods is defined as serving the public and all other products that cannot be grouped with products in the above categories. Public goods include for example, children's playgrounds, public bins, ATM machines and urinals.

This project serves as one of the first efforts that maps metals in products to geographical locations. However the initial stock estimations could contain results with questionable accuracy and wrongly made assumptions, hence part of the project aim is to make the dataset as transparent and open as possible. In order to allow experts to help improving the data, the results of this study are made available online through a developed web application, which can be found on the website provided with this study.

Results

The results in general show a high contribution in metals of objects that are present in large numbers. Districts are reflected similarly. In monetary values, the relatively high price of copper leads to a change of distribution, even though the total mass of copper is relatively low compared to that of aluminum and iron. In addition, aluminum also shows an increase of weight in monetary values in all categories with the exception of Infrastructure.

Results of the stock estimations indicate that there are certain categories and certain products that contribute highly to total iron, copper and aluminum stock in Amsterdam. Firstly, industrial equipment and the transport categories contribute the most to total iron and steel stocks in Amsterdam. The transport category is also the biggest contributor to total aluminum stocks, and infrastructure is the biggest contributor to total copper stocks in Amsterdam.

Diving deeper into the products that contribute most to these three metal stocks non-building elements in Amsterdam, results from the estimations show that tanks, personal cars and industrial machinery contain most of the iron and steel; cars, bikes and trams contain most of the aluminum; and distribution cables for electricity, drinking water pipes and cars contain most of the copper in Amsterdam.

Iron stocks in all non-building parts for Amsterdam estimated in this study are lower on a per capita basis when compared to those calculated for Connecticut. Aluminum stocks in Amsterdam are also lower than those calculated for Connecticut, but higher than those calculated for China for example. The results also suggest Amsterdam has higher copper stocks (always non-building) than Cape Town (SA), Nanjing and Shanghai (China) and Connecticut (USA), but slightly lower than Australia. These differences can be explained by difference in development or density of population in the area and scope of the study.

From the Sankey diagram for lifetimes connected to stocks one can find that for both iron/steel and aluminum the biggest contributor of metals are in sources that have an average lifespan of 10-19 years. For copper, the distribution of metals over the lifespan is more evenly distributed, with a the categories 10-19 years, 20-50 years and 50-100 years contributing almost equally to the entire amount. The distributions of sources with an average lifespan could be used for urban mining policies or plans to be implemented. For instance, the municipality could anticipate the majority of the iron/steel of today to be flown out of use within the next 20 years.

Adding up the prices of each product for their copper, aluminum and iron contents, their worth in terms of metal prices can be estimated. It is important to keep in mind that this would be the scrap value of the metals contained in these products in their total numbers as estimated in Amsterdam. For example, if all the in-use electricity distribution cables were collected, their worth would be of about 96 million euros for their copper, aluminum and iron content.

Conclusions and recommendations

The amount of iron estimated in all non-building in-use products currently is roughly of 1 million tonnes. For copper and aluminum, amounts of about 56 thousand tonnes and 80 thousand tonnes, respectively, were estimated. The quantification of secondary resources as done in this research, can provide a foundation for decision-making within industrial, commercial and political fields. A system like the proposed open-source database is recommended to use when doing stock analysis as a step towards the realization of urban mining. According to this research, parts that are essential for this open-source database are the stocks and lifetime of the products containing metals.

Another recommendation is for investors and the municipality to develop solid business plans for urban mining in the city of Amsterdam. A lack of precise knowledge of stocks can create a barrier for them to join in actually developing systems, but this research has shown that there are expected to be large stocks with large economic value. By creating business plans and starting with small initiatives retrieving 'low hanging fruit' and priority stocks found in this report, we can learn how the urban mine can be a more significant resource in the future.

This research is a first inventory of non-building stocks in Amsterdam based on direct data, but also rough estimations and indirect calculations. It is recommended for future studies to invest in exploring mainly the largest categories as infrastructure, transport and industrial machinery in order to gain more knowledge about the real sizes of those stocks.

The focus of in-depth research for Amsterdam is recommended to be on the amounts of metal becoming available. The lifetimes of products collected in this research, can provide a basis to map the outflow of metals in Amsterdam when numbers of products bought in past years and data on the year of installation of, for instance, infrastructure are added. This would result in a very valuable map for finding opportunities in periods and product categories to connect supply and demand. This expansion study would be even more valuable if the waste streams in which the metals can be found are assessed.

Additionally, further study on the comparison of metals per capita per category of Amsterdam in respect to other studies would be interesting. Studies find different values probably due to scope, development of the area and population density. In-depth study comparing the specific product categories within studies and looking further into city density, level of wealth and technical compositions of products would give more insight into regional and academic differences.

Aluminium cans, Flickr.com, 2016

1 Introduction

1.1 Context

Amsterdam has put the circular economy on their agenda, called 'Agenda Duurzaamheid'. A circular economy implies that waste is minimized and the value of the materials is maintained in the economy, leading Amsterdam to a resource efficient, competitive and low carbon economy that will not be affected by issues such as scarcity of resources and volatile market prices for materials. (COM 614/2, 2015). On a local level, a circular economy will create local jobs, new business opportunities and allow for more social cohesion. In its agenda, the municipality states that their drive towards a circular economy is mainly strategic, as resources become more scarce and costly. Hereby the municipality is preparing itself for a future with less resource availability, and thereby making their economy more robust.

Economics are a key driver in this process and need to be well communicated towards national and regional authorities. Once the economic benefits have been researched and shown to these authorities, it is up to them to enable the transition; taking away any obstacles, favoring the extraction of secondary materials over primary materials, and levelling the market to a fair playing field. From that point on, it is up to the economic actors (consumers and businesses) to drive the circular economy to its full potential. Fabrication, one of the 'Amsterdam Circulair-Visie en Routekaart' contributors, stated on their website that on a national scale, a circular economy could create economic opportunities worth 7 billion euros annually and will create about 50.000 jobs, along with cutting emissions worth 17 megaton of CO_2 and major water consumption (Fabrication, 2016).

For Amsterdam to implement circular economy in their policies and concrete plans, Amsterdam has assigned a research institute to carry out research on the opportunities and possibilities. The term 'circular economy' is an umbrella term for multiple concepts, one of which is urban mining. This is a new approach towards recycling, where anthropogenic materials from the urban environment are systematically reused. One can interpret the urban environment as a conventional mine, as there are large stocks of materials embedded in buildings and products. These products and buildings are a potential source of material, since most, if not all, sources will become available to mine once they reach their product lifetime (Brunner, 2011). Just like it is done for any type of mine, before starting any activity considering physical material extraction, the mine has to be prospected first. For natural mines this means that the metal ore deposits have to be located and assessed on their physical extractability. Once the mine has been properly explored and documented, plans and investments can be made towards extracting the materials from the source. For urban mines, prospecting the mines means to assess what products and buildings contain materials in what quantity, and how accessible these materials are on the basis of the lifespan of the sources. On the basis of the results from prospecting, also termed as stock analysis, policies can be introduced and concrete plans can be changed in favour of the realization of urban mining. An accuracy of stock estimation of +/- 25% could already be satisfactory/acceptable to base policy on (Graedel et al., 2010).

However, such stock estimations and assessments for the urban mine in Amsterdam have not been researched and documented yet. 'Prospecting the Urban Mines of Amsterdam' (PUMA) is a project fulfilling this purpose. The project is conducted by a research partnership between

Amsterdam Institute for Advances Metropolitan Solutions (AMS), Delft University of Technology, Leiden University, Waag Society and Metabolic. The main focus is looking specifically at the possibilities of Amsterdam on urban mining. As a complementary study, this research performed by an interdisciplinary project group consisting of Industrial Ecology master students focuses on urban mining for in-use products in the urban environment of Amsterdam not related to buildings. Metals are very suitable for closing the loops in the circular economy due to their high use throughout the urban environment and high recyclability, and therefore metals are present the best opportunities as a starting point to introduce the concept of urban mining. With copper, aluminum and iron & steel being the highest contributors to metals used in the urban environment, the PUMA project focuses on these three metals only (van der Voet & Huele, 2016).

The aim of this study is to quantify the stock these metals, create a 'geological' map of their availability (where and in what form the metals can be found) assess the pattern of stock becoming available. The study only focuses on non-building sources of metals and is complementary to a similar study focused only on buildings as the main source. With this information, it is possible to estimate the economic and environmental advantages of the circular economy of metals for Amsterdam. The report can aid Amsterdam to structure the pathway towards a future circular economy of metals.

1.2 Previous studies on this subject

The size of stocks and outflows of metals have already been estimated in multiple studies for different areas, with among others the aim of assessing the feasibility and desirability of urban mining, understanding the material requirements of countries as they develop, understanding recycling and assessing the environmental impact. These studies are conducted for Cape-town, Shanghai, Nanjing, Australia, State of Connecticut, New Haven, China, Stockholm and globally. No study was found on the metal stock in a European city, as the Stockholm study focuses on the emissions connected to copper in- and outflows. Appendix A contains a detailed overview of the characteristics of the studies. (Beers and Graedel 2003, Zhang et al. 2014, Zhang et al. 2011, Beers and Graedel 2006, Rauch et al. 2007, Wang et al. 2007, Rostkowski et al. 2007, Recalde et al. 2008, Wang and Graedel 2010, Bergback et al. 2000, Eckelman et al. 2007)

The studies assessing stocks find very different metal amounts per capita, which has various reasons. Firstly, the studies are conducted for very different areas. Scopes range from a city to an area and even globally. Also, the use of metals in a society is correlated with development of the society (Zhang et al. 2014). Additionally, there is no standard method to estimate stocks yet, different methods and scopes give different results. Therefore, a study specifically for Amsterdam is necessary.

1.3 Problem statement

In this study, the stocks of iron, copper and aluminum are estimated for the city of Amsterdam. From this stock estimation, the quality and accessibility assessment has to be made in order to indicate the anticipation on metals retrieved with a maximized output. This output of secondary raw materials can be translated into economic value for the resource in order to incentivize businesses or governing bodies by pointing out the economic significance. The results contribute to enabling the city of Amsterdam to anticipate the magnitude of recoverable metals. As mentioned, currently there is not one benchmarked or standardized method to conduct this stock estimation and/or assessment.

Therefore research to find the optimal method to prospect Amsterdam's urban mine, including methodologies for the collection, evaluation and managing of data, is also needed.

1.4 Goal

The main question of this study is :

What is the quantity, quality, accessibility and economic value of the urban mine of Amsterdam for iron, copper and aluminum not related to buildings?

The following sub questions are investigated to answer the main question:

- What is the quantity of copper, aluminum and iron & steel from in-use sources in the urban environment in Amsterdam? To put it differently; how much of these metals are found in Amsterdam from the products and non-building constructions all around us?
- What is the quality of the copper, aluminum and iron & steel in the urban environment in Amsterdam? In other words, what are the sources (i.e. products and non-building constructions) of the metals?
- What is the accessibility of the found copper, aluminum and iron & steel? In other words, when do the sources of the metals become available to exploit according to the life expectancy of the sources?
- What is the economic value of the urban mine and which source have the highest economic potential?

Iron scrap, Webuyscrap.com, 2016

2 Methods

2.1 Area of study

The area of focus is the city of Amsterdam and its 8 districts (see Figure 2.1): Amsterdam Centrum, West, Zuid, Oost, Noord, Zuidoost, Nieuw West and Westpoort (Gemeente Amsterdam, 2016). It is interesting to look into the different districts of Amsterdam, because it was expected they will contain different ratios and amounts of copper, iron and aluminum.

The *Centrum* contains the old city and is the historic center of Amsterdam. There are mostly offices, residential areas, and cultural areas. It is also a very dense area in terms of population. The *West* district is however considered the most densely populated and is mostly residential, with lower income residents. The *Zuid* district is also mostly residential but with the highest income per household out of all Amsterdam districts. Amsterdam *Oost* shares borders with the Amstel river and the IJ lake and therefore would be expected to contain higher amounts of coastal infrastructure and transport, along with many residential areas. The *Noord* district is connected through several tunnels and ferries, and is not served by trams for example (a metro line is planned for 2018). This district is still considered as developing, and its postindustrial areas as slowly changing to residential. It is less densely populated than other Amsterdam districts and agricultural businesses take up a large area of the district. The neighborhoods in *Nieuw-West* are newer residential areas built after an urban expansion project. The *Zuid-Oost* district contains residential areas as well as a business park and the Amsterdam Arena. It is connected to the city center by metro lines. *Westpoort* is the districts of the Port of Amsterdam, the fourth biggest port in Europe (Port of Amsterdam, 2016). The district has a very low population and is mainly considered an industrial park.

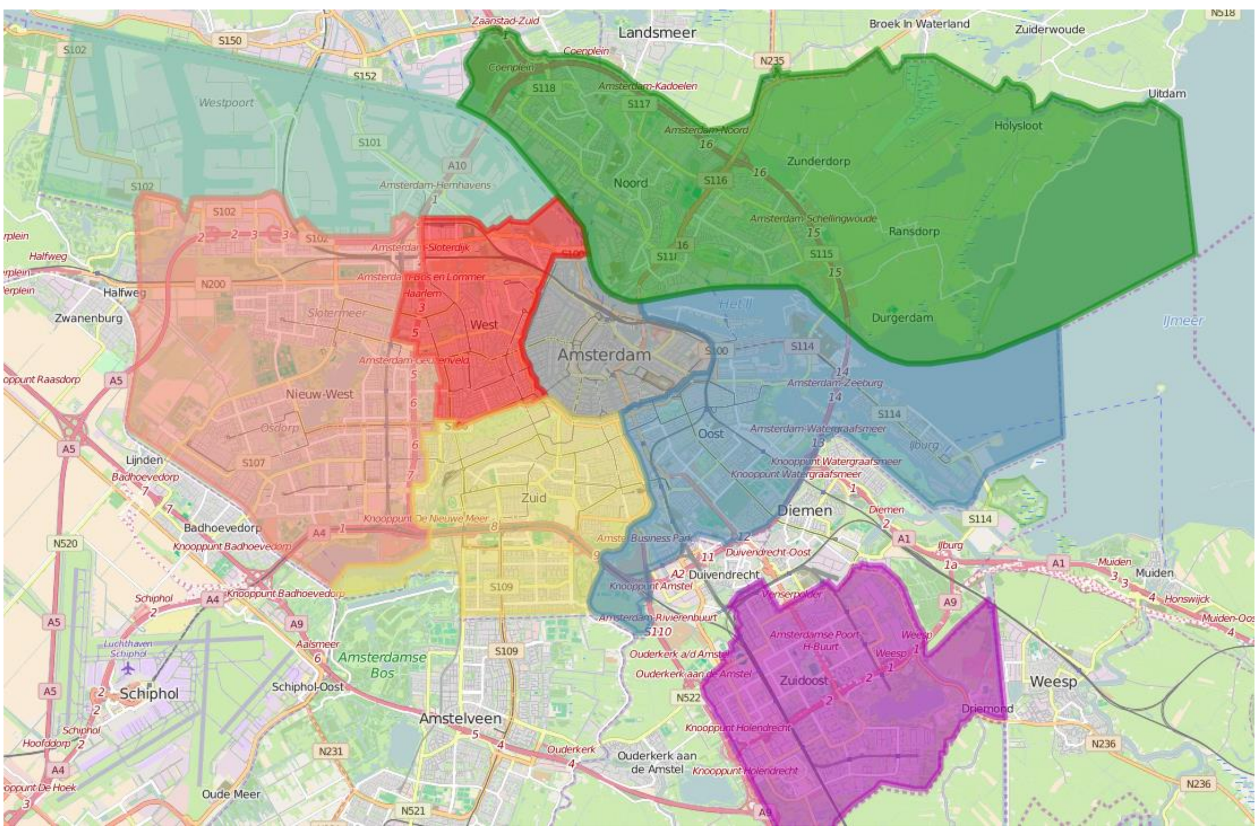


Figure 1.1: map of Amsterdam showing the districts that are taken into account in this study.

Buildings are not taken into account, because this is part of another study. Figure 2.2 shows the public-private boundary which is used to distinguish infrastructure in and outside the scope of this research. Private infrastructure or service connections are not taken into account and neither are products that are not movable, like fences, kitchen blocks, HVAC and solar panels. Products that are movable, like ovens, lighting and electronics, are taken into account in the household and commercial appliances categories of this study.

Figure 2.2: building/non-building boundary.

2.2 Methods used in previous studies

Other in-use stock studies available in the scientific literature (Appendix I) use the same approach that will be used here: a bottom-up approach, which is explained below. The other possible method to estimate in-use stocks is a top-down approach, where the difference between the inputs of a metal (imports and domestic extraction) and its outputs (exported and recovered from recycling) represents the stock, usually done on the scale of a country. This approach is used to determine stocks in their elemental form and is much more difficult to use to estimate stocks in specific products.

The bottom-up method is straightforward and explained in detail below. However, the approach used to estimate the amounts of a certain product and their metal contents vary between studies. Differences exist in data sources and estimations made. There is no one approach to estimate the amounts of a certain product and this needs to be reported in a transparent way.

2.3 Stock estimations

2.3.1 Bottom up methodology

In this study, a bottom-up approach was used. This method is commonly used to estimate stocks and provide clear spatial boundaries to a certain stock (region, city or country). Here, this method was used to make the results spatially explicit and detailed. The aim of this study is also to provide a very transparent way of achieving stock estimations, which is not the case in much of the scientific literature.

As a bottom-up study is very location specific, ideally data would be collected by hand for the area in question. However, for this study, direct and indirect data was used to make estimations for the city of Amsterdam. Results will therefore be rough but in the right magnitude and should give a correct idea of the scale of metal stocks in the city, non-related to building (consult chapter *3.3.3 Data collection* for more details).

The approach of this research follows the bottom-up specifications of a study by UNEP (Graedel et al., 2010), where the following equation is given to translate this method:

$$S_t = \sum_{i}^{A} N_{it} m_{it}$$

Equation 1: Formula for the bottom-up method.

Where S_t = current stock; A= number of different types of goods; N= number of certain good; m = metal content; it = in-use at time t.

In words, the method will follow these concise steps:

- Estimating the amount of a certain product in Amsterdam (those containing metals) and in what district/location;
- Researching the average weight of that product;
- Assessing the metal content of that product, in the form of a percentage;
- Multiplying the three steps above provides the total stock of the metal calculated for in that specific product in all of Amsterdam.

The exact metal contents of certain products are often difficult to assess. This data is not readily available, and even manufacturers often do not know because of complex supply chains. The metal content and weight of the same product type will also vary enormously among brands and year of production.

The monetary value of total stocks associated with the different product categories was estimated using scrap metal prices from aluminum, copper and iron to get an idea of the overall value of total stocks. The scrap prices used can be found in Table 2.1.

Metal	Price per ton of scrap (in €)
Iron	€ 160
Aluminum	€ 650
Copper	€ 3875

Table 2.1: Scrap prices of Fe, Al and Cu at 01/05/2016 (kh-metals.nl, 2016)

2.3.2 Product categories

In order to estimate iron, copper and aluminum stocks in all non-building related products in Amsterdam, an inventory of all possible products was made, then separated into the following categories:

Transportation is defined as carriers of people and goods, that provide mobility. The main products in this category are trams, cars, buses, bicycles and scooters.

Infrastructure is defined as all services that facilitate transportation. This includes bridges, tunnels, streetlights, underground pipes and cables (sewage and water), tram rails.

Industrial appliances including industrial machinery and tools for agriculture, construction and warehousing.

Commercial good includes products for commercial use, such as restaurant equipment and hotel beds.

Household electronics and appliances includes all equipment for personal use, that might be found in households. This includes for example, refrigerators, washing machines, desktop computers, and several more.

Public goods is defined as serving the public and all other products that cannot be grouped with products in the above categories. Public goods include for example, children's playgrounds, public bins, ATM machines and urinals.

2.3.3 Data collection

Data on all these products in Amsterdam were collected through several sources. Firstly, when possible, information was derived from municipal and national statistics in order to get the actual amount of a certain product in the city of Amsterdam or experts on the subject were contacted. If national statistics were relevant, they were scaled down to the population of Amsterdam. Estimations were made using indirect data including urban maps, information from the scientific literature, proxies, or on the basis of common sense. Other indirect methods include looking into manufacturing specifications and standards, coupling power requirements of appliances to copper content (Rauch et al., 2007), or using averages of appliances per employee or per household. Secondly, data from the scientific literature was used to find the metal contents of each product. This information came mostly from Life Cycle Assessment literature and from private companies' product manufacturing specifications.

For each case, search for direct data was the first step and indirect data was used as the last resort. The method for each individual product taken into account in this study is specified below in the results section and the appendix.

2.3.4 Hibernating stocks

Hibernating stock include all the products at their end-of-life, that are no longer in use, but are remaining in the city. They have not been disposed of and have not been fed back into the system. These includes for example the old cellphones and old laptops that do not work anymore or are obsolete but remain in your drawer, but also include for example the old underground pipes that have never been dug out even though they have not been used in decades.

These types of stocks are extremely difficult to estimate quantitatively, and have therefore been left out of this study. However, it should be kept in mind that these stocks could be significant.

2.4 Limitations to stock accessibility

2.4.1 Temporal limitations

The products currently in use all have different lifetimes and will therefore be disposed of at different times in the years to come. This means the metal stocks that will be calculated are not all available to mine at this moment in time, but does indicate the current composition of the mine. The lifetime of these products need to be taken into account to calculate a rate of outflow of metals in the coming years, and efforts will have to go into managing this outflow properly in order for these products to take the recycling path.

Lifetimes of products can be found in the literature and in manufacturing specifications but these do not reflect the reality. Certain products are disposed of way before their supposed end of life, for causes that include obsolescence, disposal instead of repair, and many other causes. On the other hand, certain products will come to their end of life much later than their supposed life time. These are therefore limitations to calculating an exact rate of outflow of metal stocks in Amsterdam.

2.4.2 Technical limitations

There are several technical limitation to accessing these metal stocks in products. These include accessing the products themselves (costs of removing old pipes and [14] cables, electronics collection system,etc.),

but also includes technical limitation in recovering the metals when recycling (cost of dismantling, separation technologies, blending alloy problems, etc.). Some products will also be traded out of the system, in second hand markets for example. All these factors will have to be taken into account when estimating a realistic amount of metal that can be recovered from urban mining.

2.4.3 Socio-economic and policy barriers

Trying to estimate the feasibility and economic benefits of urban mining is very hypothetical, as a city like Amsterdam in a society like this one is very dynamic in many ways that might affect the outcomes of urban mining effort. Major socio-technical changes should not be overseen, these could include higher recycling rates due to better recycling technologies, or an increase in the outflow due to new technologies making other products obsolete overnight, for example. There will also be limitations to urban mining when it comes to governance issues. Possible issues could include product ownership, private or public recycling facilities, regulations on end-of-life products and their disposal, ownership and governance of the whole urban mining scheme. These are points that should be taken seriously as they could pose barriers to urban mining.

Copper scap, Metalrecyclingcentre.nl, 2016

3 Results

3.1 Stock estimations

The results in general show a high contribution in metals of objects that are present in large numbers. Districts are reflected similarly. In monetary values, high prices of copper lead to a change of distribution, even though copper amounts are relatively low compared to aluminum and iron. In addition aluminum also shows an increase of weight in monetary values in all categories with the exception of Infrastructure.

3.1.1 Infrastructure

In infrastructure all items facilitating transport of people and goods are included. The list of objects is inspired on Zhang et al. 2011, Wang and Graedel 2010, Van Beers & Graedel 2003 and Rauch et al 2007. Data on amounts of these items and their average lifetimes was estimated from this literature, annual reports, online municipality data, communication with experts. Metro, train, tram and highway related district data is based on own measurements from a map. For other products the amount per district is based on inhabitants. Figure 3.1 shows the results.

Iron/steel

According to Rauch et al. water, road, bridge, rail and electricity infrastructure are major categories of iron stock on state level (Rauch et al 2007). The contents of iron and steel in these objects and others were estimated with use of producers data or existing stock estimations. For water, data on pipelines was from water supplier 'Waternet'. The amount of iron in pumps was found in Rauch et al. 2007. For roads it was assumed that the situation in Amsterdam is the same as in Connecticut and assumptions from Rauch et al. were used for this research as well. Because of time restrictions for this study, the high amount of different types of bridges in Amsterdam and their long lifetime, this category was neglected. The amount of iron in rail infrastructure was estimated by multiplying the lengths of the rails (twice) with the amount of iron per meter.

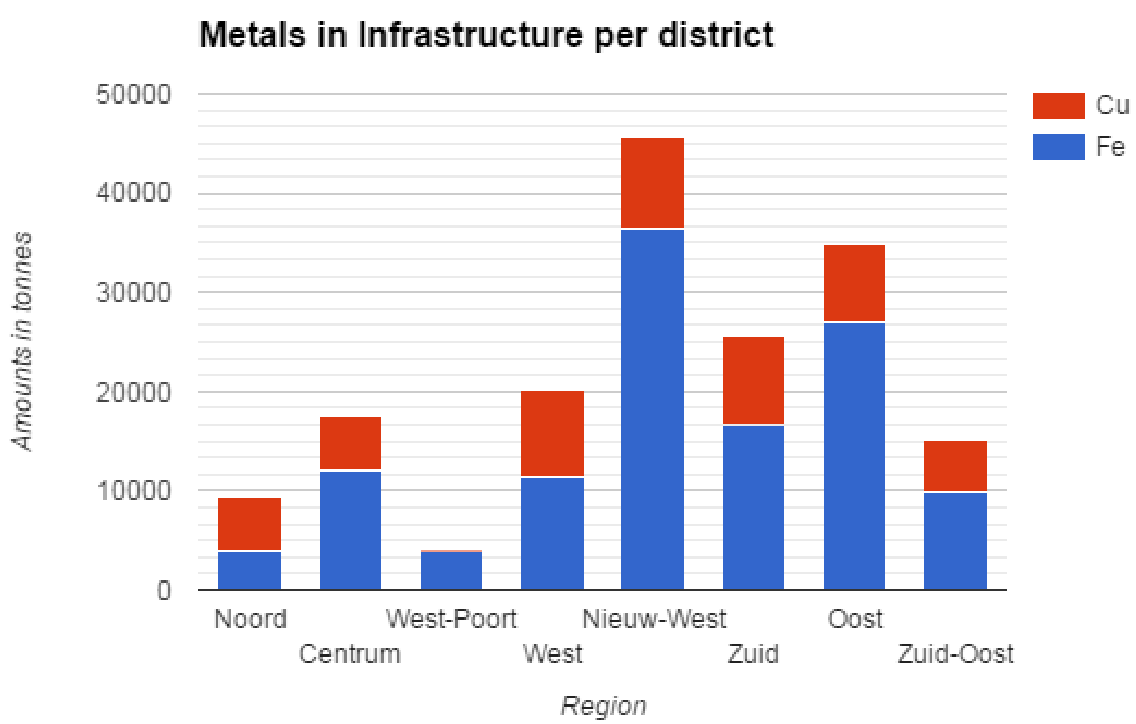


Figure 2.1: Stock estimations per district for Infrastructure.

For metro lines and tramlines the material characteristics of the most common rail types were used, as described in Tatasteel 2014 and Alom no year. Data on train rails was supplied by an expert (Koncak 2016). Due to a lack of data on the iron in poles supporting the wires for the train, the amount of poles across the railroad was assumed to be the same as in Connecticut and calculated with data from Rauch et al. 2007. Iron from support towers for overhead electricity transmission lines are neglected as overhead transmission lines do not exist within the borders of Amsterdam (Hoogspanningsnet 2016). Finally an estimation of the average amount of steel in public transport abri's was supplied by the designer of the abri's (Bubberman 2016).

Other infrastructure items included in the list containing iron/steel are manhole covers on highways, grates on local roads, natural gas distribution pipes, streetlights, street signs, overhead trusses and guard rails. Manhole covers on highways and for telecommunication are assumed the same as in Rauch et al. 2007. Considering streetlights, 30% is assumed to have a steel streetlight attached as done in Rauch et al. 2007 as well. From this article also the amount of steel in distribution pipes, big street signs, small street signs and overhead trusses were used.

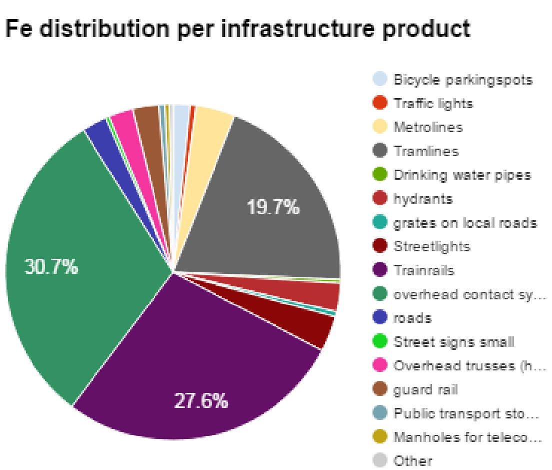


Figure 3.2: Iron distribution in the infrastructure category.

Guardrails are assumed to be used on A- and N-roads, the amount of steel in them was retrieved from Bonhof no year.
Figure 3.2 shows the distribution of iron in the infrastructure iron stock.

Aluminum

Wang and Greadel 2010 mention that for Aluminum electrical distribution and transmission provide the significant amount in infrastructure (Wang and Graedel 2010). However, it was found that transmission cables do not exist within the borders of Amsterdam (Hoogspanningsnet 2016) Additionally, in electrical distribution the aluminum is found in above ground infrastructure (Rijksdienst voor Ondernemend Nederland no year).

Since 1940 the electricity cables within the borders of Amsterdam are installed within the ground, so Aluminum is not found here either (Hoogspanningsnet 2016) Furthermore no other stocks were found.

Copper

Copper is in Zhang et al. mentioned to have the largest stocks in water and electricity supply, telecommunication, rail lines, streetscapes and traffic lights (Zhang et al. 2011). Like for the iron/steel stock, data on water pipelines was received from water supplier 'Waternet'. For the electricity transformers, copper content for transmission transformers and distribution transformers was based on averages from Rauch et al. 2007.

Copper content for underground distribution cables was calculated as in Zhang et al. 2011. Copper cables for telecommunication are assumed to be the size and amount per household as described in Zhang 2011. Considering rail lines, the amount of wires per km rail was found in a ProRail report (TNO 2014).

The amount of streetlights and traffic lights per km of road and the amount of materials in them was inspired on Zhang et al. 2011. Figure 3.3 shows the distribution of copper in the infrastructure copper stock.

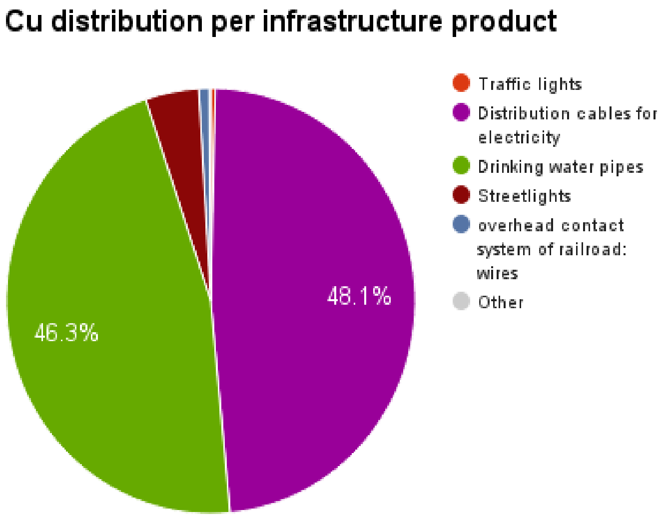


Figure 3.3: Copper distribution in the infrastructure category.

3.1.2 Transportation

In transportation the following vehicles were taken into consideration: personal cars, business cars, business vans, business trucks, motorcycles, trams, bicycles, scooters, public buses, metro's. Only vehicles that were registered in Amsterdam were quantified. Data on registered vehicle amounts are retrieved from the Amsterdam's Research, Information And Statistics dataset (Gemeente Amsterdam, 2016). Lifetime data was used from various sources such as Van Beers, D., & Graedel, T. E. (2003), Nevada Department Of Taxation (2011) and Ducker Worldwide (2015). See appendix 2b for an overview of vehicle amounts taken into consideration, assumptions, sources, average lifetimes and metal content descriptions.

As expected it was found that in general, metal stock distribution is reflected by object amounts hence the transport category is less elaborated in comparison to other categories. In transportation in total 224353.5 tonnes of iron and steel, 31929.3 tonnes of aluminum,5675.4 tonnes of copper was calculated. The results per district are shown in Figure 3.4.

The districts Nieuw-West and Zuid have the largest metal stocks. The amount of objects in these districts compared to other districts are in general larger, hence the relatively bigger contribution. In Figures 3.5, 3.6 and 3.7 a further breakdown of objects per metal type is shown.

Iron and steel

Iron stocks are dominated by personal cars with 81.5%, whereas the other products make up the remaining 18.5%, mainly in business vans and business trucks. See Figure 3.5 for the distribution of iron among the various products.

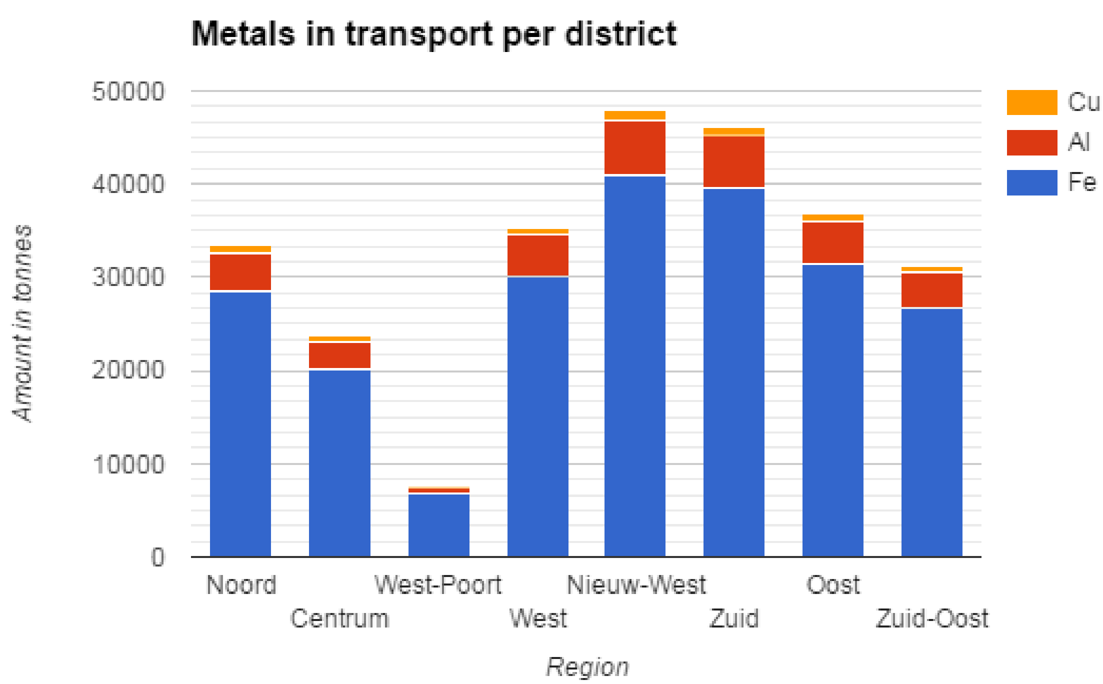


Figure 3.4: Stock estimations per district for transport.

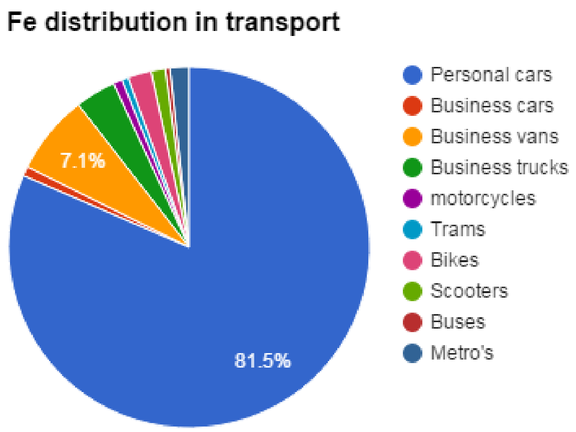


Figure 3.5: Iron distribution in the transport category.

Aluminum

The aluminum stock is different from Iron and Copper in the sense that personal cars does not dominate as extremely. Bikes (10.3%) and trams (7.9%) in aluminum have more impact on the stock estimations than for the other metal types. See figure 3.6 for the distribution of aluminum among the various products.

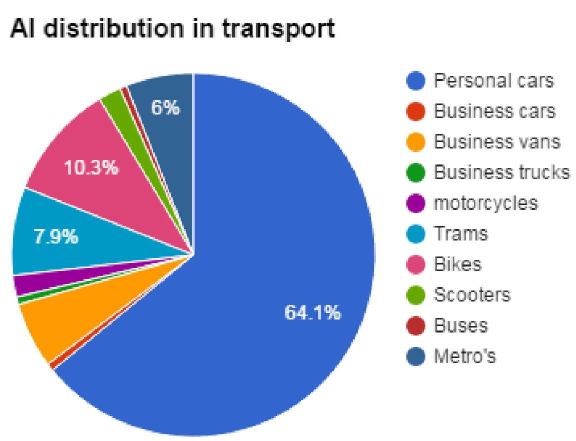


Figure 3.6: Aluminum distribution in the transport category.

Copper

Similarly to Iron stock in transport, personal cars (81.9%) have the largest contribution followed by business vans (7.2%) and trams (3.6%). Bicycles are considered to have negligible amounts of Copper, however e-bikes may serve as a potential stock for copper for the bike category. For future research e-bikes may be added to the stock estimations, yet statistical data on amount of e-bikes in Amsterdam was not readily found. See Figure 3.7 for the distribution of copper among the various products.

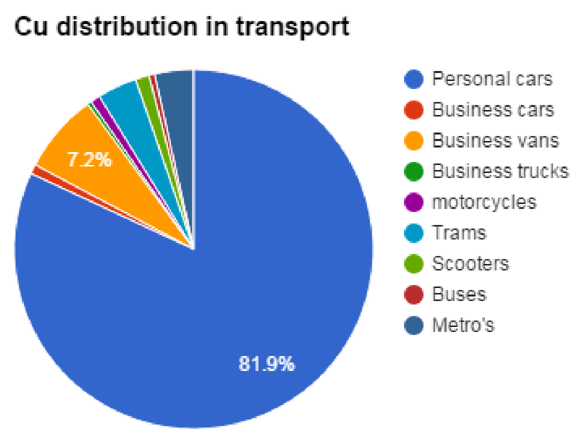


Figure 3.7: Copper distribution in the transport category.

The sheer amount of registered personal cars in Amsterdam makes the metal stocks of personal cars the largest contributor in transportation (Fe:192100, Al:27214, Cu: 5031 tonnes).

3.1.3 Household appliances and electronics

The products taken into account in this category are assumed to be the most relevant in terms of metal contents in households and are the following: printers, cell phones, laptop computers, desktop computers, televisions, dishwashers, dryers, washing machines, hoovers, electric ovens, microwave ovens, and refrigerator/freezers. The amount of each product in Amsterdam was estimated using household data (StadIndex, 2014) in Amsterdam and each of its 8 district (Centrum, Noord, West-Poort, West, Nieuw-West, Zuid, Oost and Zuid-Oost). These estimations on the number of products per household was taken mostly from household appliance energy use studies in the Netherlands (Tselekis, 2013 ; Papachristos, 2015), or world statistics websites (NationMaster, 2016). This average data for the Netherlands has then been scaled down to the size of Amsterdam, relative to population size and number of households. See appendix 2c for an overview of sources, assumptions, lifetimes and calculations made for the products in this category. Results per district of Amsterdam can be found in Figure 3.8.

Iron & steel

Certain assumptions were made for the iron or steel content of household appliances and consumer electronics. The model of cellphone used for its metal content was an iPhone 6, as considered one of the most widespread types of phones (and smartphones have taken over the market). Those which were not accounted for are the cellphones from previous generations which are still in people's homes, as they are difficult to make estimations for. The metal contents of the other household appliances were taken from recent literature and white papers (see Appendix 2c). The steel content of household electric ovens was taken from an average commercial oven (which are much bigger) and scaled down to the weight of a household oven. The total amount of steel in household appliances in Amsterdam was calculated to be approximately 79 576 tonnes of steel/iron. The distribution among the appliances can be seen in Figure 3.9.

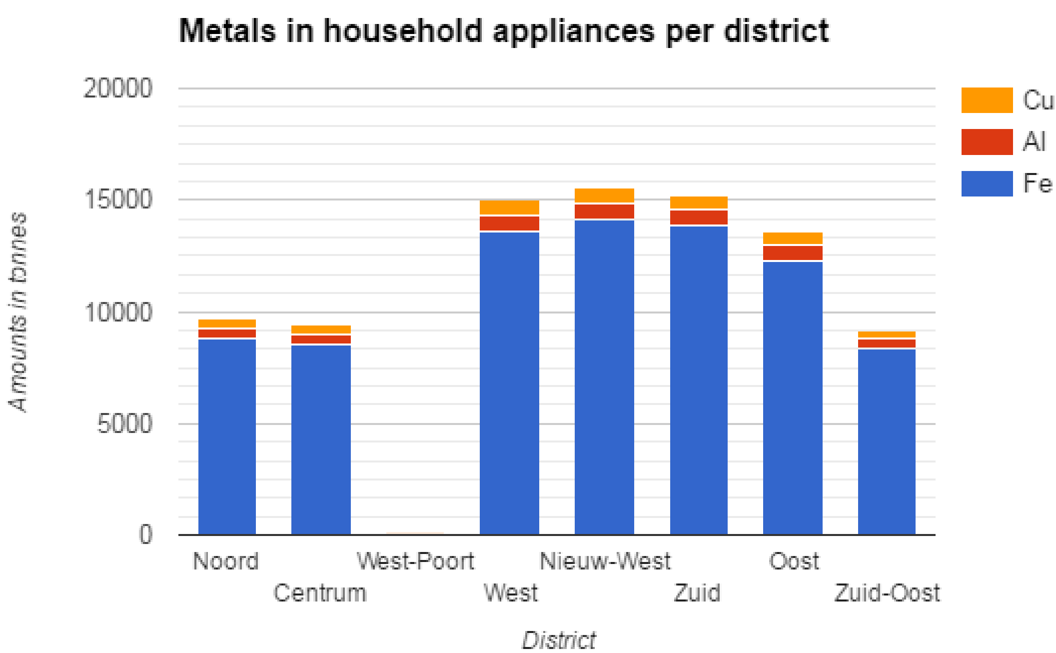


Figure 3.8: Stock estimations per district for household appliances.

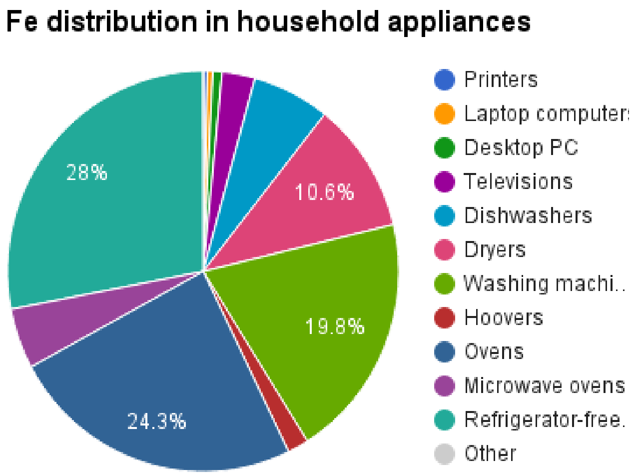


Figure 3.9: Iron distribution in the household appliances category.

Aluminum

The same total weight of the objects as for iron and copper were used for aluminum calculations and most of the metal contents came from the same literature as well (see Appendix 2c for more detail). The amount of aluminum in all these products added up to approximately 4 100 tonnes of Al, according to the calculations. See Figure 3.10 for the distribution among appliances.

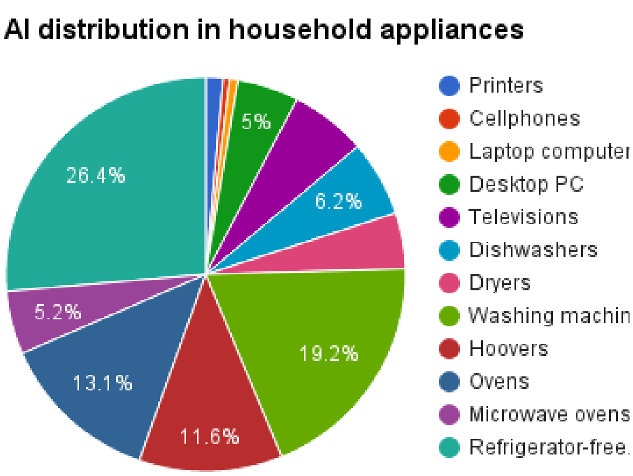


Figure 3.10: Aluminum distribution in the household appliances category.

Copper

The copper contents of household appliances were also sourced from the same literature as for iron and aluminum (Appendix 2c). Cell-phones were found not to contain copper in any significant amount. Copper in other electronics is mostly present in the wiring and tubing, as well as the printed wiring boards. The total mass of copper from all these household appliances and electronics amounted to approximately 3 970 tonnes in Amsterdam. The distribution of this total amount among household appliances and electronics can be found in Figure 3.11.

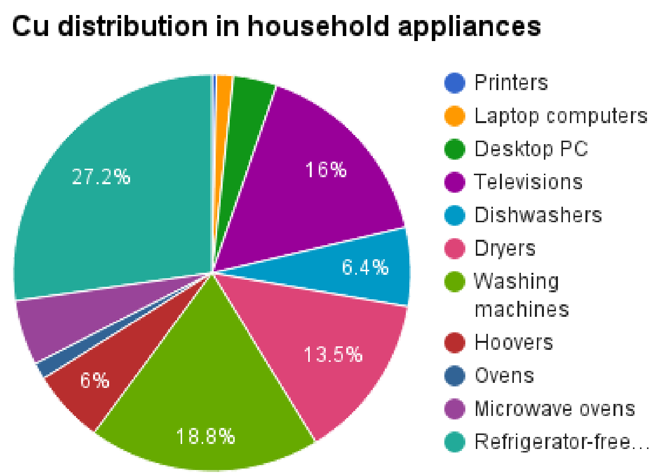


Figure 3.11: Copper distribution in the household appliances category.

For all three metals, refrigerators are the biggest contributors to metal stocks in Amsterdam, followed by washing machines, ovens and televisions, in terms of mass. When looking at results in term of monetary value, the overall picture changes.

3.1.4 Commercial appliances

Commercial goods are products used in commercial businesses, educational and health care institutions. The generated list of types of goods is influenced by the findings in literature by Eckelman et al.(2007), Recalde et al. (2008), Rauch et al. (2007). The products that contain a significant amount of metal in commercial appliances included in this category are; (mini) refrigerators, washing machines, dryers, dishwashers, oven-stove combinations, microwaves, computers, televisions, telephones, stereo/radio devices, copy/printing machines, hospital and hotel beds, filing cabinets, shelving, office desks, office chairs, restaurant equipment, automotive tools, dumpsters, and laboratory and hospital equipment. The information used to quantify and locate these types of products has been done by using the open geodata (available from the Amsterdam municipality website), internet research (e.g. for finding the amount of hospital beds), Google Earth and scaling the findings from previously executed stock estimations. All lifetime estimations are taken from a property manual from the Nevada Department of Taxation (2010).

See appendix 2d for an overview of sources, assumptions, lifetimes and calculations made for the products in this category. Results per Amsterdam district, the distributions of products per metal can be found in Figure 3.12.

Iron/steel

To come to the result of iron stocks in commercial goods, mostly product catalogues and stock estimation studies have been used to come to the (assumed) average weight of the product. The metal content was either determined by the use of stock estimation literature and LCA studies, and for some products like dumpsters and bed frames, the entire product was assumed to be iron/steel. All products except for laboratory/hospital equipment were possible to calculate to a rather detailed level. For laboratory/hospital equipment the total has been calculated by scaling the per capita result from the stocks estimation study for Connecticut (Eckelman et al. 2007).The total amount of steel in commercial goods in Amsterdam was calculated to be roughly 57 thousand tonnes of steel/iron. The distribution among the appliances can be seen in Figure 3.13.

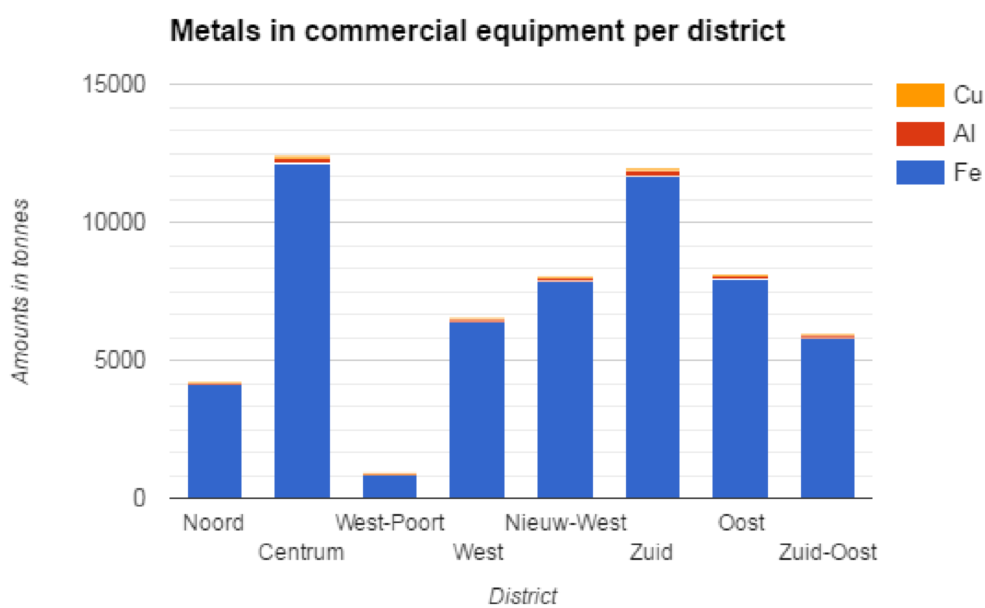


Figure 3.12: Stock estimations per district for commercial appliances.

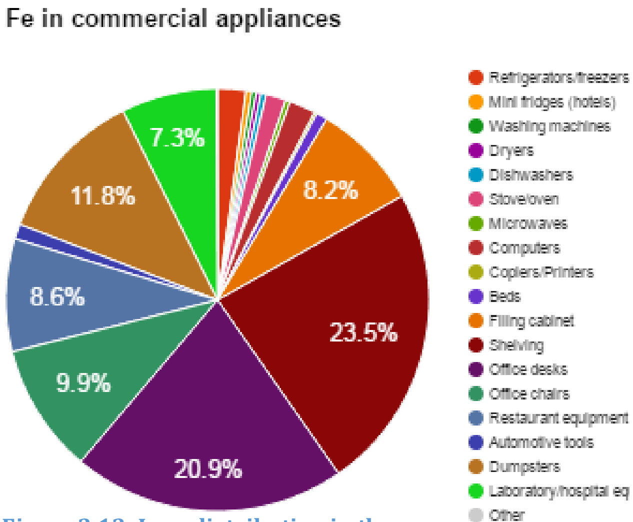


Figure 3.13: Iron distribution in the commercial appliances category.

Aluminum

The stock of aluminum has been calculated in the same way as been done for iron/steel. Again, just like for iron/steel products, all products except for laboratory/hospital equipment were possible to calculate to a rather detailed level. For laboratory/hospital equipment the total has been calculated by scaling the per capita result from the aluminum stocks estimation study for Connecticut (Recalde et al. 2008). The total amount of aluminum in commercial goods in Amsterdam was calculated to be roughly 850 tonnes of aluminum. The distribution among the appliances can be seen in Figure 3.14.

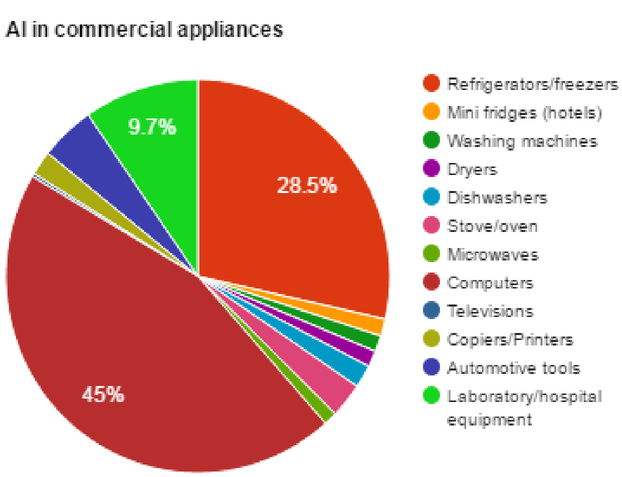


Figure 3.14: Aluminum distribution in the commercial appliances category.

Copper

The stock of copper has been calculated in the same way as been done for iron/steel. The total amount of aluminum in commercial goods in Amsterdam was calculated to be roughly 410 tonnes of copper. The distribution among the appliances can be seen in Figure 3.15.

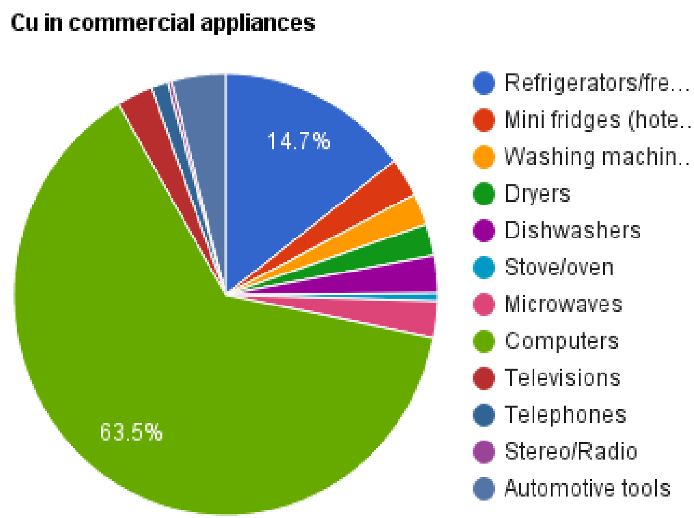


Figure 3.15: Copper distribution in the commercial appliances category.

For iron and steel, almost half of the total mass found is contributed by office desks and shelving. For both copper and aluminum, computers account for more than half of the amount of mass, followed by refrigerators.

A more detailed inventory of commercial appliances worth in Amsterdam can be found in Appendix 2d.

3.1.5 Industrial appliances

The category industrial goods contains any machinery or objects to produce or process physical goods in industrial businesses. The generated list of types of goods is influenced by the findings of Recalde et al. (2008), Rauch et al. (2007), and Eckelman et al. (2007). The products that contain a significant amount of metal in commercial appliances included in this category are; tractors, agricultural machinery, construction vehicles, large and small cranes, construction/repair tools, forklifts, shelving, tanks, wind turbines, servers in datacenters, large and small industrial machinery.

The information used to quantify the specific types of products has been done by using the open geo data(available from the Amsterdam municipality website), internet research (e.g. Drimble and Datacentrumgids.nl), Google Earth and scaling findings from previously executed stock estimations. All lifetime estimations are taken from a property manual from Nevada Department of Taxation (2011).

See appendix 2e for an overview of sources, assumptions, lifetimes and calculations made for the products in this category. Results per Amsterdam district can be found in Figure 3.16.

Iron/steel

The stock of iron/steel has been calculated by using the average product weight from product catalogues and stock estimation literature, and using the iron/steel content from the stock estimation literature or LCA studies. Small and large machinery have been scaled per capita from the iron/steel stock estimation paper by Eckelman et al. (2007). There are many different sizes found in the port, but for the sake of calculation the oil storage tanks are calculated by taking a radius of 6.5 m and 15.2 m with a wall thickness of roughly 6 cm as an assumed average. The total amount of iron/steel in industrial goods in Amsterdam was calculated to be roughly 590 thousand tonnes of iron/steel. The distribution among the appliances can be seen in Figure 3.17.

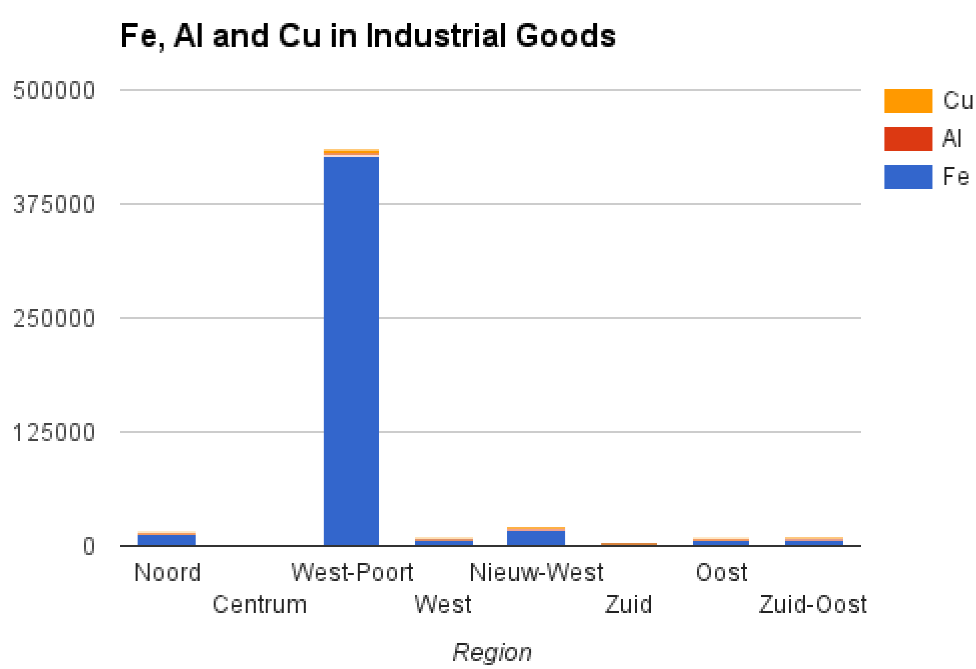


Figure 3.19: Stock estimations per district for industrial appliances.

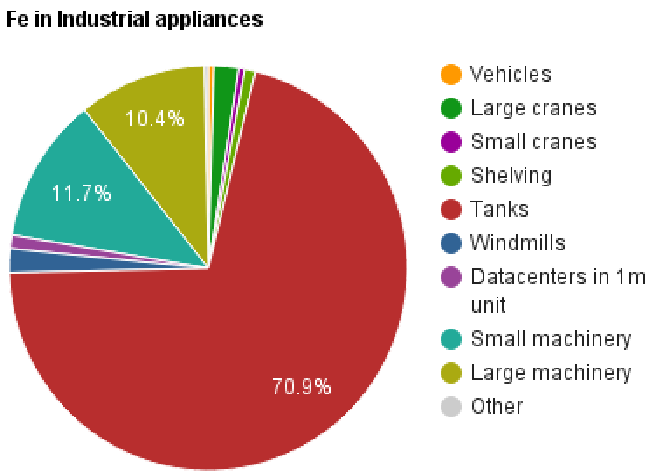


Figure 3.17: Iron distribution in the industrial appliances category.

Aluminum

The stock of aluminum has been calculated in the same way as is done for iron/steel. Similarly, small and large machinery have been scaled per capita from the aluminum stock estimation paper by Recalde et al. (2008). The total amount of aluminum in industrial goods in Amsterdam was calculated to be roughly 8 thousand tonnes of iron/steel. The distribution among the appliances can be seen in Figure 3.18.

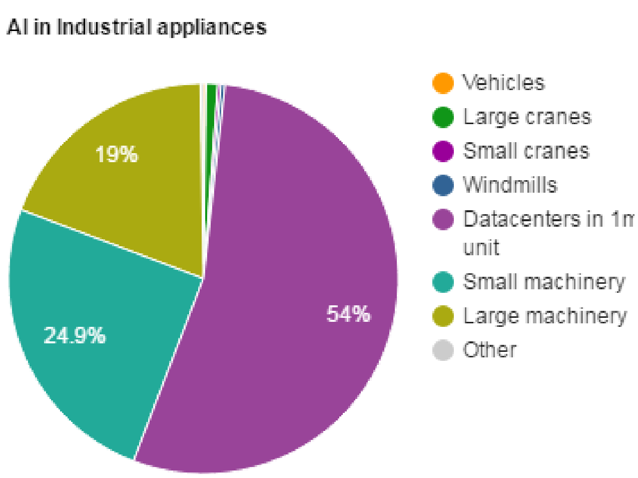


Figure 3.18 : Aluminum distribution in the industrial appliances category.

Copper

The stock of aluminum has been calculated in the same way as is done for iron/steel. Similarly, small and large machinery have been scaled per capita from the aluminum stock estimation paper by Rauch et al. (2007). The total amount of aluminum in industrial goods in Amsterdam was calculated to be roughly 17 thousand tonnes of copper. The distribution among the appliances can be seen in Figure 3.19.

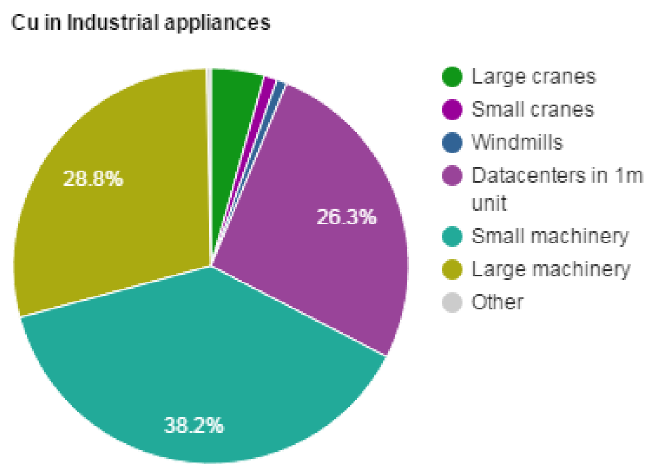


Figure 3.19: Copper distribution in the industrial appliances category.

For iron and steel, almost 3/4 of the total mass found is contributed by oil storage tanks. For aluminum, the largest contributors are servers in the data centers. Five different products are roughly equally contributing to most of the copper mass, which are tractors, agricultural machinery, servers in data centers, and large and small machinery. A more detailed inventory of commercial appliances worth in Amsterdam can be found in Appendix 2e.

3.1.6 Public goods

For public goods, products that are in public areas, that serve the community or that are difficult to trace back to an owner are included. The list of objects is a result from a brainstorm with the group of researchers and have been taken from various literature studies. The data on the total number of objects were mainly taken from the Amsterdam database and contacts within the municipality. The lifetime data was taken from the online product information that was available and contacts with producers. In appendix 2f an overview of sources, assumptions, lifetimes and calculations made for the public goods can be found. The distribution of the metals across the neighborhoods of Amsterdam can be seen in Figure 3.20.

Iron and steel

Most of the iron and steel stock has been calculated by multiplying the weight provided in product information times the total amount available. The number of products have been obtained from data in literature, municipality websites and governmental databases.

The total amount of iron and steel in the public goods of Amsterdam is about 260 tonnes. Iron and steel was the largest stock of metals in the public goods category in Amsterdam, as can be seen in Figure 3.24. Mainly the bulky canal waste that contains large fractions of iron like bicycles and shopping charts. The distribution of iron across products in the city can be seen in Figure 3.21.

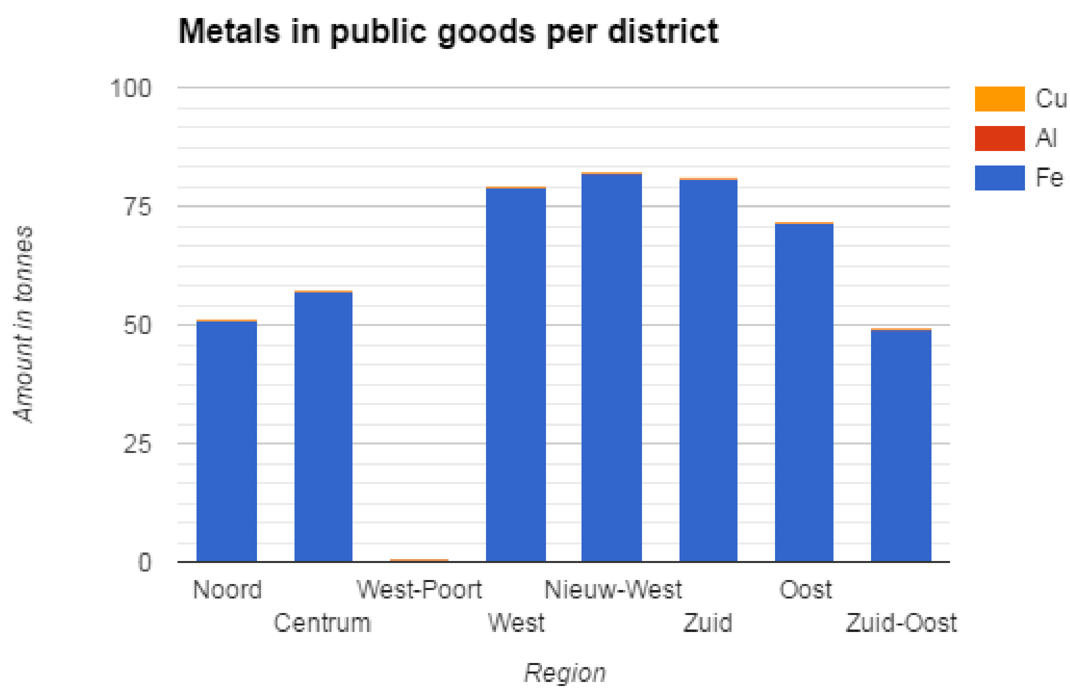


Figure 3.20: Stock estimations per district for public goods.

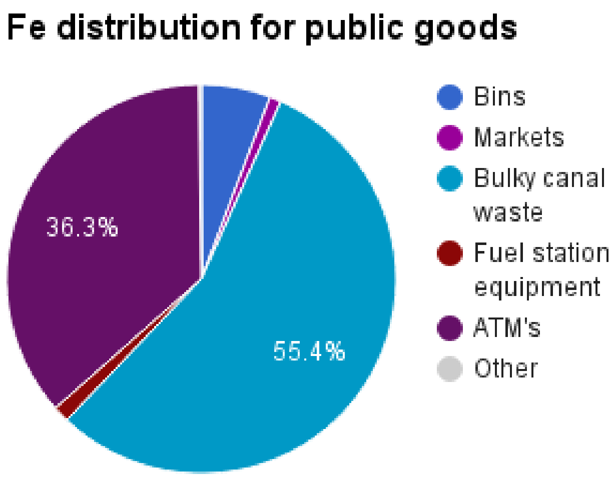


Figure 3.21: Iron distribution in the public goods category.

Aluminum

Aluminum was also found by multiplying the weight of the product times the number of products in Amsterdam. The total amount of aluminum in public goods in Amsterdam is 0.04 tonnes. An overview of the distribution of aluminum across the products can be seen in Figure 3.22.

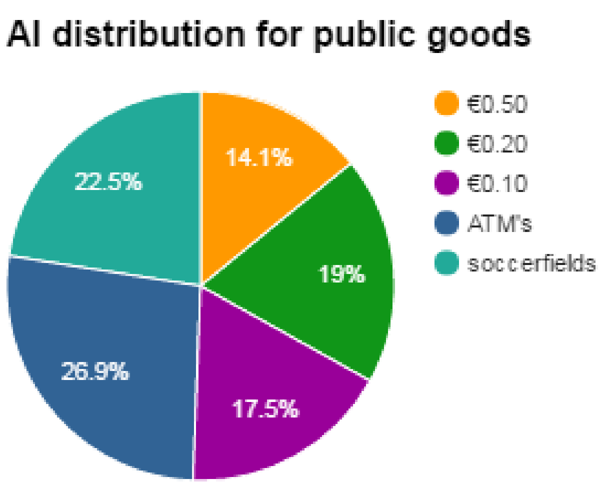


Figure 3.22: Aluminum distribution in the public goods category.

Copper

Copper was calculated the same way as aluminum and iron and steel, by multiplying the weight of the product times the total amount available in Amsterdam.

Copper was mainly found in coins and the total amount of copper in public goods of Amsterdam is about 0.7 tonnes. An overview of the distribution of copper across the products can be seen in Figure 3.23.

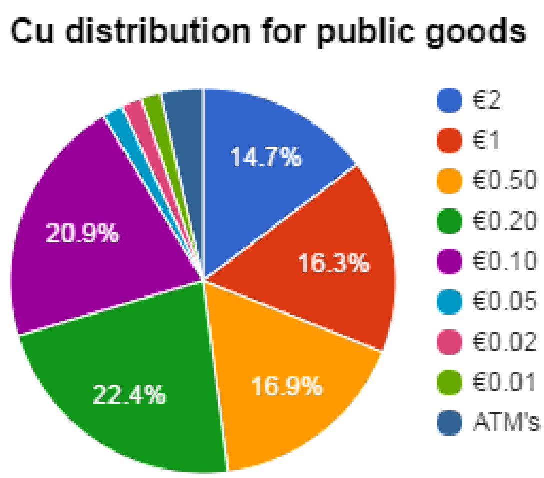


Figure 3.23: Copper distribution in the public goods category.

The main contributing products to iron/steel are different compared to aluminum and copper, that are both mainly characterized by coins. More than half of the iron results from the bulky canal waste that is dredged from the water every year. These are only the main fractions that have been sold to scrap dealers. The ATMs are also big contributors to the iron/steel category, this is because of their large safe.

3.3 Amsterdam districts stock estimations

In Figure 3.24 on the next page, an overview of stock estimations per district is presented. Consult Appendix 2g for detailed information. Westpoort is a big outlier in the data due to the large tanks of industrial machinery masking data on the other districts. Logically, in the district Centrum the industrial machinery category is underrepresented. Public goods as a category is in all districts many order of magnitudes smaller than other categories.

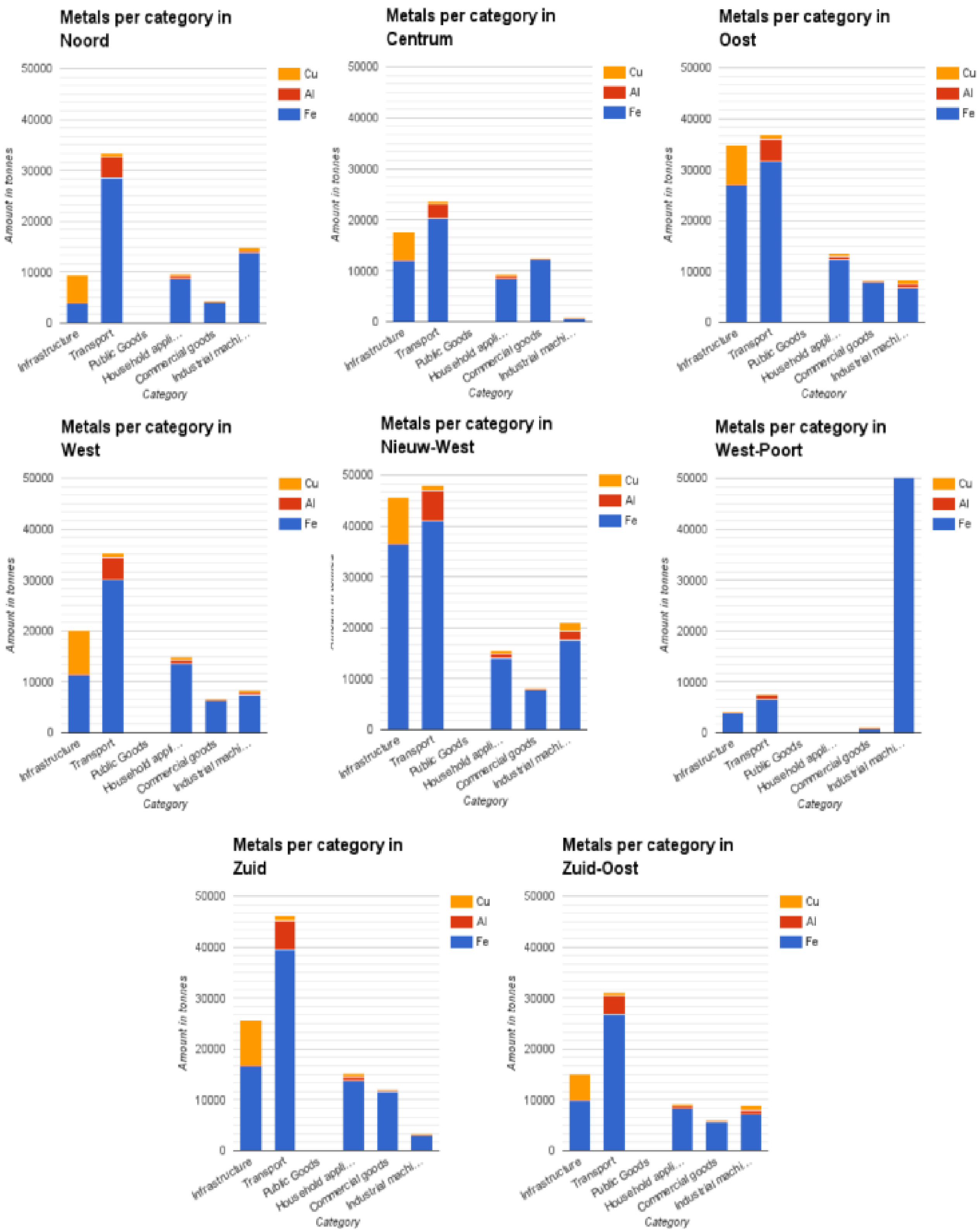
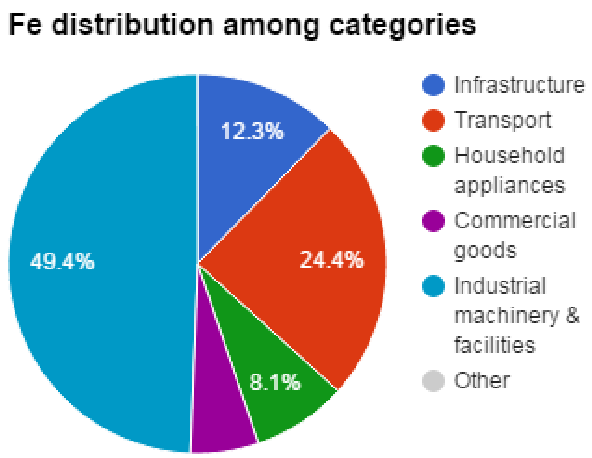
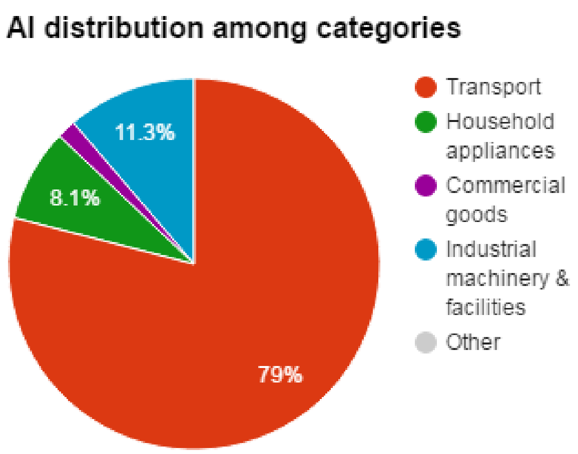


Figure 3.24: Metal stock estimations per district (blue: Fe, red: Al, orange: Cu).

3.4 Overview Amsterdam stock estimations

The distribution of iron, aluminum and copper among the different product categories are shown in Figure 3.25. As can be observed, the metal are all abundant in different product categories: iron in industrial machinery, aluminum in transport and copper in infrastructure.





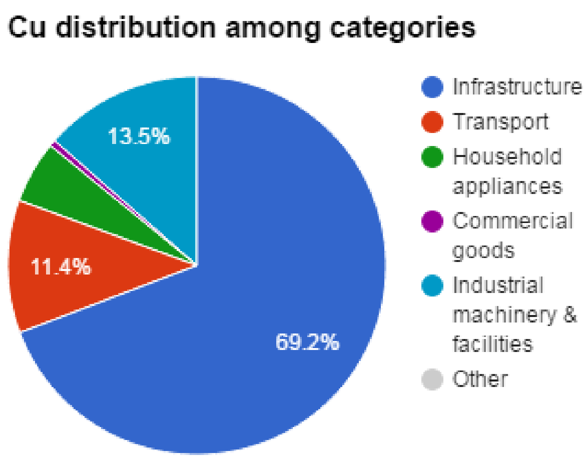


Figure 3.25: distribution of the total iron, aluminum and copper in the different product categories in Amsterdam.

The total Fe, Al and Cu amounts of each category are shown in Figure 3.26, alongside their scrap metal value in each category, for comparison.

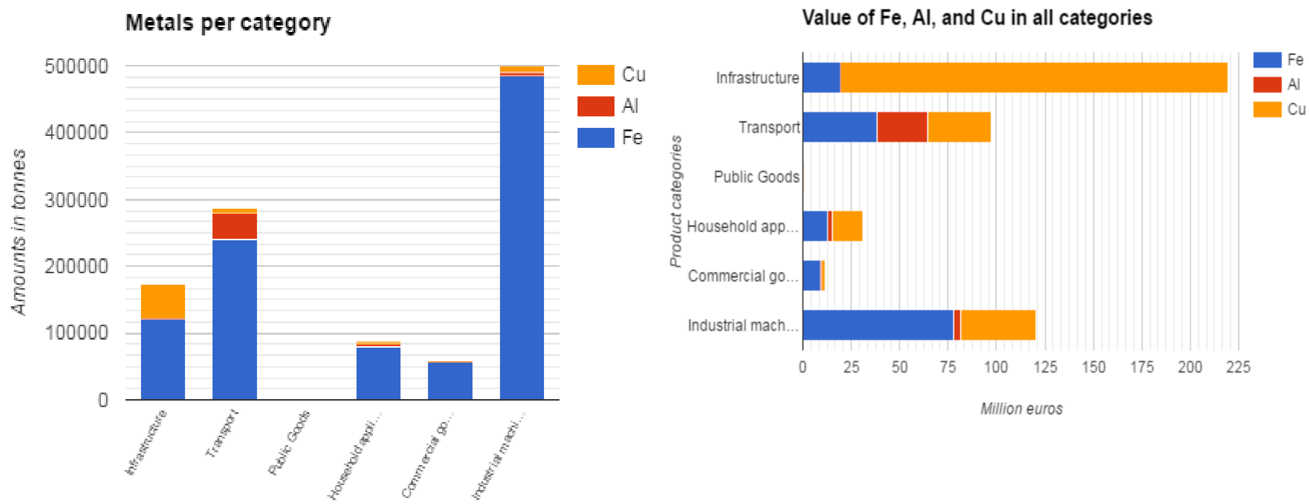


Figure 3.26: Amounts of Fe, Al and Cu in the different categories in tonnes and in euros.

The price of scrap copper is much higher than that of scrap iron or scrap aluminum. This results in infrastructure being the category with the most worth in term of its scrap content, whereas it was not the biggest category in terms of metal mass. Transport was also the second biggest category in terms of mass but only third in terms of scrap metal value.

The total amounts of iron, aluminum and copper are shown in Table 3.1, along with their scrap metal value and the total value of all iron, aluminum and copper in non-buildings parts of Amsterdam.

	Total in tonnes	Total in Euros (€)
Iron and steel (Fe)	1.1 million	€ 175 000 000
Aluminum (Al)	55 thousand	€ 35 000 000
Copper (Cu)	80 thousand	€ 310 000 000
TOTAL		€ 490 000 000

Table 3.1: total amounts of iron, aluminum and copper in all categories in Amsterdam, with their scrap metal value.

According to the estimations and calculations, the total worth of non-building products in Amsterdam amounts to around 500 million euros, only considering their scrap metal content.

3.5 Stock outflows

Three Sankey diagrams are presented for the distributions of iron/steel, aluminum and copper over the city districts, product categories and average lifespan for the product sources. The lifespan distribution is made over 0-4 years, 5-9 years, 10-19 years, 20-49 years and 50-100 years to make a distinctions between the (almost) immediate, farther and far future of outflow of the in-use stocks. In the first two Sankey diagrams of Figure 3.27 and 3.28, one can see that the biggest contributor of metals are found in sources that have an average lifespan of 10-19 years for both iron/steel and aluminum. For copper (Figure 3.29), the distribution of metals over the lifespan is more evenly distributed, with a the categories 10-19 years, 20-50 years and 50-100 years contributing almost equally to the entire amount.

The distributions of sources with average lifespan could be used for waste policies or legislation to be implemented. For instance, the municipality could anticipate the majority of the iron/steel of today to be flown out of use within the next 20 years. As is addressed earlier on the limitations of the stock accessibility, the outflow of the stock is very dynamic and unpredictable and the current distribution of the stock over the lifetimes might not represent the future reality. Again, this can be used as mainly an indication for when there is the largest outflow of the in-use stock or for which years the implementation of policies and legislation have greater priority.

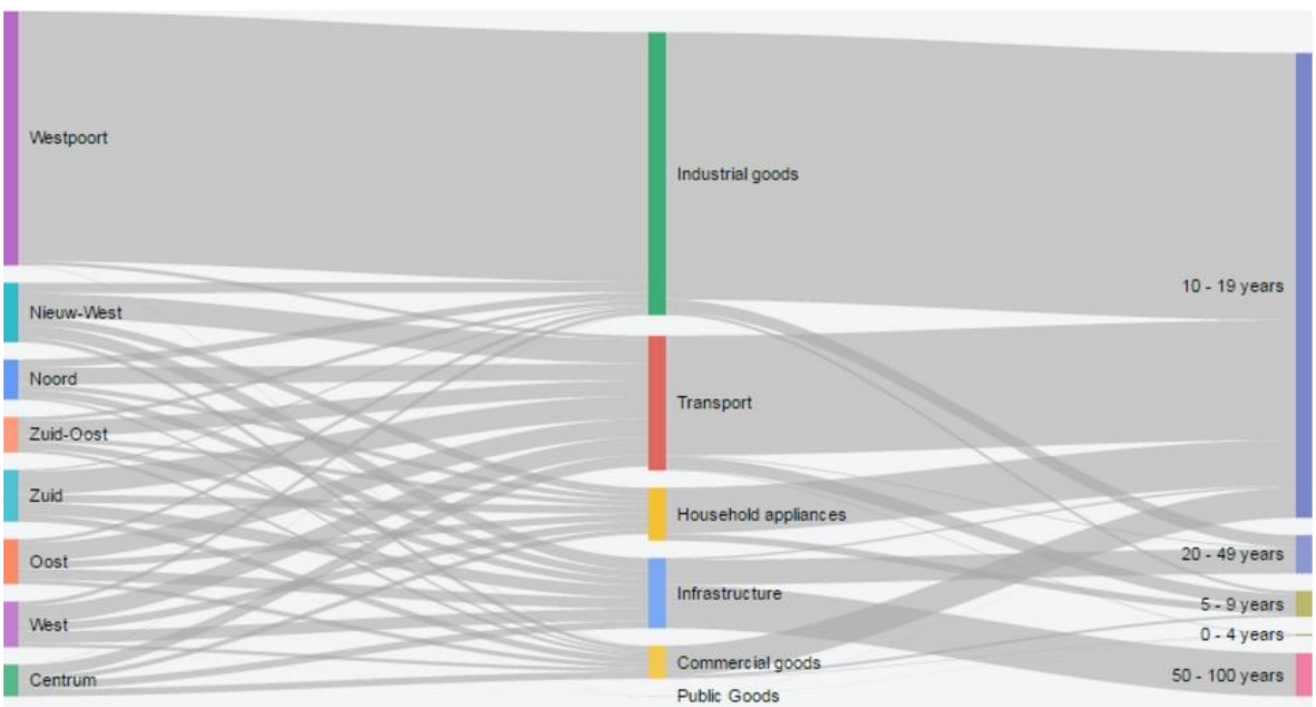


Figure 3.27: Sankey diagram for iron.

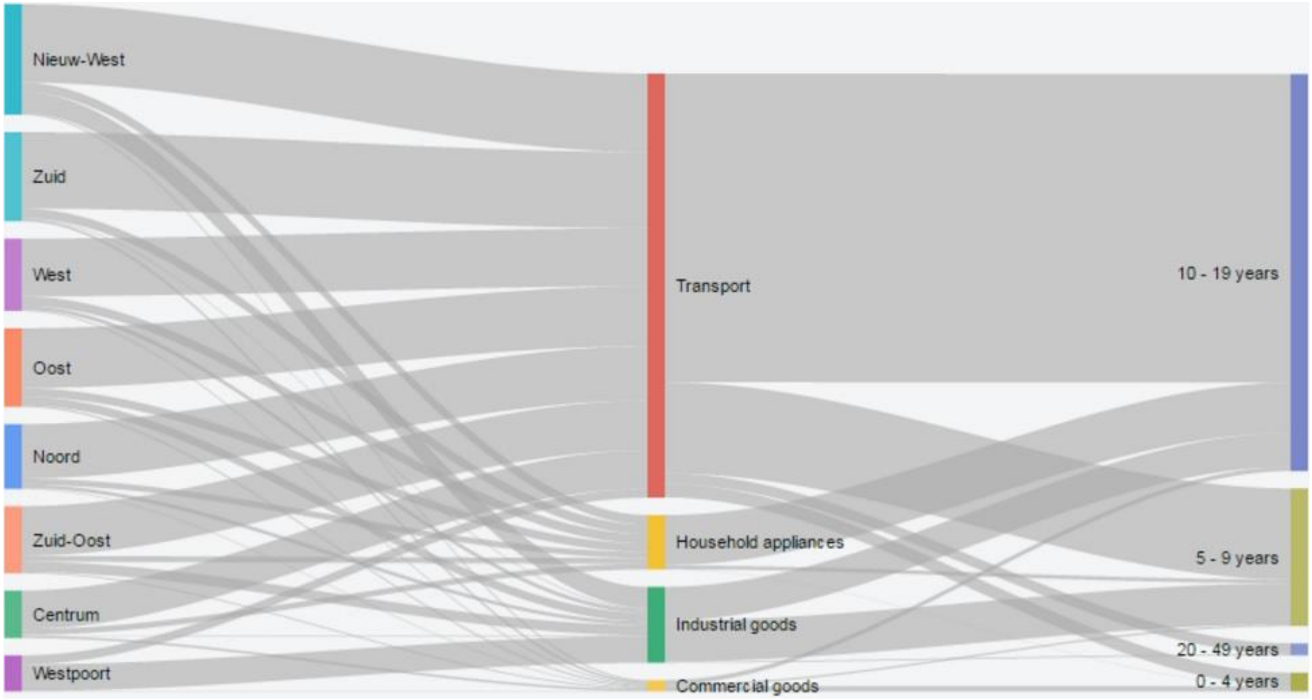


Figure 3.28: Sankey diagram for aluminum.

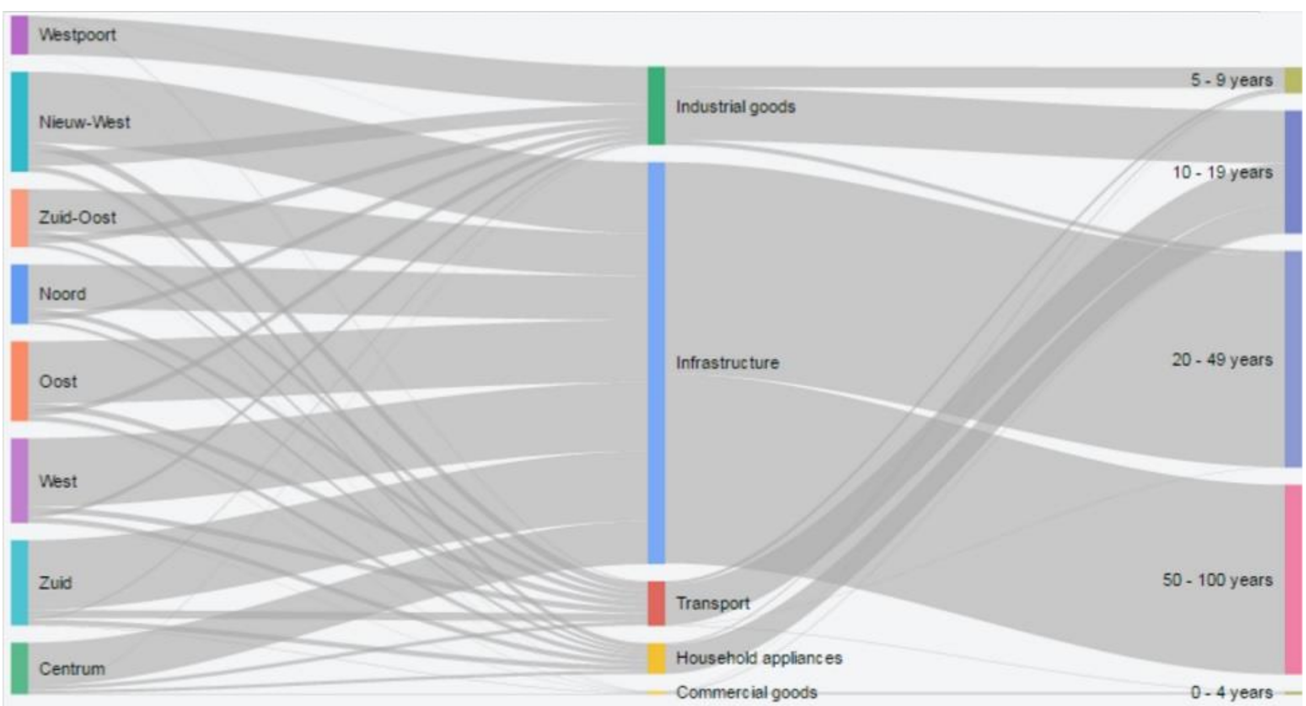


Figure 3.29: Sankey diagram for copper.

Aluminum, copper and steel, FMC Metals, 2016

4 Discussion

4.1 Results and interpretation

Results of the stock estimations indicate that there are certain categories and certain products that contribute highly to total iron, copper and aluminum stock in Amsterdam. First, industrial equipment and the transport categories contribute the most to total iron and steel stocks in Amsterdam. The transport category is also the biggest contributor to total aluminum stocks, and infrastructure is the biggest contributor to total copper stocks in Amsterdam. Consult Figure 3.26 for more details.

Diving deeper into the products that contribute most to these three metal stocks non-building elements in Amsterdam, results from the estimations show that tanks, personal cars and industrial machinery contain most of the iron and steel; cars, bikes and trams contain most of the aluminum; and distribution cables for electricity, drinking water pipes and cars contain most of the copper in Amsterdam. The 15 biggest stocks for each metal were ranked in Table 4.1 that can be found on the next page. This is either due to their big volume or the fact that they exist in large numbers in Amsterdam.

Ranking	Iron/steel	Aluminum	Copper
#1	Tanks	Personal cars	Distribution cables for electricity
#2	Personal cars	Bikes	Drinking water pipes
#3	Small machinery	Trams	Personal cars
#4	Tractors	Data centres	Small machinery
#5	Large machinery	Metros	Tractors
#6	Agricultural machinery	Business vans	Large machinery
#7	Overhead contact system of railroads (poles)	Small machinery	Agricultural machinery
#8	Train rails	Tractors	Data centers
#9	Tram lines	Large machinery	Streetlights
#10	Refrigerator-freezers	Agricultural machinery	Refrigerator-freezers
#11	Household ovens	Refrigerator-freezers	Washing machines (households)
#12	Business vans	Scooters	Televisions (households)
#13	Household washing machines	Motorcycles	Dryers
#14	Shelving in institutions (commercial appliances)	Washing machines (household)	Large cranes
#15	Office desks	Household ovens	Business vans

Table 4.1: Ranking of the 15 products that contribute most by mass to iron, aluminum and copper stocks in Amsterdam (excluding buildings).

The amounts of metals in these products were translated into monetary value using scrap metal prices and can be found in detail in Appendix 3. Adding up the prices of each product for their copper, aluminum and iron contents, their worth in term of metal content can be estimated. This was done for all the products taken into account in this study, and for the biggest 15 of them, their monetary value can be found in Table 4.2. It is important to keep in mind that this would be the scrap value of the metals contained in these products in their total numbers as estimated in Amsterdam. For example, if all the distribution cables for electricity now in use were collected, their worth would be of about 96 million euros, considering their copper, aluminum and iron content. This gives an idea of the worth of these products in Amsterdam and could be another incentive for urban mining.

Ranking	Product	Monetary value (rounded)	Average lifetime
#1	Distribution cables for electricity	€ 96 million	40 years
#2	Drinking water pipes	€ 93 million	
#3	Personal cars	€ 68 million	14 years
#4	Tanks	€ 55 million	15 years
#5	Small machinery	€ 25 million	17 years
#6	Tractors	€ 25 million	15 years
#7	Large machinery	€ 20 million	15 years
#8	Agricultural machinery	€ 20 million	15 years
#9	Data centres	€ 13 million	5 years
#10	Streetlights	€ 9 million	25 years
#11	Refrigerator-freezers	€ 8.5 million	13 years
#12	Business vans	€ 6 million	7 years
#13	Overhead contact system of railroads (pole)	€ 6 million	50 years
#14	Household washing machines	€ 6 million	12 years
#15	Train rails	€ 5.4 million	50 years

Table 4.2: Value of products in their total numbers in Amsterdam, considering the scrap prices of their iron, copper and aluminum content, and average lifetimes. (1st to 15th biggest ones).

Out of these big stocks, it is necessary to identify the ones that are accessible in terms of their in-use lifetimes and difficulty of recovery. The difficulty of recovery will depend on the form in which the metal is present in the product: degree of dissemination, need for manual dismantling or mechanical crushing for example, cost of recycling, whether collecting and recycling a certain product is an economy of scale (which is not the case for electronics for example). There are therefore any factors that need to be assessed to end up with a feasible business plan for urban mining, but in any case, collecting data and creating a map of metal stocks in an urban environment is the first step.

Looking at the lifetimes, it seems to be a general trend that products representing the biggest stocks also have the longest lifetimes, generally infrastructure and industrial equipment. Most the industrial equipment metal stocks and some of the infrastructure metal stocks were calculated indirectly and are likely to have a very high associated uncertainty and margin of error.

Ranking	Product	Monetary value (rounded)	Average lifetime
#16	Tramlines	€ 3.8 million	25 years
#17	Household ovens	€ 3.6 million	10 years
#18	Bicycles	€ 3.6 million	8 years
#19	Household dryers	€ 3.6 million	10 years
#20	Large cranes	€ 3.3 million	20 years
#21	Tramways	€ 3.2 million	30 years
#22	Metros	€ 3.1 million	20 years
#23	Household televisions	€ 3 million	15 years
#24	Commercial shelving	€ 2.1 million	15 years
#25	Household dishwashers	€ 1.9 million	10 years
#26	Office desks	€ 1.9 million	15 years
#27	Windmills	€ 1.8 million	
#28	Overhead contact system of railroad: wires)	€ 1.7 million	50 years
#29	Business trucks	€ 1.6 million	10 years
#30	Household microwave ovens	€ 1.6 million	10 years

Table 4.3: value of products in their total numbers in Amsterdam, considering the scrap prices of their iron, copper and aluminum content, and average lifetimes. (16th to 30th biggest ones).

When looking at the next batch of products with the highest value in Amsterdam, it seems household appliances and transport related products have shorter lifetimes but also a considerable worth. These might be the better ones to start with in an urban mining project.

Comparison of the results of this study with previous studies on in-use stocks can be done. Table 4.4 shows the in-use stocks per capita of different regions. Only studies that indicated the building fraction of the result were used to be able to compare with the non-building in-use stocks.

Metal	Where	Total stock per capita	Percentage of total stock associated with buildings	Non-building metal stock	Source and year
Iron	Connecticut state, USA	*9 300* kg Fe/capita	59%	*5 673* kg Fe/capita	Eckelman et al., 2007
Copper	Shanghai, China	*38.4 to 64.1* kg Cu/capita	23%	*29.5 to 49.3* kg Cu/capita	Zhang et al., 2014
Copper	Nanjing, China	*46.9* kg Cu/capita	28.10%	*33.8* kg Cu/capita	Zhang et al., 2012
Copper	Australia	*240* kg Cu/capita	50%	*120* kg Cu/capita	van Beers & Graedel, 2007
Copper	Connecticut state, USA	*157* kg Cu/capita	53%	*73.8* kg Cu/capita	Rauch et al., 2007
Copper	Cape Town, South Africa	*36* kg Cu/capita	28%	*26* kg Cu/capita	van Beers & Graedel, 2003
Aluminum	Connecticut state, USA	*363* kg Al/capita	60% (infrastructure & buildings)	*145.2* kg Al/capita	Recalde & Graedel, 2008
Aluminum	China	*37* kg Al/capita	48% (buildings & electrical sector)	*19.2* kg Al/capita	Wang & Graedel, 2010 (data for 2005)

Table 4.4: (non-building) in-use stocks per capita for other regions available in the literature.

	Fe	Al	Cu
Total metal stocks in Amsterdam (non-building)	*1 100 000* tonnes	*55 000* tonnes	*80 000* tonnes
Stocks per capita (non-building), considering an Amsterdam population of 790 110.	*1 500* kg Fe/capita	*70* kg Al/capita	*100* kg Cu/capita

Table 4.5: The rounded and approximated results in tonnes and in kg/capita.

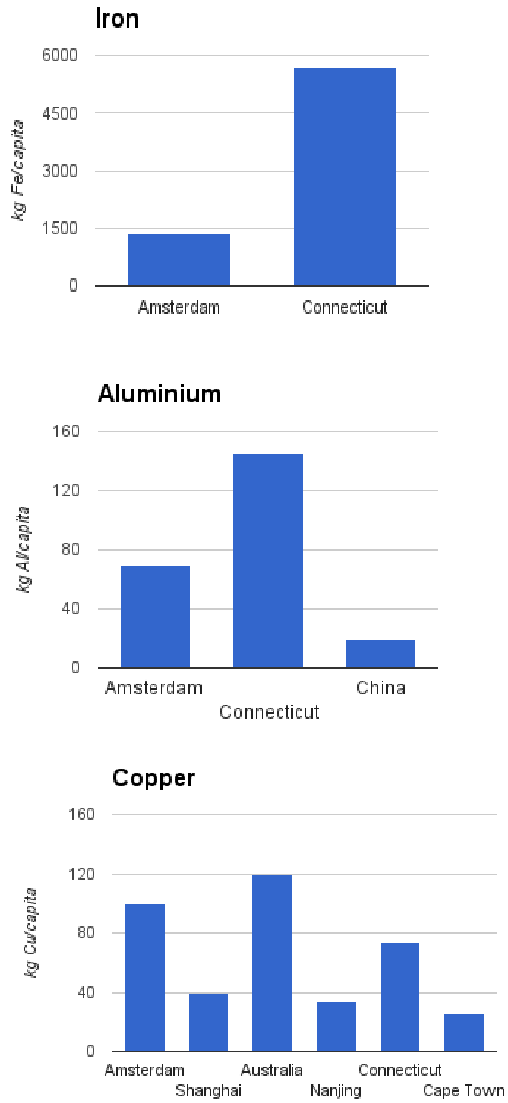


Figure 4.1: Comparisons of the stock estimations for Amsterdam with other countries and cities (cited in table 4.4).

Iron stocks in all non-building parts for Amsterdam estimated in this study are lower when compared to those calculated for Connecticut (Figure 4.1). Aluminum stocks in Amsterdam are also lower than those calculated for Connecticut but higher than those calculated for China for example, as can be seen in Figure 4.1. The results also suggest Amsterdam has higher copper stocks (always non-building) than Cape Town (SA), Nanjing and Shanghai (China) and Connecticut (USA), but slightly lower than Australia.

4.2 Data handling

This project serves as one of the first efforts that maps metals in products to geographical locations. The goal is to develop stepping stones towards urban mining and circular systems. However the initial stock estimations could contain results with questionable accuracy and wrongly made assumptions, hence part of the project aim is to make the dataset as transparent and open as possible. By doing so experts e.g. engineers (domain experts), sustainability consultants, producers, consumers can gain access to the dataset and can through facilitated discussions contribute to the quality of the dataset.

The vision of open data within the field of IE was coined as Industrial Ecology 2.0 by Chris Davis and colleagues in 2010. One may argue that the research done on metals in Amsterdam belongs to one of many researches aimed to create pathways for a Circular Economy. For this an holistic understanding of societies along with its industrial systems and the environment is needed. Therefore the research done in this report is only a building block that needs to be connected with other researches and experts. Analysis of current policies and stakeholders linked to quantified data can be of value to not only the municipality of Amsterdam, but to the field of Industrial Ecology as well. Collecting, processing, curating and sharing such amounts of data and knowledge is required, unfortunately one may argue that in Industrial Ecology this can be improved (Chris Davis et al., 2010).

With the advent of Information, Communication technology sharing information on vast amounts of data has become possible. The Internet already serves as the medium for knowledge exchange, and some fields in academia have already taken up the possibilities that current software (open source and licenced) provides. For example Bio-informatics emerged as a field that combines biological data with computer science to gain a better understanding of the functions of organisms (Isea, 2015). It has to be mentioned that appreciable amounts of data already exists, however that it is largely a challenge of interlinking data. Enabling collaboration, standardization and dealing with resistance due to privacy issues are key to successfully reaching a community-driven, collective knowledge web within the field of IE. As mentioned by Chris Davis creating feedback loops in which information that is gathered can be reused and replicated is of great value. In addition the quality of information can be improved through continual peer reviews.

Based on the notion of IE 2.0 the first steps are taken in this project. All the results are made available online through a developed web application (url: cml.liacs.nl/softlab/puma, username:cml, password:VanSteenis), see Figure 4.2 for a screenshot of the homepage, for technical details please refer to Appendix 4. Google Sheets© were used to structure the data and create the possibility to add data dynamically by different project members. The basis of the structure was to at least contain: products under consideration, amount of products, metal contents, data source/reference (associative trails with links), lifetime of products with its reference, taken assumptions and district data availability. The Google Sheet on stock estimations can be downloaded through the web application, in turn users can see more specific details such amount of products per region. Next to making the raw data available, significant time is invested in visualizations of the data. This way the data ideally tends to be better accessible and transparent. Google's interactive plotting mechanisms were used for most visualizations, which creates the possibility to automatically update visuals based on changes in the Google Sheet. For district specific data an interactive map was created which is shown below as a screenshot in Figure 4.3. This map utilizes geographical data combined with popup functionality (containing Google Sheet's graphs) to show specific information. In addition a concept has been developed in which domain experts can login to the application and comment/flag on made estimations (see Figure 4.4). The moderator would then be able to adjust this in the dataset when deemed necessary, in turn improving the quality of the dataset. With the web application the research results becomes easily accessible and visitors can quickly gain an overview of the work done, but can also dive deeper in specific categories or districts.

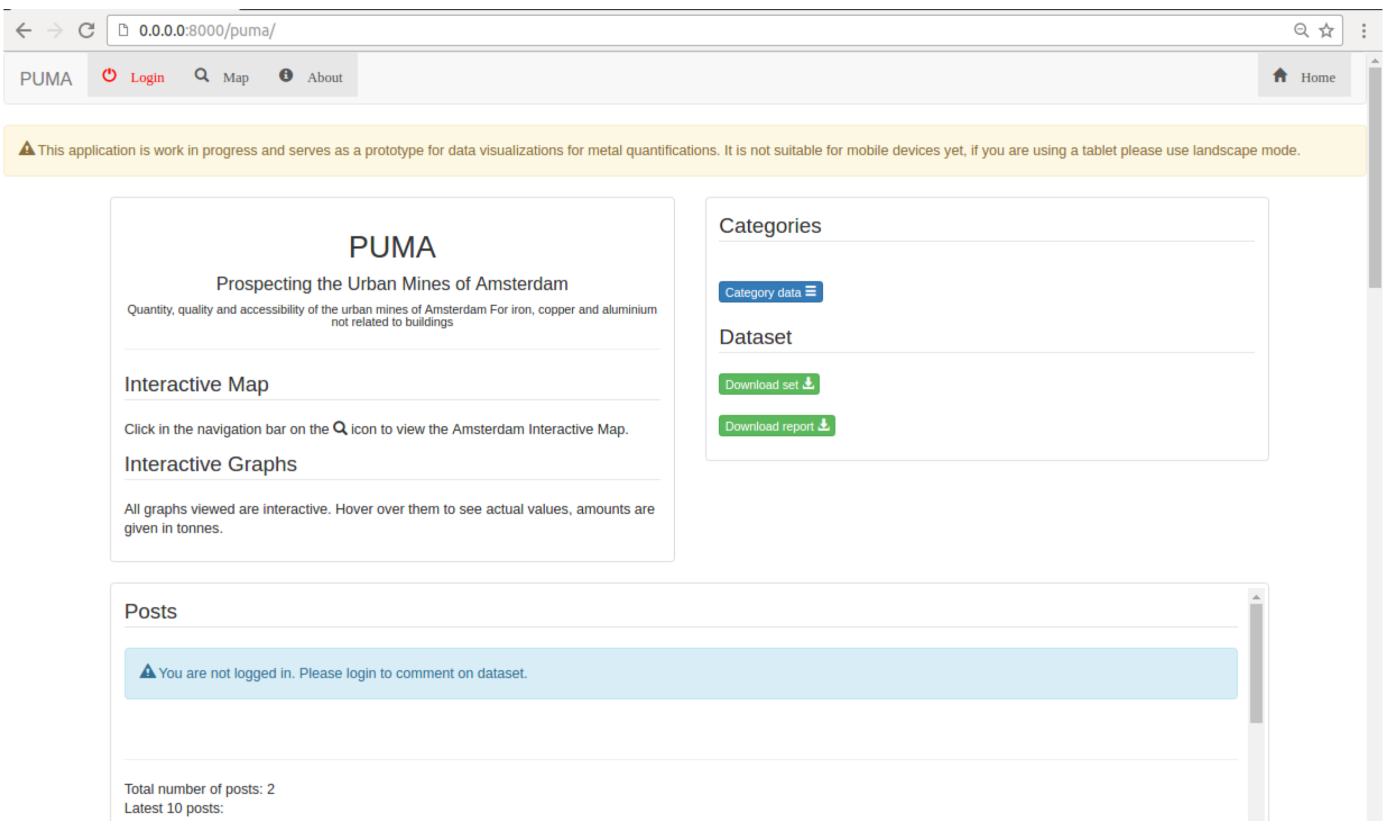


Figure 4.2: Homepage of the web application.

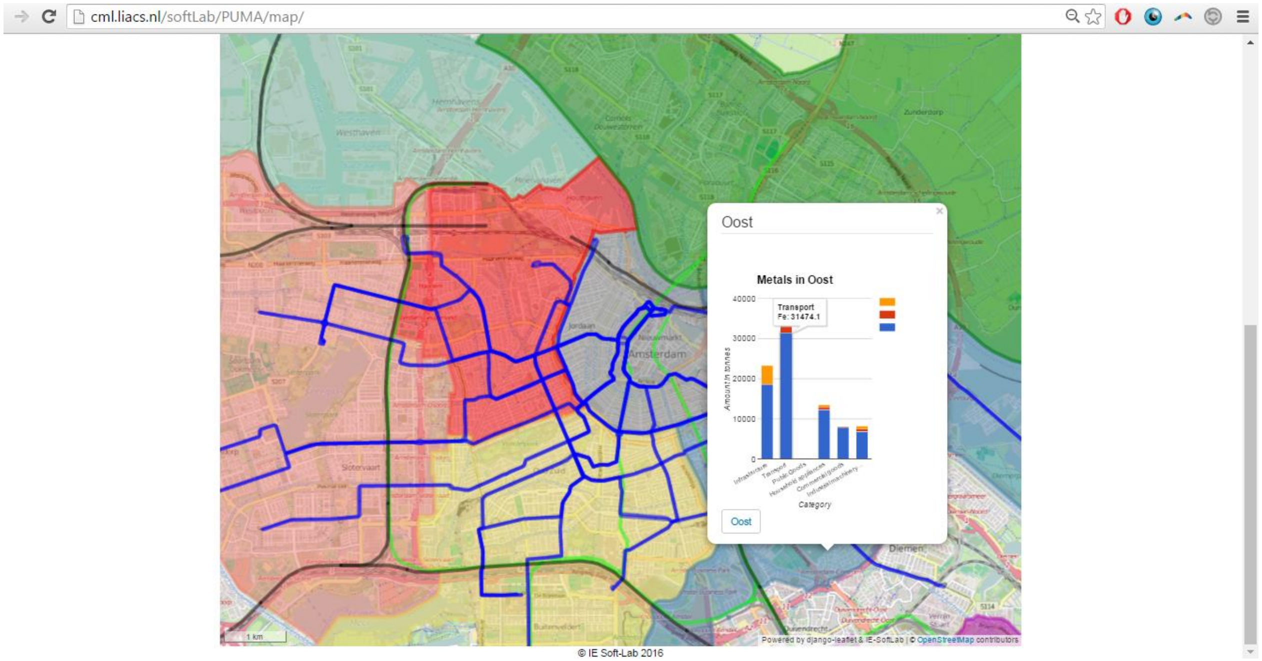


Figure 4.3: Amsterdam's interactive map on metal contents.

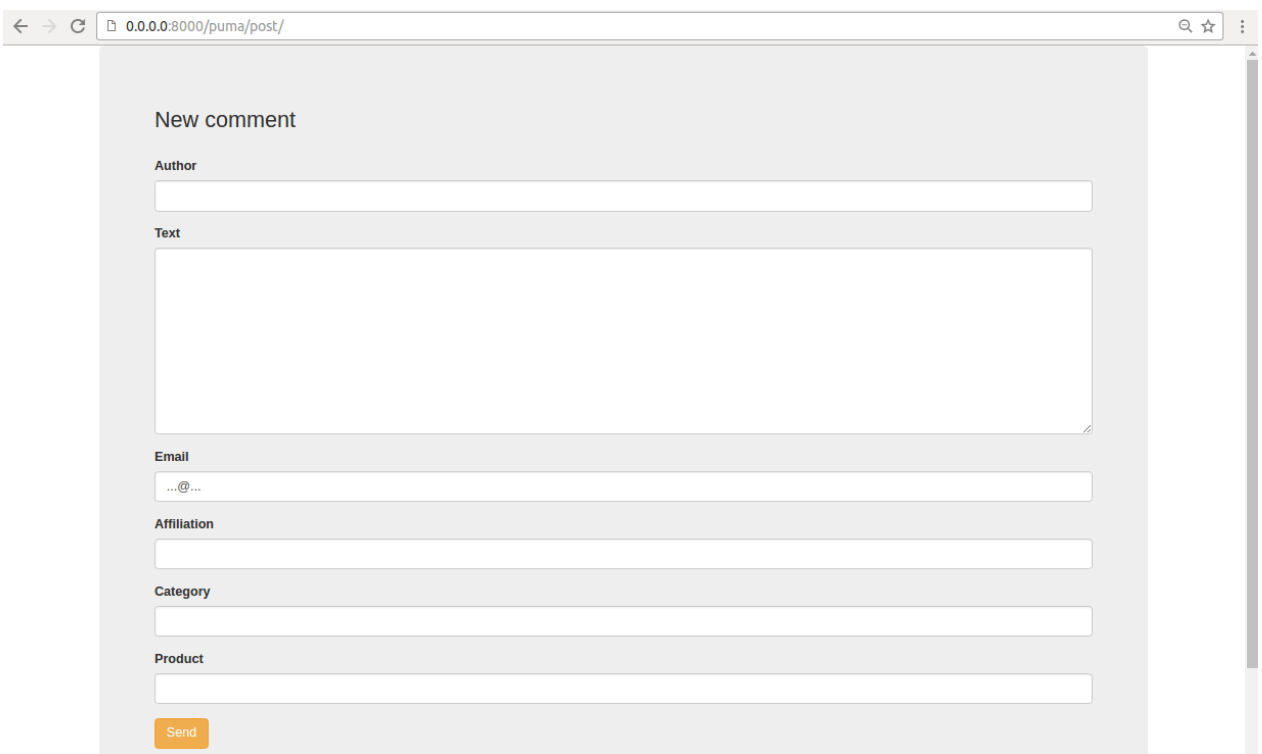


Figure 4.4: Web application post comment system.

5 Conclusion and recommendations

5.1 Conclusions

This bottom-up study has estimated the quantity, quality, accessibility and economic value of iron, copper and aluminum in non-building products in the urban mine of Amsterdam. The amount of iron estimated in all non-building in-use products currently is roughly of 1 million tonnes. For copper and aluminum, amounts of about 56 thousand tonnes and 80 thousand tonnes, respectively, were estimated.

In terms of quantity , industrial machinery make up for the largest in-use stock of iron, among the six categories assessed. This because of the large silos in the harbour. For copper, however, infrastructure seems to be the highest contributor, mainly due to electricity distribution cables. Finally, the largest contributor to aluminum stocks is the transportation category due to the large amount of personal cars registered in the city. On the contrary, the smallest of all categories is public goods that is almost non-contributing to the totals.

When converting the the total mass of iron, copper and aluminum to their economic value (using their scrap metal prices), the overall contribution distributions alter. Infrastructure becomes much more important compared to the physical sizes of transport and industrial machinery and is therefore considered to have the highest economic potential. The assessed total value of iron, copper and aluminum together in in-use products in the urban mine of Amsterdam was calculated to be approximately 515 million euros.

The accessibility of the metals was also assessed in terms of location and time. All materials are rather geographically scattered throughout the eight neighborhoods of Amsterdam.

On the other hand, from a temporal aspect based on the lifetime of the products taken into account, over 50% of both iron and aluminum will become available within the next ten to twenty years. Meanwhile copper will become available more spread out over time, the majority stocks between 10 to 100 years' time.

5.2 Recommendations for commissioner

The quantification of secondary resources as done in this research, can provide a foundation for decision-making within industrial, commercial and political fields. A system like the proposed open-source database is recommended to use when doing stock analysis as a step towards the realization of urban mining. According to this research, parts that are essential for this open-source database are the stocks and lifetime of the products containing metals.

Another recommendation is for investors and the municipality to develop solid business plans for urban mining in the city of Amsterdam. A lack of precise knowledge of stocks can create a barrier for them to join in actually developing systems, but this research has shown that there are expected to be large stocks with large economic value. By creating business plans and starting with small initiatives retrieving 'low hanging fruit' and priority stocks found in this report, we can learn how the urban mine can be a more significant resource in the future.

5.3 Recommendations for future study

This research is a first inventory of non- building stocks in Amsterdam based on direct data, but also rough estimations and indirect calculations. It is recommended for future studies to invest in exploring mainly the largest categories as infrastructure, transport and industrial machinery in order to gain more knowledge about the real sizes of those stocks.

The focus of in-depth research for Amsterdam is recommended to be on the amounts of metal becoming available. The lifetimes of products collected in this research, can provide a basis to map the outflow of metals in Amsterdam when numbers of products bought in past years and data on the year of installation of, for instance, infrastructure are added.

This would result in a very valuable map for finding opportunities in periods and product categories to connect supply and demand. This expansion study would be even more valuable if the waste streams in which the metals can be found are assessed.

Additionally, further study on the comparison of metals per capita per category of Amsterdam in respect to studies might be interesting. As mentioned before, studies find different values probably due to scope, development of the area and population density. In-depth study comparing the specific product categories within studies and looking further into city density, level of wealth and technical compositions of products would give more insight into regional and academic differences.

More in-depth research is recommended to be done on the amounts of metal containing products that become available every year. This can be done by taking into account, next to the lifetime and stocks, the number of products bought every year. It can be expanded by assessing in what waste streams the metals can be found again.

For follow up studies a comparison of metals per capita per category of Amsterdam in respect other cities might be interesting. Although the products taken into consideration could be different, it may show similarities or huge differences due to city density, level of wealth, technical compositions of products.

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Appendix 1 - Literature review

Table on Literature review

Metal	Study	Aim	Approach	Method	Location	Validation
Copper	Beers and Graedel (2003)	Assess the in-use copper stocks in Cape Town with regards to resource depletion and environmental impacts, and to address the feasibility and desirability of mining in-use stocks as a future source of materials	Bottom-up	Identify, quantify, estimate in-use lifetime and assess spatial infrastructure	Cape-town	
Copper	Zhang et al. (2014)		Bottom-up	Data collection from statistics database, experts, estimations and assumptions. Formulas are used to come to final results transparently	Shanghai	
Copper	Zhang et al (2011)	Provide useful information for future recycling installations/systems	Bottom-up	Collection of data through expert consultation on copper fabrication and recycling, and through searching the national statistics database. Use the found acquired data as key parameters for formulas on the identified major categories.	Nanjing, China	Per capita comparison with other regions/countries
Copper	Van Beers and Graedel (2006)	Create awareness among metal recyclers and policy makers on resources and integrate knowledge into a technical and social framework	Bottom-up	Data collection from experts, statistical bureaus, literature and estimations. Accuracy of products in percentages to calculate accuracy of entire study.	Australia	n/a
Copper	Rauch et al (2007)	Understand the state of recycling practices	Bottom-up	Collect data through life time analysis of in-use stocks, scaled estimates and actual data from	State of Connecticut	Qualitative assessment of results & per capita comparison

				connecticut.		of a top-down study
Iron	Wang et al (2007)		MFA, import and export data		Global	
Nickel	Rostkowski et al. (2007)		Bottom-up		New Haven	
Aluminum	Recalde, Wang, Graedel (2008)	Construct a bottom-up estimate of the amount of aluminum in active use	Bottom-up		Connecticut	Informed estimates were used to approximate information & uncertainty analysis
Aluminum	Wang & Graedel (2010)	First aluminum in-use stock for a developing country	Bottom-up		China	
	Bergback et al. 2000	Analyse metal flows and accumlation in the anthroposphere and biosphere to assess risk for man and environment		Use metal content in solid waste from households and industry to calculate metals in waste per year.	Stockholm	
Iron	Eckelman et al. 2007	Evaluate in-use stocks over the larger geographic entity of the state of Connecticut to find more accurate reflections of the national average			Connecticut	

Appendix 2 - Stock calculations data

Appendix 2a: Infrastructure

Table A2.1 shows an overview of amounts and average lifetimes for infrastructure products. Table A2.2 & A2.3 show the amounts of metal used for each object.

Table A2.1: an overview of objects taken into account for Infrastructure.

Object	Amount of objects	Source	Average lifetime	Source
Bicycle parkingspots	39393 bike stances	Gemeente Amsterdam 2016	25 years	Gemeente Amsterdam - Dienst Infrastructuur Verkeer en Vervoer 2007
Traffic lights	372	Gemeente Amsterdam 2016	25 years	Wang & Graedel 2009
Metrolines	42,5 km	Wikipedia 2016	25 years	Wang & Graedel 2009
Tramlines	200 km	GVB no year	25 years	Wang & Graedel 2009
Distribution cables for electricity	*Amount of material calculated indirectly*	Zhang et al. 2011	40 years	Wang & Graedel 2009
Drinking water pipes	2800 km	Gemeente Amsterdam 2008	80 years	Vloerbergh & Beuken 2011
hydrants	18490 hydrants	Centraal buro voor de Statistiek no year	30 years	Van Beers & Graedel 2003
pumps	4 pumps	Gemeente Amsterdam 2008	30 years	Van Beers & Graedel 2003
manhole covers on highways	3236 manhole covers	Rauch et al. 2007	30 years	Van Beers & Graedel 2003
grates on local roads	25266 grates	Rauch et al. 2007	30 years	Van Beers & Graedel 2003
natural gas distribution pipes	2000 km	Gemeente Amsterdam 2008	To receive	Wang & Graedel 2009
cityheating pipes	150 km	Gemeente Amsterdam 2008	To receive	Wang & Graedel 2009
city cooling pipes	12 km	Gemeente Amsterdam 2008	To receive	Wang & Graedel 2009
Streetlights	133500 masts	Gemeente Amsterdam - Dienst Infrastructuur Verkeer en Vervoer 2007	25 years	Gemeente Amsterdam - Dienst Infrastructuur Verkeer en Vervoer 2007
Trainrails	334 km	Koncak 2016	50 years	Bolidt Ballastloze Kunststoftoepassing no year
overhead contact system of railroad: poles	4133 overhead poles	Koncak 2016	50 years	Bolidt Ballastloze Kunststoftoepassing no year

overhead contact system of railroad: wires	237,868 km rail with overhead system	Koncak 2016	50 years	Bolidt Ballastloze Kunststoftoepassing no year
Roads	14.8 km	Centraal buro voor de Statistiek no year	50 years	Van Beers & Graedel 2003
Tunnels	7 tunnels, 7,361 km	Gemeente Amsterdam no year, Schrijver 2015, Wikipedia 2016, WIkipedia 2016, Wikipedia 2016, Wikipedia 2016,	100 years	InfraQuest no year
Street signs small	23 per mile of local road	Rauch et al. 2007	25 years	Wang & Graedel 2009
street signs big (highway)	6251 signs	Rauch et al. 2007	25 years	Wang & Graedel 2009
overhead trusses (highway)	919 trusses	Rauch et al. 2007	25 years	Wang & Graedel 2009
guard rail	296 km	Bonhof no year	15 years	Eindhovens dagblad 2009
Public transport stops-stations; abri	1150 abri's	JC Decaux 2016	15 years	Gemeente Amsterdam no year
Copper cables for telecommunication	12978 km	Zhang et al. 2011	60 years	Bosch 2012
Manholes for telecommunication	11464 covers	GVB no year, Rauch et al. 2007	30 years	Van Beers & Graedel 2003

Table A2.2: An overview of iron/steel contents taken into consideration for the infrastructure category. .

Object	Iron/steel stock in tonnes	Average assumed weight in kg	Iron/steel content in kg	Source
Bicycle parkingspots	1970	N/A	50 kg per spot	TNO 2014
Traffic lights	702	N/A	98 kg per unit	Eckelman et al. 2007
Metrolines	4590	108000 kg per km	108000 kg per km	Tata Steel 2016
Tramlines	23880	119400 kg per km	119400 kg per km	Alom no year
Drinking water pipes	413	N/A	8550 kg per km	Saint-Gobain Pipe Systems BV 2006
pumps	32	N/A	8000 kg per unit	Rauch et al. 2007
manhole covers on highways	146	N/A	45 kg per unit	Rauch et al. 2007
grates on local roads	581	N/A	23 kg per unit	Rauch et al. 2007
Streetlights	4139	N/A	31 kg per unit	Rauch et al. 2007
Trainrails	33474	N/A	100222 kg per km	Expert opinion
overhead contact system of railroad:	37259	N/A	9015 kg per unit	Rauch et al. 2007

poles				
Roads	2915	N/A	197095 kg per km	Rauch et al, 2007
Tunnels	108	N/A	12634 kg per km	A2 Maastricht no year
Street signs small	422	N/A	16 kg per unit	Rauch et al 2007
street signs big (highway)	143	N/A	23 kg per unit	Rauch et al 2007
overhead trusses (highway)	2809	N/A	3057 kg per unit	Rauch et al 2007
guard rail	3089	N/A	10436 kg per km	Bonhof no year
Public transport stops-stations; abri	690	N/A	600 kg per unit	Expert opinion
Manholes for telecommunication	520	N/A	45 kg per unit	Rauch et al 2007

Table A2.3: An overview of copper contents taken into consideration for the infrastructure category.

Object	**Copper stock in tonnes**	**Average assumed weight in kg**	**Copper content in kg**	**Source**
Traffic lights	192	N/A	27 kg per unit	Zhang et al. 2011
Distribution cables for electricity	24866	N/A	48000 kg per MW	Eckelman et al 2007
Transmission transformers for electricity	TO ADD	N/A	1400 kg per unit	Eckelman et al. 2007
Distribution transformers for electricity	TO ADD	N/A	20 kg per unit	Eckelman et al. 2007
Drinking water pipes	23942.394	N/A	148 kg per km	Hamel Metaal no year
Streetlights	2180.71805	N/A	16 kg per unit	Zhang et al. 2011
overhead contact system of railroad: wires	426	N/A	1790 kg per km	TNO 2014
Copper cables for telecommunication	59.635963	N/A	0.14 kg per household	Zhang et al. 2011

Appendix 2b: Transportation

See Table A2.4 for an overview of vehicles amounts and average lifetimes. For metro's, buses and trams additional data was found from the public transportation company in Amsterdam "GVB" (2016):

- Metro's (90 objects total): before 2017 24 out, 15 in, before 2020 13 out, before 2014 12 out, before 2027 37 out.
- Buses (172 objects total): before 2018 40 out, before 2020 10 out, before 2021 33 out, before 2022 70 out.
- Trams (211 objects total): before 2017 13 out, before 2020 45 out.

Table A2.4: An overview of vehicles taken into consideration for the transport category.

Object	Total number of objects	Source object	Average lifetime	Source lifetime
Personal cars	228691	Gemeente Amsterdam, 2016	14 years	Rauch et al. 2007
Business cars	2377	Gemeente Amsterdam, 2016	14 years	Rauch et al. 2007
Business vans	20009	Gemeente Amsterdam, 2016	7 years	Nevada Department of Taxation, 2011
Business trucks	1096	Gemeente Amsterdam, 2016	10 years	Ducker Worldwide (2015)
Motorcycles	18009	Gemeente Amsterdam, 2016	120700.8 km (≈ 20 years)	Chester, M., & Horvath, A. (2009)
Trams	211 (151 Combino/newer-type)	GVB, 2016	30 years	Nevada Department of Taxation, 2011 & GVB
Bicycles	≈ 800000	IAmsterdam: cycling facts and figures	8 years	Rauch et al. 2007
Scooters	56253 (31.900 50cc, 908 E-scooter+mopeds, 23.445 >50cc)	Gemeente Amsterdam, 2016	50000 km (≈ 13 years)	Marianne Leuenberger & Rolf Frischknecht. (2010)

Public buses	172 (70 hybrid, 102 diesel)	GVB, 2016	15 years	Nevada Department of Taxation, 2011 & GVB
Metro's	90	GVB, 2016	30 years	Siemens AG. (2006) & GVB

Iron/steel

Table A2.5: An overview of iron/steel contents taken into consideration for the transport category.

Object	Iron/steel stock in tonnes	Average assumed weight in kg	Iron/steel content in kg or %	Source
Personal cars	192100	1300	60% (840 kg)	Factbox 2010
Business cars	1997	1300	60% (840 kg)	Factbox 2010
Business vans	16808	1300	60% (840 kg)	Factbox 2010
Business trucks	8549	10000	78% (7800 kg)	Rauch et al. 2007
Motorcycles	1891	190	55.4% (105 kg)	Tatemichi Y. & Yoshida T. 2001
Trams*	1381	34000	65% (22100 kg)	*assumed with GVB data
Bikes	4928	17	6.16 kg	Marianne Leuenberger & Rolf Frischknech 2010
Scooters	3009	E-scooter 106 kg, conventional scooters 90kg	E-scooter 40.8 kg steel conventional scooters 53.7 kg	Tatemichi, Y. & Yoshida T. 2001
Public buses	998	Not used	Conventional buses 6251 kg Hybrid 5142 kg	Kärnä 2012
Metros	4024	62 objects 48 tonnes 28 objects 190 tonnes based on GVB data	48.5%	Struckl & Wimmer 2007

*Limited information was found for trams due to the specific types of trams in Amsterdam. An assumption was made that older trams (60 objects of each ≈34 tonnes) have 65% of weight as steel and newer trams (151 objects of 34 tonnes) almost none as they are mainly made out of plastic and aluminum (NRC, 2003). Thanks to GVB data was available on how many trams of older types and newer types there are in Amsterdam, although it should be mentioned that the trams that are going to replace the newer ones may contain steel again.

Aluminum

Table A2.6: An overview of aluminum contents taken into consideration for the transport category.

Object	Aluminum stock in tonnes	Average assumed weight in kg	Aluminum content in kg or %	Source
Personal cars	27214	1300	119 kg average of small car & typical sedan	Ducker Worldwide
Business cars	283	1300	119 kg based on average of small car & typical sedan	Ducker Worldwide
Business vans	2481	1300	123.8 kg	Ducker Worldwide
Business trucks	288	10000	262.5 kg based on average of source	Rauch et al.2007
Motorcycles	810	190	45 kg	Tatemichi Y. & Yoshida T. 2001
Trams*	3337	34000	65% newer type 1% old types of weight	*assumed with GVB data
Bikes	4376	17	5.47 kg based on average of the two sources	Rauch et al. 2007 Marianne Leuenberger & Rolf Frischknech 2010
Scooters	853	E-scooter 106 kg, conventional scooters 90kg	E-scooter 25.1 kg conventional 15 kg	Marianne Leuenberger & Rolf Frischknech 2010
Public buses**	263	Not used	hybrid:1535 kg diesel: 1541 kg	Kärnä 2012
Metros	2555	62 objects 48 tonnes 28 objects 190 tonnes based on GVB data	30.8% of weight	Struckl & Wimmer 2007

*Rauch's article 1% of Al is mentioned for trams, although based on a literature study on types of trams in Amsterdam, this number may be larger as explained in the iron/steel section on trams. Therefore an assumption was made that the newer trams contain 65% Al and the older ones 1%.

**The number for buses may be a high estimate as in Rauch's 2007 paper only 200 kg has been described. For sake of homogeneity in terms of buses the same source reference has been used for all metals.

Copper

Table A2.7: An overview of copper contents taken into consideration for the transport category.

Object	Copper stock in tonnes	Average assumed weight in kg	Copper content in kg or %	Source
Personal cars	5031	1300	22 kg average based on source	European Copper Institute (2016)
Business cars	52	1300	22 kg average based on source	European Copper Institute (2016)
Business vans	440	1300	22 kg average based on source	European Copper Institute (2016)
Business trucks	22	10000	20 kg	Van Beers & Graedel 2003
Motorcycles	54	190	3 kg	Van Beers & Graedel 2003
Trams	218	34000	3% of weight	Siemens A. 2006
Bikes	0	17	0	Bicycles are considered to have negligible amounts of Copper.
Scooters	76	E-scooter 106 kg, conventional scooters 90kg	50 cc (1.41 kg) E- scooters 7.67 k <50 cc (1.12 kg)	Braconi 2014
Public buses	31	Not used	Conventional 163 kg hybrids 212 kg	Kärnä 2012
Metros	216	62 objects 48 tonnes 28 objects 190 tonnes based on GVB data	2.6% of weight	Struckl & Wimme 2007

Appendix 2c: Household appliances

The number of households used in Amsterdam was of 432 610 households, and a number of inhabitants of 790 110 (StadIndex, 2016). From the same source, it was assumed that each Amsterdam district contained the following number of inhabitants: Centre (84 775), Westpoort (450), West (135 070), Nieuw-West (139 910), South (137 375), Oost (122 265), Noord (87 405) and Zuidoost (82 855).

Table A2.8: overview of products included in the household category, their amounts in the city of Amsterdam and their lifetimes.

Object	Total number of objects	Source object	Average lifetime	Source lifetime
Inkjet printers	289 849	Papachristos, 2015	8 years	estimation
Cellphones	834 925	Nation Master, 2016	3 years	Eugster et al., 2007
Laptop computer	718 133	Tselekis, 2012	5 years	Eugster et al., 2007
Desktop PC	216 305	Tselekis, 2012	8 years	Eugster et al., 2007
Television	423 958	Papachristos, 2015	15 years	Truttman & Rechberger, 2006
Dishwasher	203 327	Papachristos, 2015	10 years	Truttman & Rechberger, 2006
Dryer	255 240	Papachristos, 2015	10 years	Truttman & Rechberger, 2006
Washing machine	415 306	Papachristos, 2015	12 years	Eugster et al., 2007
Hoover	432 610	Tselekis, 2012	10 years	estimation
Electric oven	268 218	Papachristos, 2015	10 years	Truttman & Rechberger, 2006
Microwave oven	363 392	Papachristos, 2015	10 years	Truttman & Rechberger, 2006
Refrigerator/freezer	432 610	Papachristos, 2015	13 years	Eugster et al., 2007

Iron/steel

Table A2.9: An overview of iron/steel contents taken into consideration for the household appliances category.

Object	Iron/steel stock in tonnes	Average assumed weight in kg	Iron/steel content in kg or %	Source
Inkjet printers	275	5 kg	19% (0.95 kg)	Eco3e (2016)
Cellphones	20.8		25 g	Apple (2014)
Laptop computer	351.3		489 g	Sahni et al. (2010)
Desktop PC	612.4	9.9 kg (Eugster et al. 2007)	28.6% (2.8 kg)	EPA (2015) for WARM
Television	2 162	30 kg	17% (5.1 kg)	Truttman & Rechberger (2006)
Dishwasher	5 083	50 kg	50% (25 kg)	Truttman & Rechberger (2006)
Dryer	8 417	49 kg	67% (33 kg)	Oeko Institut (2011)
Washing machine	15 782	75 kg	51% (38 kg)	Truttman & Rechberger (2006)
Hoover	1 395	8 kg	40% (3.2 kg)	WRAP (2012)
Electric oven	19 312	100 kg	72% (72 kg)	Assumptions based on commercial oven
Microwave oven	3 886	15 kg	71% (10.7 kg)	Truttman & Rechberger (2006)
Refrigerator/freezer	22 279	84.5 kg	61% (51.5 kg)	Chul Kim et al. (2006)

Aluminum

Table A2.10: An overview of aluminum contents taken into consideration for the household appliances category.

Object	Aluminum stock in tonnes	Average assumed weight in kg	Aluminum content in kg or %	Source
Inkjet printers	58	5 kg	4% (0.2 kg)	Eco-3e (2016)
Cellphones	21.7		26 g	Apple (2014)
Laptop computer	27.2		37.9 g	Sahni et al. (2010)
Desktop PC	203	9.9 kg (Eugster et al. 2007)	9.5% (0.94 kg)	EPA (2015) for WARM
Television	254	30 kg	2% (0.6 kg)	Truttman & Rechberger (2006)
Dishwasher	254	50 kg	2.5% (1.25 kg)	Truttman & Rechberger (2006)
Dryer	188	49 kg	1.5% (0.74 kg)	Oeko Institut (2011)
Washing machine	789		1.9 kg	Recalde et al. (2008)
Hoover	476	8 kg	14% (1.1 kg)	WRAP (2012)
Electric oven	536.4	100 kg	2%	Assumption based on commercial oven
Microwave oven	212	15 kg	4%	Truttman & Rechberger (2006)
Refrigerator/freezer	1 081	84.5 kg	3% (2.5 kg)	Eco-3e (2016)

Copper

Table A2.11: An overview of copper contents taken into consideration for the household appliances category.

Object	Copper stock in tonnes	Average assumed weight in kg	Copper content in kg or %	Source
Inkjet printers	14.5	5 kg	1%	Eco-3e (2016
Cellphones				
Laptop computer	54		75 g	Sahni et al. (2010)
Desktop PC	141	9.9 kg (Eugster et al. 2007)	6.6%	EPA (2015) for WARM
Television	636	30 kg	5% (1.5 kg)	Truttman & Rechberger (2006)
Dishwasher	254	50 kg	2.5% (1.25 kg)	Truttman & Rechberger (2006)
Dryer	538	49 kg	4.3%	Oeko Institut (2011)
Washing machine	748	75 kg	2.4% (1.8 kg)	Truttman & Rechberger (2006)
Hoover	239	8 kg	6.92% (0.55 kg)	WRAP (2012)
Electric oven	53	100 kg	0.2%	Assumption based on commercial oven
Microwave oven	212	15 kg	3.9% (0.58 kg)	Truttman & Rechberger (2006)
Refrigerator/freezer	1 081	84.5 kg	3% (2.5 kg)	Eco-3e (2016)

Appendix 2d: Commercial appliances

Table A2.12: overview of products included in the commercial category, their amounts in the city of Amsterdam and their lifetimes.

Object	Total number of objects	Source object	Average lifetime	Source lifetime
Refrigerators/freezers	23936	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	For all: Nevada Department of Taxation (2011)
Mini fridges (hotels)	26287	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	
Washing machines	1772	Eckelman et al. (2007); Gemeente Amsterdam (2016)	7 years	
Dryers	1772	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	
Dishwashers	7528	Eckelman et al. (2007); Gemeente Amsterdam (2016)	7 years	
Stove/oven	15056	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	
Microwaves	18781	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	
Computers	402032	Eckelman et al. (2007); Gemeente Amsterdam (2016); HBO Bachelors.nl (2016); Universitaire Masters.nl (2016); AHK, (2015); UvA (2016); Dutch Cowboys (2011)	3 years	
Televisions	44487	Eckelman et al. (2007); Gemeente Amsterdam (2016)	5 years	
Telephones	294792	Eckelman et al. (2007); Gemeente Amsterdam (2016)	5 years	
Stereo/Radio	15316	Eckelman et al. (2007); Gemeente Amsterdam (2016)	7 years	
Copiers/Printers	3376	Eckelman et al. (2007); Gemeente Amsterdam (2016); HBO Bachelors.nl (2016); Universitaire Masters.nl (2016); AHK, (2015); UvA (2016)	5 years	
Beds	60339	Eckelman et al. (2007); Gemeente Amsterdam (2016); Sint Lucas Andreas Ziekenhuis (2015)	15 years	
Filing cabinet	51714	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	
Shelving	217832	Eckelman et al. (2007); Gemeente Amsterdam-Dienst Onderzoek en Statistiek (2007)	15 years	
Office desks	562634	Eckelman et al. (2007); Gemeente Amsterdam (2016); HBO Bachelors.nl (2016); Universitaire	15 years	

		Masters.nl (2016); AHK, (2015); UvA (2016)		
Office chairs	562634	Eckelman et al. (2007); Gemeente Amsterdam (2016); HBO Bachelors.nl (2016); Universitaire Masters.nl (2016); AHK, (2015); UvA (2016)	15 years	
Restaurant equipment (per retaurant)	2450	Eckelman et al. (2007); Gemeente Amsterdam (2016)	10 years	
Automotive tools (per repair shop)	1692	Eckelman et al. (2007); Gemeente Amsterdam (2016)	15 years	
Dumpsters	21116	Eckelman et al. (2007); Gemeente Amsterdam (2016)	10 years	
Laboratory/hospital equipment	0.1 kg Al/capita; 5.1 kg iron&steel/capita;	Eckelman et al. (2007); Recalde et al. (2008); Sint Lucas Andreas Ziekenhuis (2015)	5 years	

Clarification/commentary to results of total number of objects:
White goods are found in gastronomic businesses, such as restaurants and hotels, offices and educational institutes. For refrigerators and freezers, it is assumes that there are two refrigerators/freezers found in each gastronomical business, and six found in each supermarket. To get to the final number, the open geodata provided by Amsterdam is used ('Vestigingen horeca' and 'Vestigingen winkels dagelijkse goederen'). It is also assumed that each hotel room in Amsterdam (number and location provided by Amsterdam's open geo data) contains a mini fridge. Each gastronomical business is likely to own one dishwasher and two gas fired stove-oven combination (Eckelman et al., 2007), for which the number and location of gastronomic business could be used from the Amsterdam open geo data (Gemeente Amsterdam, 2016).
The number of washing machines and dryers are assumed to be the same. To get to the total number of washing machines, first the total amount of beds and their location has been taken from the Amsterdam open geo data. Assumed that the weight of bed linen for each bed is 3.5 kg and the average load for a heavy duty washing machine and dryer is 14 kg/h (Edrocorp, 2016), a total of 1772 washing machines and dryers are needed in hotels in Amsterdam if the machines are on for 8 shifts a day.
Microwaves are found in gastronomic businesses, offices and educational institutions. An earlier study found that one microwave is provided for 50 students/employees (Eckelman et al, 2007). First, the number of offices employees was taken from the open geo data and corrected for the average worker's hours/week, which is 28 hours, meaning the total number of office employees has been multiplied with 28/40 (Werken 2.0, 2011). The total number and students and the location of the faculties was found through annual reports and various other sources (HBO Bachelors.nl, 2016; Universitaire Masters.nl, 2016; AHK, 2015; UvA, 2016). The results of the numbers of gastronomic businesses, employees and students resulted in the total amount of microwaves in use in Amsterdam.

Electronic and electrical equipment products often found in commercial and educational institutions

are computers, televisions, telephones, stereos/radios and printers. Taken the earlier calculated number of employees and students, we are able to come to the final numbers when the following findings are used for computers: there is 1 computer per 5 lower education students (Dutch Cowboys, 2011), 1 computer per 2.6 students in secondary and higher education (OECD, 2015), 1 computer per employees in offices, companies and other services(corrected for average working hours), and one computer per gastronomic business, store and 'other' establishments. For televisions the following numbers were used: 1 television per hotelroom, 1 television per 50 employees and 1.5 television per gastronomic business (Eckelman et al., 2007). The total of landline telephones are found for: 1 telephone per hotel room, 1 telephone per every type of commercial establishment and 1 per office employee. Radios/stereos were assumed to be found in each gastronomic business, each store and per 100 employees in offices and other types of companies (Eckelman et al., 2007).
From field work (TU Delft, 2016), it is found that there are roughly 6 printers are available for 1000 students and employees.

Other types of products taken into the estimation are beds, filing cabinets, racks for in-store shelving, office desks, office chairs, restaurant equipment, automotive tools, dumpsters and laboratory/hospital equipment.
The total amounts of beds from hotels are taken from the Amsterdam open geodata, beds found in hospitals were taken from an annual report on hospitals (Sint Lucas Andreas Ziekenhuis, 2015). For each office employee that there is assumed to be one office desk, one office chair and that there is 1 filing cabinet per 4 employees.
For shelving, it is assumed that one rack with a width of 1.76 m is used per 4.1 m2 (when a 3.65 m spacing is applied) in a store where 70% of the floor area is used for shelving (Ikea #1, 2016; Eckelman et al., 2007). The average floor size is 133 m2 for a convenience store and 178 m2 for a non-convenience store (Gemeente Amsterdam- Dienst Onderzoek en Statistiek, 2007). With the Amsterdam open geo data on the number and location of (non) convenience stores, the final amount of racks could be calculated.
From the previously conducted stock estimation in Connecticut, it was found that each restaurant establishment has about as much metal contents as a new McDonalds establishment (Eckelman et al., 2007). The Amsterdam open geodata was used to find the number and location of restaurants. In the same stock estimation, the metal content for (automotive) repair tools were found per repair. The number and location of the repair shop is also provided by the Amsterdam open geodata.
Furthermore, it is assumed that every 10 commercial stores share one metal dumpster and that every industrial business owns 3 metal dumpsters. The number and location of stores and industrial business can be found on the Amsterdam open geodata.
The toughest estimation to make for commercial goods are the hospital and laboratory equipment. With the lack of information on the location and sizes of laboratories in Amsterdam, the per-capita findings of the Connecticut stock estimation papers were used and scaled to Amsterdam. The distribution of the metals were done according to hospital beds in each region (Sint Lucas Andreas Ziekenhuis, 2015).
All lifetime estimations are taken from a property manual from Nevada Department of Taxation (2011).

Iron and steel

Table A2.13: An overview of iron/steel contents taken into consideration for the commercial appliances category.

Object	Iron/steel stock in tonnes	Average assumed weight in kg	Iron/steel content in kg or %	Source
Refrigerators/freezers	1234	84.5	61 %	Kim et al.(2006)
Mini fridges (hotels)	241	15	61 %	Kim et al.(2006)
Washing machines	202	225	50.7 %	XXL Horeca (2016); Truttman & Rechberger (2006)
Dryers	202	225	50.7 %	XXL Horeca (2016); Truttman & Rechberger (2006) * Assumed to me similar to washing machines
Dishwashers	226	60	50 %	XXL Horeca (2016); Truttman & Rechberger (2006)
Stove/oven	867	80	72%	Horecaworld (2016); Öko-Institut (2011)
Microwaves	201	15	71.3 %	Truttman & Rechberger (2006)
Computers	1138	9.9	28.6 %	EMPA (2009)
Televisions	43	5.1	19 %	Coolblue (2016; Eckelman et al. (2007)
Telephones	4	0.2	70 %	EMPA (2009); Wrap (2012)
Stereo/Radio	5	3	10 %	Eckelman et al. (2007)
Copiers/Printers	114	80	42.13 %	WRAP (2012)
Beds	483	8	100 %	Woon Express (2016)

Filing cabinet	4654	90	100 %	Corcraft (no year)
Shelving	13353	61.3	100 %	Ikea #1 (2016)
Office desks	11855	21.07	100 %	Ikea #2(2016)
Office chairs	5626	10	100 %	Ikea #3 (2016)
Restaurant equipment (per retaurant)	4900	2000	100 %	Eckelman et al. (2007); Nickel Institute (2005)
Automotive tools (per repair shop)	652	453.5	85 %	Eckelman et al. (2007)
Dumpsters	6704	317.5	100 %	Eckelman et al. (2007
Laboratory/hospital equipment	4149	-	5.1 kg/cap	Eckelman et al. (2007)

Aluminum

Table A2.14: An overview of aluminum contents taken into consideration for the commercial goods category.

Object	Aluminum stock in tonnes	Average assumed weight in kg	Aluminum content in kg or %	Source
Refrigerators/freezers	239	84.5	3 %	Kim et al.(2006); Recalde et al. (2008)
Mini fridges (hotels)	12	15	3 %	Kim et al.(2006); Recalde et al (2008)
Washing machines	11	225	2.8 %	XXL Horeca (2016); Recalde et al. (2008)
Dryers	11	225	2.8 %	XXL Horeca (2016); Recalde et al. (2008)
Dishwashers	16	60	3.5 %	XXL Horeca (2016); Recalde et al. (2008)
Stove/oven	24	80	2 %	Horecaworld (2016); Recalde et al. (2008)
Microwaves	9	15	0.5 kg	Recalde et al. (2008)
Computers	378	9.9	9.5 %	US EPA (2015)
Televisions	2	5.1	1 %	Coolblue (2016; Eckelman et al. (2007)
Telephones	1	0.2	1 %	EMPA (2009); Wrap (2012)
Stereo/Radio	1	3	2 %	Eckelman et al. (2007)
Copiers/Printers	17	80	5 kg	Recalde et al. (2008)
Automotive tools	38	453.5	5 %	Recalde et al. (2008)
Laboratory/hospital equipment	81	-	0.1 kg/cap	Recalde et al. (2008)

Copper

Table A2.15: An overview of copper contents taken into consideration for the commercial goods category

Object	Copper stock in tonnes	Average assumed weight in kg	Copper content in kg or %	Source
Refrigerators/freezers	61	84.5	3 %	Kim et al.(2006); Rauch et al. (2007)
Mini fridges (hotels)	12	15	3 %	Kim et al.(2006); Rauch et al. (2007)
Washing machines	10	225	2.4 %	XXL Horeca (2016); Truttman & Rechberger (2006)
Dryers	10	225	2.4 %	XXL Horeca (2016); Recalde et al. (2008)
Dishwashers	11	60	2.5 %	XXL Horeca (2016); US EPA (2015)
Stove/oven	2	80	0.2 %	Horecaworld (2016); Rauch et al. (2007)
Microwaves	11	15	3.9 %	Rauch et al. (2007)
Computers	263	9.9	6.6 %	US EPA (2015)
Televisions	11	5.1	5 %	Coolblue (2016; Truttman & Rechberger (2006)
Telephones	5	0.2	8.92 %	Rauch et al. (2007)
Stereo/Radio	1	3	3 %	Rauch et al. (2007)
Automotive tools	17	453.5	10 kg	Rauch et al. (2007)

Appendix 2e: Industrial goods

Table A2.16: overview of products included in the industrial category, their amounts in the city of Amsterdam and their lifetimes.

Object	Total number of objects	Source object	Average lifetime	Source lifetime
Tractors	82	Drimble (2016)	15 years	Nevada Department of Taxation (2011)
Agricultural machinery	246	Drimble (2016)	15 years	"
Construction vehicles	105	Gemeente Amsterdam (2016)	15 years	"
Large cranes	42	Eckelman et al. (2007); Gemeente Amsterdam (2016)	20 years	"
Small cranes	31	Eckelman et al. (2007); Gemeente Amsterdam (2016); Google Earth	20 years	"
Tools	21854	Eckelman et al. (2007); Gemeente Amsterdam (2016)	7 years	"
Forklifts	203	Eckelman et al. (2007); Drimble(2016); European Commision- Eurostat (2016)	15 years	"
Shelving	67713	Eckelman et al. (2007); Supply Chain Magazine (2007)	15 years	"
Tanks	640	Eckelman et al. (2007); Google Earth	15 years	"
Wind turbines	39	Gemeente Amsterdam (2016)	20 years	Windmeasurementinternational (no year)
Datacenters in 1m unit	21346	Datacentrumgids (2016)	5 years	Nevada Department of Taxation (2011)
Small machinery	1.7 kg aluminum /capita; 4.6 kg copper/capita; 67.6 kg iron&steel/capita	Eckelman et al. (2007); Rauch et al. (2007); Recalde et al. (2008); Gemeente Amsterdam (2016)	17 years	"
Large machinery	1.3 kg aluminum/capita; 3.5 copper kg/capita; 60.2	Eckelman et al. (2007); Rauch et al. (2007); Recalde et al. (2008); Gemeente Amsterdam (2016)	15 years	"

	iron&steel kg/capita			

Clarification/commentary to results of total number of objects:

From Drimble (2016), it was found that there are 82 agricultural businesses within the borders of Amsterdam. It was assumed that each business owns one tractor and three units of agricultural machinery. The distribution of the agricultural businesses over the municipality of Amsterdam has been made by using the land use for agricultural establishments over the region ('bedrijvigheid sectie vestigingen landbouw, bosbouw en visserij).

In construction, it is assumed that there are 2 construction vehicles per 10000 hectare of development site (area of development site can be retrieved on the interactive maps of the City of Amsterdam). In a previous stock estimation for Connecticut it was found that each of the bigger cities of Connecticut (with a population of around 120.000) accounts for 6 large cranes. It is therefore assumed that Amsterdam, with a population of around 830.000, has a factor 7 of 6 cranes, 42 cranes, on its development sites. The cranes and construction vehicles have been distributed over the regions by using the share of the total development area in Amsterdam (Drimble, 2016). Small cranes, used at the water side of the IJ, are traced by using Google Earth. 26 small cranes have been found in Westpoort and 5 are found in Noord. It is assumed that each employee in the construction industry has a tool set and all tool sets could be distributed over each region by the amount of employees in construction ('Werkzame personen in de bouwnijverheid') (Drimble, 2016).

In the logistics industry, estimations are made for the following products; forklifts, shelving (in warehouses) and fuel/liquid storage tanks. All products are only found in Westpoort, where the port of Amsterdam lies. There are ca. 65 companies in Westpoort registered in the warehousing and distribution industry (Drimble, 2016). According to Eckelman et al.(2007), there is one forklift per 8 employees. By taking the number of the European Commission on the average size of warehousing companies in the Netherlands, which is around 25 employees (European Commission -Eurostat, 2016), it results in a total of 203 forklifts. For shelving, it was accounted for that there is one steel rack with a width of 1.76 m per 4.1 m2 for the entire 27.7 hectares of warehouse area in the port of Amsterdam (Ikea #1, 2016; Eckelman et al., 2007; Supply chain magazine, 2007). By using Google Earth, around 640 fuel/liquid storage tanks were found in the port, where the average size for the tank is taken to be 13 meter in diameter (Google Earth), 25.2 m in height with walls 6.35 cm thick (Eckelman et al., 2007)

Two types of products, wind turbines and servers in data centers, that were either not significant or were not found in Amsterdam a decade ago according to the three stock estimation papers (Eckelman et al., 2007; Recalde et al., 2008; Rauch et al., 2007), were added to the list of the products. According to the open data provided by the municipality of Amsterdam [4], there are 28 wind turbines in Westpoort, 9 in Nieuw-West and 2 in Noord. There are 26 registered datacenters in Amsterdam, for which the data floor surface area is given for 15 of those. When assumed that the other 11 data centers the data floor surface is 200 m2, the total floor area is 59766 m2 (Datacentrumgids, 2016). For a data rack of 0.8 m x 1.0 m x 2.0 m (WxHxD) (Data center solutions, 2016) with a floor area (including aisle) of 2.8 m2, there is a total of 21346 racks found in Amsterdam. The distribution of the racks was done according to the location and data floor size of the registered data centers (Datacentrumgids, 2016).

The hardest estimation to make in the category of industrial goods is small and large machinery. For this reason, the per capita amount is taken from the stock estimation paper for the state Connecticut (Eckelman et al., 2007; Recalde et al., 2008; Rauch et al., 2007). Even though Connecticut has quite a significant manufacturing industry, Amsterdam also has the fourth biggest port of Europe and is therefore this method can be justified. To get to the final figures, the per capita weight has been multiplied by the number of inhabitants of Amsterdam, and then distributed over the regions according to the distribution of industrial offices ("Business- Industrial Areas")(Gemeente Amsterdam, 2016).
All lifetime estimations are taken from a property manual from Nevada Department of Taxation (2011).

Iron and steel

Table A2.17: An overview of iron/steel contents taken into consideration for the industrial goods category.

Object	Iron/steel stock in tonnes	Average assumed weight in kg	Iron/steel content in kg or %	Source
Tractors	517	7000	90 %	Van Kampen (2003); Eckelman et al. (2007)
Agricultural machinery	261	1250	85 %	Devos Agri(2016); Eckelman et al. (2007)
Vehicles	2174	23000	90 %	Werktuigen.nl (2016);Eckelman et al. (2007)
Large cranes	9716	272155	85%	Eckelman et al. (2007)
Small cranes	2390	90718	85%	Eckelman et al. (2007)
Tools	261	22.6	90 %	Eckelman et al. (2007)
Forklifts	568	4000	70 %	Eckelman et al. (2007)
Shelving	4151	61.3	61.3 kg	Ikea #1 (2016)
Tanks	343718	537059	100%	Eckelman et al. (2007); Google Earth
Wind turbines	9163	-	234961	Haapala & Prempreeda (2014_
Datacenters in 1m unit	5217	900	244	Datacentrumgids (2016); Meza et al. (2010)
Small machinery	56592	-	67.6	Eckelman et al. (2007)
Large machinery	50397	-	60.2	Eckelman et al. (2007)

Aluminum

Table A2.18: An overview of aluminum contents taken into consideration for the industrial goods category.

Object	Aluminum stock in tonnes	Average assumed weight in kg	Aluminum content in kg or %	Source
Tractors	3	7000	0.5%	Van Kampen (2003); Recalde et al. (2008)
Agricultural machinery	3	1250	1%	Kim et al.(2006); Recalde et al. (2008)
Vehicles	12	23000	0.5 %	Werktuigen.nl (2016); Recalde et al (2008)
Large cranes	57	272155	0.5 %	Recalde et al. (2008)
Small cranes	14	90718	0.5%	Recalde et al. (2008)
Tools	1	22.6	0.2 %	Recalde et al. (2008)
Forklifts	6	4000	30 kg	Recalde et al. (2008)
Wind turbines	19	-	490 kg	Haapala & Prempreeda (2014_
Datacenters in 1m unit	3089	900	145 kg	Datacentrumgids (2016); Meza et al. (2010)
Small machinery	1423	-	1.7	Recalde et al. (2008)
Large machinery	1088	-	1.3	Recalde et al. (2008)

Copper

Table A2.19: An overview of copper contents taken into consideration for the industrial goods category.

Object	Copper stock in tonnes	Average assumed weight in kg	Copper content in kg or %	Source
Tractors	2	7000	29 kg	Van Kampen (2003); Rauch et al. (2007)
Agricultural machinery	7	1250	29 kg	Werktuigen.nl (2016); Rauch et al. (2007)
Vehicles	12	23000	0.5 %	Rauch et al. (2007)
Large cranes	441	272155	10500	Rauch et al. (2007)
Small cranes	109	90718	3500	Rauch et al. (2007)
Forklifts	13	4000	63 kg	Rauch et al. (2007)
Wind turbines	83	-	2123	Haapala & Prempreeda (2014)
Datacenters in 1m unit	2660	900	125 kg	Datacentrumgids (2016); Meza et al. (2010)
Small machinery	3865	-	4.6	Rauch et al. (2007)
Large machinery	2915	-	3.5	Rauch et al. (2007)

Appendix 2f: Public goods

Table A2.20 shows an overview of the products, their amounts and lifetime for public goods. The tables below show the amount of metals in the products.

Table A2.20: overview of objects taken into account for Public goods

Object	Total number of objects	Source object	Average lifetime	Source lifetime
Amsterdammertjes	11616	Allesoveramsterdammertjes.nl, 2016	15 years	Mokums.nl, 2016
ATM's	341	Mastercard.com, 2016	15 years	Computable.nl, 2016
Billboards	13	JCDecaux, 2016	11 years	JCDecaux, 2016
Bins	1500	Publicspaceinfo.nl, 2016	10 years	Publicspaceinfo.nl, 2016
Bulky canal waste	260 (in tonnes of weight)	Waternet, 2016	1 year	Waternet, 2016
Children playground items:				
monkeybars	27	Kidsproof.nl, 2016	10 years	Publicspaceinfo.nl, 2016
slide	27	Kidsproof.nl, 2016	10 years	Gotsis et al, 2003
Coins:				
€0.01	91851	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
€0.02	71419	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
€0.05	55969	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
€0.10	41102	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
€0.20	31451	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
€0.50	17436	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
€1.-	20799	Tradingeconomics.c	15 years	Rijksoverheid.nl, 2016

		om, 2016. Statline.nl, 2016		
€2.-	16527	Tradingeconomics.com, 2016. Statline.nl, 2016	15 years	Rijksoverheid.nl, 2016
Fuel station equipments	252	Detelefoongids.nl, 2016	20 years	Tankstationinstallaties.nl, 2016
Market stands	74	Maps.amsterdam.nl, 2016	15 years	Markt Leiden, 2016
Public sportsfields:				
soccer fields	285	Maps.amsterdam.nl, 2016	20 years	Knvb, 2016
Security camera's	1100	Gemeente Amsterdam, 2016	6 years	Camerainstallatie.nl, 2016
Statues	213	Gemeente Amsterdam, 2016	Forever	-
Urinoirs	35	Data.overheid.nl, 2016	15 years	Urilift.nl, 2016

Iron and steel

Table A2.21: An overview of products, their iron content and the sources for the public goods.

Object	Iron stock in tonnes	Average assumed weight in kg	Iron content	Source
Amsterdammertjes	0.2904	25	100%	www.allesoveramsterdammertjes.nl (2016)
ATMs	0.1705	510	98%	Sahni, Boustani et al. (2010)
Billboards	0.01	8255	92%	JCDecaux (2016)
Bins	0.027	18	100%	Afvalcontainerkopen.nl (2016)
Bulky canal waste	260	-	100%	Waternet (2016)
Coins:				
€0.05	0.002	0.0039	92%	Koninklijke Nederlandse Munt (2016)
€0.02	0.002	0.003	96%	Koninklijke Nederlandse Munt (2016)
€0.01	0.002	0.0023	94%	Koninklijke Nederlandse Munt (2016)
Fuel station equipment	0.063	250	100%	Gilbargo (2016)
Markets	0.088	60	100%	Albert Cuyp markt (2016)
Monkeybars	0.006	23.16	100%	Klimrek.nl (2016)
Security cameras	0.004	0.4	100%	Bol.com (2016)
Slide	0.003	117	100%	bol.com (2016)
Urinoir	0.027	204	100%	Data.overheid.nl (2016)

The “Amsterdammertjes” have been found to weight 25kg per piece (Gemeente Amsterdam, 2016). Ever since 2003 they are being removed from the city streets by 2000 a year (Alles over Amsterdammertjes, 2007). This was extrapolated to calculate the number of Amsterdammertjes for 2016.
The ATM’s were found to be weighing between 500 and 800 kg (Die Welt, 2009). The lower boundary was taken to be able to make a minimum estimation.
For the bins, no information on the weight could be found. Therefore the bins are assumed to be completely made of iron and the sizes of a representative bin have been used what resulted in a weight of 18 kg per bin.
In the bulky canal waste was data provided by Waternet. Employees go “scrap fishing” every year, what is

yielded are bicycles, shopping charts, light wreck boats etc. In 2015 this was about 260 tonnes. All of it was transported to scrap traders that sort it better per metal. There was also about
30 000m3 dredged material but the metal content of that was unknown and therefore not taken into account.
There are 27 children playgrounds in Amsterdam (Kidsproof, 2016), no information on the available equipment was found. Therefore the number of money bars and slides in Amsterdam have been extrapolated from the assumption that every playground has 3 bars and one slide. All are assumed to be made of iron with the same thickness and the foundations are assumed to be made of other materials. For the calculated sizes, productinformation of the equipment have been used.
For the coins, information on the total amount of every kind of coin in the EU has been taken (Statistical Data Warehouse, 2016). This was interpolated by the rate of the GDP of the Netherlands to the EU (Trading Economics, 2016). This resulted in the amount of every coin in the Netherlands. Second, the rate of inhabitants of Amsterdam to the Netherlands was used to calculate the amount of every coin in the city. For the steel used in the €0.05, €0.02 and €0.01, the information of the Royal Dutch Coin was used and multiplied per number of coins in the city (Koningklijke Nederlandse Munt, 2016).
There were 42 fuel stations found in Amsterdam (Telefoongids, 2016). Assumed it that every station has 6 fuel dispenser. From productinformation on such a dispensed, the total surface was calculated and assumed to be made out of iron. All other parts are assumed to be made out of other materials than iron/copper/aluminum.
In the city of Amsterdam, there are 74 markets (Maps Amsterdam, 2016).Assumed is that every market has 20 stands (for reference: the Albert Kuyp market has around 25). From productinformation on market stands, it was calculated that a stand is made of 60 kg of iron.
According to the Advisor of Transport Systems of the municipality, there are about 1100 surveillance camera's in the city. Assumed from various product descriptions, the weight of a camera is 0.4 kg. Assumed is they are made of 25% aluminum.

Aluminum

Table A2.22: An overview of products, their aluminum content and the sources for the public goods.

Object	Aluminum stock in tonnes	Average assumed weight in kg	Aluminum content	Source
ATMs	0.013	510	0.7%	Sahni, Boustani et al. (2010)
Billboards	0.0006	45	8%	JCDecaux. 2016
Coins:				
€0.50	0.007	0.008	86	Koninklijke Nederlandse Munt (2016)
€0.20	0.009	0.0057	90	Koninklijke Nederlandse Munt (2016)
€0.10	0.008	0.004	91	Koninklijke Nederlandse Munt (2016)
Soccerfields	0.011	38	100	voetbalgoals.nl

The ATM''s have a build-in computer, that is assumed to be one that is comparable to the one used in households. The same amounts of aluminum are used as the household computers (Sahni, Boustani et al., 2010). The billboards are equipped with a body made mostly from aluminum, according to the building drawings supplied by JCDecaux Nederland BV.
For the coins of €0.50, €0.20 and €0.10, aluminum is used. The information of amount of aluminum per coin was taken (Koningklijke Nederlandse Munt, 2016) and multiplied with the number of coins in Amsterdam (Statistical Data Warehouse, 2016) (Trading Economics. 2016).
According to the municipality's database, there are 285 soccer fields in the city. From product information it was learned that goals are made of 38 kg aluminum, so this is assumed for all soccer fields, also the public ones. Assumed is that every soccer field has 2 goals, 570 goals were calculated.

Copper

Table A2.23: An overview of products, their copper content and the sources for the public goods.

Object	Copper stock in tonnes	Average assumed weight in kg	Copper content	Source
ATMs	0.03	510	1.3%	Sahni, Boustani et al. (2010)
Coins:				
€2	0.105	0.0085	75%	Koninklijke Nederlandse Munt (2016)
€1	0.117	0.0075	75%	Koninklijke Nederlandse Munt (2016)
€0.50	0.121	0.0078	90%	Koninklijke Nederlandse Munt (2016)
€0.20	0.161	0.0057	90%	Koninklijke Nederlandse Munt (2016)
€0.10	0.15	0.0041	89%	Koninklijke Nederlandse Munt (2016)
€0.05	0.012	0.004	5.5%	Koninklijke Nederlandse Munt (2016)
€0.02	0.012	0.003	5.6%	Koninklijke Nederlandse Munt (2016)
€0.01	0.012	0.002	6.5%	Koninklijke Nederlandse Munt (2016)

The only copper found in this category is in ATM's and coins. The ATM'st are assumed to be equipped with a computer, as explained before, that contains some copper (Sahni, Boustani et al., 2010).
The other suppliers of copper in this category are the coins. The estimations to calculate the amount of coins in Amsterdam and the amount of copper per coin have been used again (Koningklijke Nederlandse Munt, 2016) (Statistical Data Warehouse, 2016) (Trading Economics. 2016).

Appendix 2g: Stock estimations per district

Table A2.24: an overview of stock estimations per district, amounts given in tonnes (if no metal type described, the amount is negligible).

	Transport	Infrastructure	Public goods	Household appliances	Commercial goods	Industrial machinery
Noord	Fe:28596. Al:40 91.9 Cu:7 25.1	Fe:3861 Cu:5678	Fe:28.9 Cu:0. 1	Fe:8800 Al:45 4 Cu:4 39	Fe:4121 Al:57 Cu:2 5	Fe:13846 Al:27 2 Cu:7 82
Centrum	Fe:20227.8 Al:2904.4 Cu:511.7	Fe:12078 Cu:5542	Fe:28.0 Cu:0. 1	Fe:8538 Al:44 0 Cu:4 26	Fe:12150 Al:17 1 Cu:9 1	Fe:697 Al:55 Cu:7 0
Zuid	Fe:39499.7 Al:5721.6 Cu:1 024.7	Fe:16737 Cu:8966	Fe:45.4 Cu:0.1	Fe:13837 Al:71 3 Cu:6 90	Fe:11694 Al:17 8 Cu:8 8	Fe:3015 Al:75 Cu:1 89
Zuid-oost	Fe:26762.8 Al:3747.8 Cu:6 73.6	Fe:9818 Cu:5423	Fe:27.4 Cu:0. 1	Fe:8347 Al:43 0 Cu:4 16	Fe:5803 Al:95 Cu:4 2	Fe:7200 Al:77 3 Cu:9 20
Westpoort	Fe:6675.2 Al:68 0.0 Cu:1 13.8	Fe:4008 Cu:52	Fe:0.2	Fe:48 Al:2 Cu:2	Fe:884 Al:16 Cu:1 0	Fe:428369 Al:2011 Cu:4 857
West	Fe:30151.0 Al:4361.5 Cu:7 70.0	Fe:11452 Cu:8808	Fe:44.7 Cu:0.1	Fe:13606 Al:70 1 Cu:679	Fe:6394 Al:91 Cu:4 5	Fe:7513 Al:295 Cu:5 63
Nieuw-west	Fe:40966.6 Al:5909.2 Cu:1 055.0	Fe:36414 Cu:9249	Fe:46.3 Cu:0.1	Fe:14091 Al:72 6 Cu:7 03	Fe:7876 Al:11 8 Cu:5 3	Fe:17614 Al:15 85 Cu:1 926
Oost	Fe:31474.1 Al:4512.9 Cu:8 01.4	Fe:26865 Cu:8048	Fe:40.4 Cu:0.1	Fe:12309 Al:63 5 Cu:6 14	Fe:7934 Al:11 7 Cu:5 9	Fe:6871 Al:65 2 Cu:7 97

Appendix 3 - Monetary value

Using the scrap prices of aluminum, copper and iron, the monetary worth of products in each category was calculated and are presented in the following tables.

Transport

	Fe	Al	Cu	TOTAL
Personal cars	30 736 000€	17 689 100€	19 495 125€	67 920 225€
Business cars	319 520€	183 950€	201 500€	704 970€
Business vans	2 689 280€	1 612 650€	1 705 000€	6 006 930€
Business trucks	1 367 840€	187 200€	85 250€	1 640 290€
motorcycles	302 560€	526 500€	209 250€	1 038 310€
Trams	220 960€	2 169 050€	844 750€	3 234 760€
Bikes	788 480€	2 844 400€	0€	3 632 880€
Scooters	481 440€	554 450€	294 500€	1 330 390€
Buses	159 680€	170 950€	120 125€	450 755€
Metro's	643 840€	1 660 750€	837 000€	3 141 590€
TOTAL	37 709 600€	27 599 000€	23 792 500€	89 101 100€

Household appliances

	Fe	Al	Cu	TOTAL
Printers	44000	37700	54250	135 950€
Cellphones	3360	14300	0	17 660€
Laptop computers	56160	17550	209250	282 960€
Desktop PC	96960	131950	546375	775 285€
Televisions	345920	165100	2464500	2 975 520€
Dishwashers	813440	165100	984250	1 962 790€
Dryers	1347840	122200	2084750	3 554 790€
Washing machines	2525280	512850	2898500	5 936 630€
Hoovers	221440	309400	922250	1 453 090€
Ovens	3090240	348400	209250	3 647 890€
Microwave ovens	622240	138450	817625	1 578 315€
Refrigerator-freezers	3565120	703300	4192750	8 461 170€
TOTAL	12732000	2666300	15383750	30 782 050€

Infrastructure

	Fe	Cu	TOTAL
Bicycle parkingspots	315 200€	0€	315 200€
Traffic lights	0€	744 000€	744 000€
Metrolines	734 400€	0€	734 400€
Tramlines	3 821 120€	0€	3 821 120€
Distribution cables for electricity	0€	96 355 750€	96 355 750€
Drinking water pipes	66 080€	92 775 250€	92 841 330€
Hydrants	535 520€	0€	535 520€
Service connection drinking water	0€	387 500€	387 500€
Pumps	5 120€	0€	5 120€
Manhole covers on highways	23 360€	0€	23 360€
Grates on local roads	92 960€	0€	92 960€
Streetlights	662 240€	8 451 375€	9 113 615€
Trainrails	5 356 320€	0€	5 356 320€
Overhead contact system of railroad: poles	5 962 080€	0€	5 962 080€
Overhead contact system of railroad: wires	0€	1 650 750€	1 650 750€
Tunnels	14 880€	0€	14 880€
Street signs small	67 680€	0€	67 680€
Street signs big (highway)	23 040€	0€	23 040€
Overhead trusses (highway)	449 600€	0€	449 600€
Guard rail	494 240€	0€	494 240€
Public transport stops-stations; abri	110 400€	0€	110 400€
Copper cables for telecommunication	0€	232 500€	232 500€
Manholes for telecommunication	83 200€	0€	83 200€
TOTAL	18 817 440€	200 597 125€	219 414 565€

Commercial equipment

	Fe	Al	Cu	
Refrigerators/freezers	197 440€	155 350€	236 375€	589 165€
Mini fridges (hotels)	38 560€	7 800€	46 500€	92 860€
Washing machines	32 320€	7 150€	38 750€	78 220€
Dryers	32 320€	7 150€	38 750€	78 220€
Dishwashers	36 160€	10 400€	42 625€	89 185€
Stove/oven	138 720€	15 600€	7 750€	162 070€
Microwaves	32 160€	5 850€	42 625€	80 635€
Computers	182 080€	245 700€	1 019 125€	1 446 905€
Televisions	6 880€	1 300€	42 625€	50 805€
Telephones	640€	650€	19 375€	20 665€
Stereo/Radio	800€	650€	3 875€	5 325€
Copiers/Printers	18 240€	11 050€	0€	29 290€
Beds	77 280€	0€	0€	77 280€
Filing cabinet	744 640€	0€	0€	744 640€
Shelving	2 136 480€	0€	0€	2 136 480€
Office desks	1 896 800€	0€	0€	1 896 800€
Office chairs	900 160€	0€	0€	900 160€
Restaurant equipment	784 000€	0€	0€	784 000€
Automotive tools	104 320€	24 700€	65 875€	194 895€
Dumpsters	1 072 640€	0€	0€	1 072 640€
Laboratory/hospital equipment	663 840€	52 650€	0€	716 490€
TOTAL	9 096 480€	546 000€	1 604 250€	11 246 730€

Industrial equipment

	Fe	Al	Cu	TOTAL
Tractors	9 054 720€	924 950€	14 976 875€	24 956 545€
Agricultural machinery	8 063 520€	707 200€	11 295 625€	20 066 345€
Vehicles	347 840€	7 800€	46 500€	402 140€
Large cranes	1 554 560€	37 050€	1 708 875€	3 300 485€
Small cranes	382 400€	9 100€	422 375€	813 875€
Tools	41 760€	650€	0€	42 410€
Forklifts	90 880€	3 900€	50 375€	145 155€
Shelving	664 160€	0€	0€	664 160€
Tanks	54 994 880€	0€	0€	54 994 880€
Windmills	1 466 080€	12 350€	321 625€	1 800 055€
Datacenters in 1m unit	834 720€	2 007 850€	10 307 500€	13 150 070€
Small machinery	9 054 720€	924 950€	14 976 875€	24 956 545€
Large machinery	8 063 520€	707 200€	11 295 625€	20 066 345€
TOTAL	94 613 760€	5 343 000€	65 402 250€	165 359 010€

Public goods/other

	Fe
Bins	4 320€
Security cameras	13€
Market stands	704€
Bulky canal waste	41 600€
Coins (money)	96€
Fuel station equipment	1 008€
ATMs	27 280€
Amsterdammertjes	48€
TOTAL	75 069€

Appendix 4 - Web app

Web mapping directly maps specific geographic data to region-divided world maps. This technique is commonly used in Geographical Information Systems (GIS) with the use of standardized geographic data infrastructure and plotting mechanisms. Web mapping is only part of the process of putting an interactive map accessible on the Internet. Web application development need for instance Web frameworks that assist in building (interactive) web pages. Web frameworks are designed to eliminate the overhead needed in web application development. In simple words without Web frameworks you have to explicitly code all aspects such as HTTP communication, and interaction of otherwise separate modules. Web development would take much more time and would be very difficult to achieve. The Web framework used in this project is called Django and is based upon the programming language Python [1].

Leaflet

Leaflet is a JavaScript library for developing user-friendly interactive maps [2]. Whereas JavaScript in general is a way to program the behavior of web pages and to built dynamic pages [3]. Many libraries of JavaScript have been developed that are freely reusable by other developers, one of them is the Leaflet library specialized in the creation of interactive maps.

Django-leaflet

Django-leaflet provides a way to easily embed the Leaflet library in the Django Web framework. Within the Django configurations, settings can be adjusted for Leaflet maps [4].

GeoJson

GeoJson however is not a JavaScript library, but are geographical JSON objects. This means that it contains geographical data that can be used by the Leaflet JavaScript library [4]. JSON itself is officially called a language agnostic data-interchange format. It is inspired by data interchange in JavaScript through JavaScript objects. Basically there are for example occasions in which data needs to be shared in different applications. JSON objects provide ways for communication in between different applications.

Django-geojson

Similar to Django-leaflet is Django-geojson an embedding of JavaScript assets in Django. Django-geojson is used to manipulate GeoJson objects that are shown on the interactive map.

Datasets used for PUMA

All datasets used for the PUMA projects are from Esri Shape files, which are geospatial vector data that can be used by GIS software [5]. However in this project the Esri Shape files are converted to GeoJson objects by a software data convert tool called “ogr2ogr”. These GeoJson objects contain more information than needed such as the infrastructure of bicycle pads in Amsterdam, hence Python scripts are developed to filter out data. Not only filtering is necessary, also adding additional data from our own research results are done with Python scripts.

Amsterdam region data and metro line data were gathered from Amsterdam's Open Geo Data datasets [6]. Namely “Administrative Areas” for region data and “Plusnetworks infrastructure” for metro line data. Due to mixing of bus line with tram line data it was not possible to used the

"Plusnetworks infrastructure" dataset for tram. In turn for the tram lines the dataset from Open OV was used [7]. For train line data the VU GeoPlaze dataset platform was used [8].

Commands

Commands used for conversion are described below, the commands provided here are used in the Linux command shell.

```
#convert regional shape file to regional GeoJson

$ogr2ogr -f GeoJSON -t_srs crs:84 Stadsdelen.geojson  Stadsdelen_region.shp

#convert plusnetworks shape file to geoJson

$ogr2ogr -f GeoJSON -t_srs crs:84 test.geojson Plusnetten_polyline.shp

#convert Open OV shape file to geojson

$ogr2ogr -f GeoJSON -t_srs crs:84 all2.geojson shape_counter.shp

#convert train line shape file to geojson

$ogr2ogr -f GeoJSON -t_srs crs:84 train.geojson railways_nl_2015.shp
```

References

[1]https://www.djangoproject.com/

[2] http://leafletjs.com/

[3]http://www.w3schools.com/js/

[4] http://fle.github.io/easy-webmapping-with-django-leaflet-and-django-geojson.html

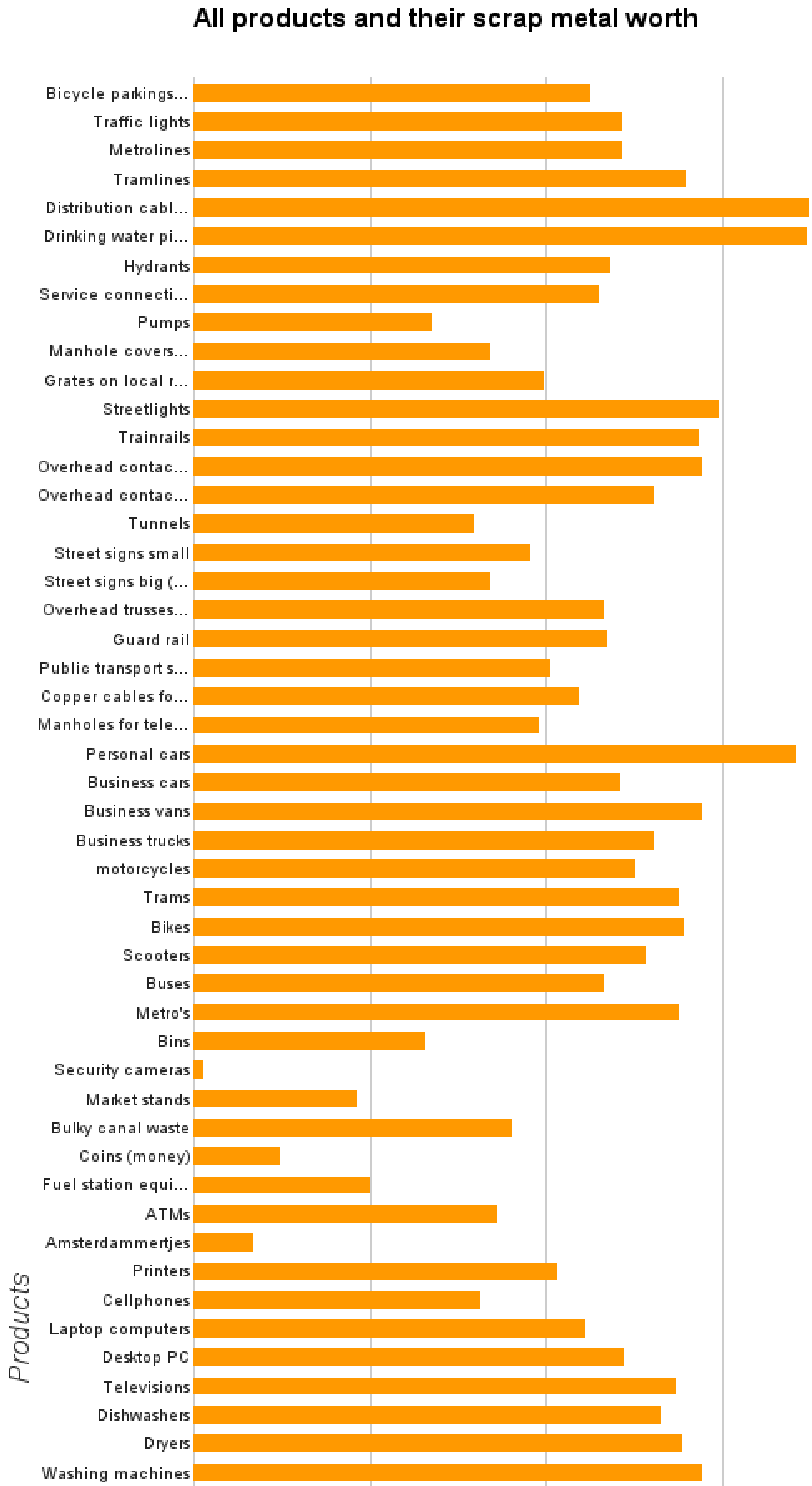
[5] https://www.esri.com/library/whitepapers/pdfs/shapefile.pdf

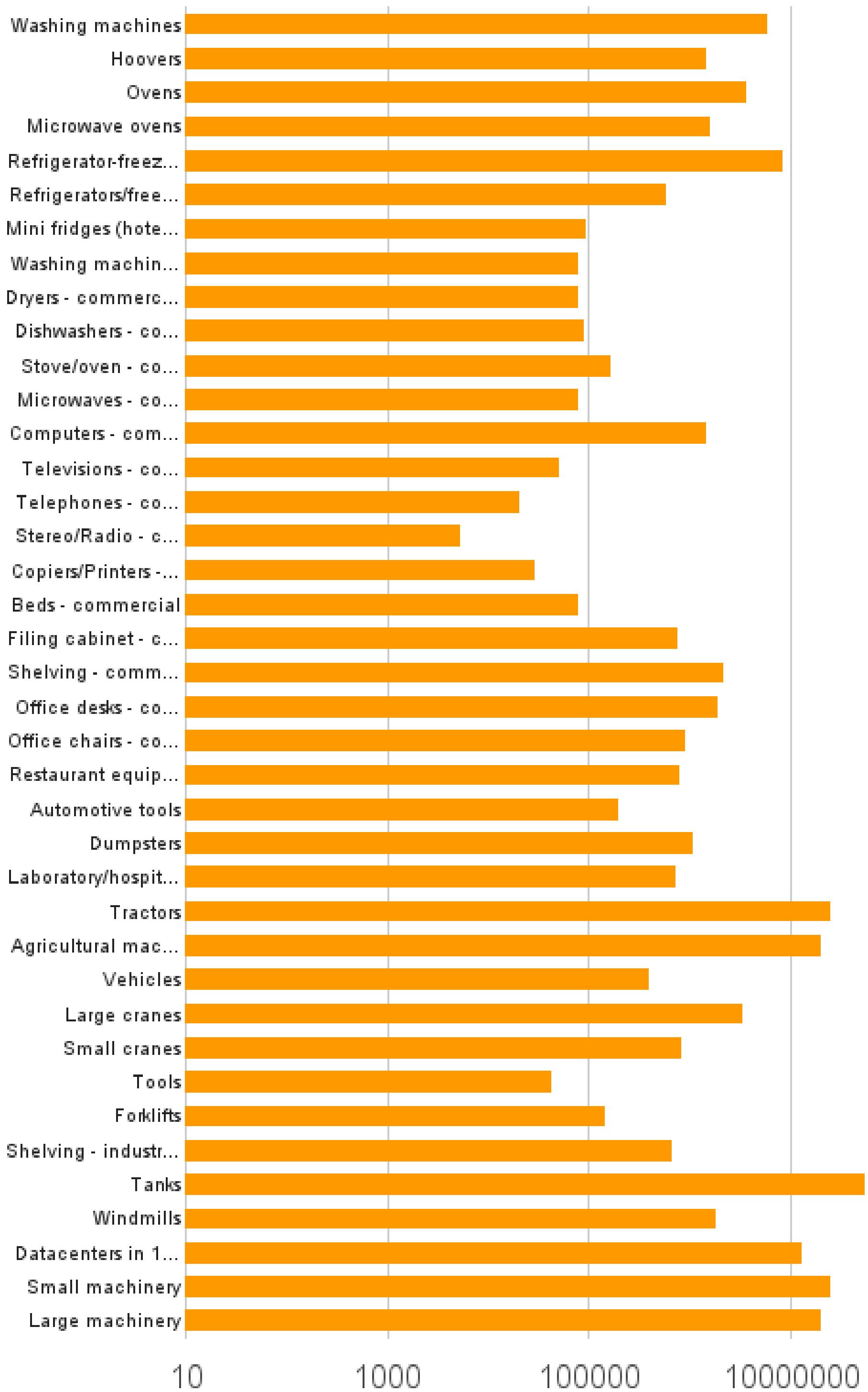
[6] http://maps.amsterdam.nl/open_geodata/

[7] http://openov.nl/

[8]http://geoplaza.vu.nl/data/dataset/railway-stations-railway-tracks/resource/d1535055-b45b-4da2-ae22-bee0e529e880

Appendix 5 - Overview of monetary value





Value (of scrap metal content) in euros - log scale

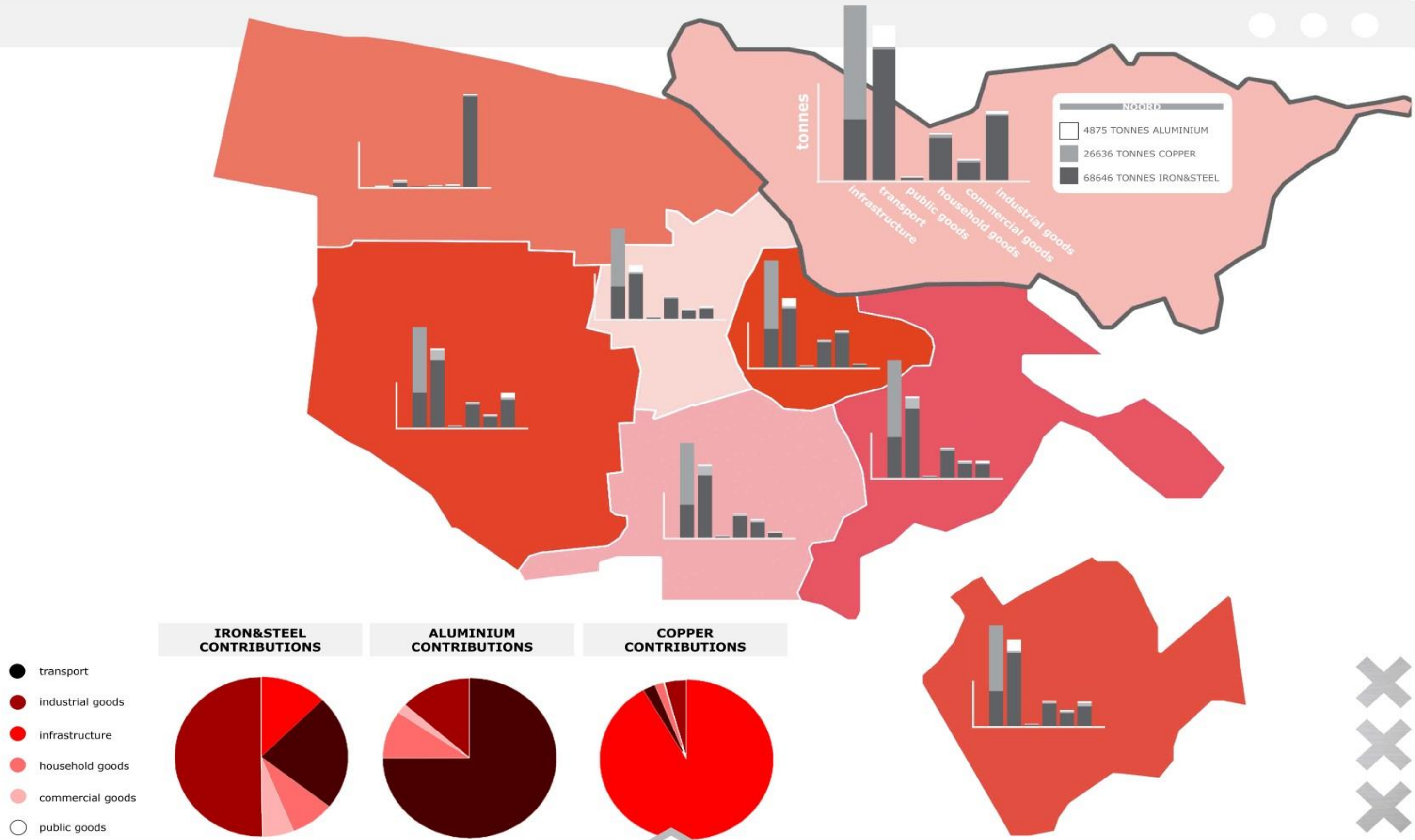
Appendix 6 – Poster

Please see the next page.

Yours or Mine?

COMMUNITY DRIVEN DATA COLLECTION SYSTEM

source	prospecting	extracting	processing
natural mine	locating metal ore deposits determining physical extractability	drilling blasting threshing	milling crushing separating refining
urban mine	**what** products contain **how much** metals and **how accessible** is the metal?	EoL product collection	dismantling sorting mechanical/ chemical separation



DATABASE

region: NOORD

product category: TRANSPORT

product type: BUS PUBLIC TRANSPORT

product ID	# of products	life expect.	%Fe	%Cu	%Al	recycling rate	reference

The stock estimation results are detailed on these 3 different aspects - the type of metals it contains, in which product group it is found, and how much of it is for each region. So basically, we want to know which metals are there, in what products they can be found, how many of these products are found in Amsterdam and lastly, where we can find these products exactly. Also one other aspect we needed to find in order to complete the urban mining database, is the life time expectancy. To answer all these questions, we hope to get input from the municipality (e.g. knowledge of public procurement), manufacturers (e.g. knowledge on metal content in products and sales within regions), public utility industries and services (e.g. waste collection information), private companies (e.g. machinery inventories) and households (for input on products in -average- households). To ensure data integrity, an editorial office or main moderator is needed to check the data regularly. This is the first step toward a functional circular economy that include novel organizational arrangements and a knowledge base on in-use products and their recoverable value.

Prospecting the Urban Mines of Amsterdam (PUMA) is a project conducted by a research partnership between AMS, TU Delft, Leiden University, de Waag and Metabolic. The main PUMA project focus is looking specifically at the possibilities of Amsterdam as an urban mine from the built environment. As a complementary study, the interdisciplinary student project team focuses on the metals in in-use products in the urban environment of Amsterdam apart from buildings. The PUMA project is expected to end at the start of 2017. PUMA is study conducted in the context of Amsterdam's recently published agenda for sustainable long-term developments, with the assumption that resources such as metals become more valuable and scarce in future scenarios.

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