Potential for Urban Mining in Norrköping
– a Static Quantification of Metal in Subterranean Infrasystems

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As the society’s demand for metal increases, the rate of mineral extraction will do the same. This contributes to environmental implications in the form of emissions and depletion of finite natural resources. Conventional recycling is a common practice used to reduce the need for extraction of metal ore and in turn reduce the environmental impact. Recycling is an important source to satisfy the metal demand; as much of 30 % of the metal demand is covered by recycling in some markets. Another form of recycling is the practice of urban mining. A practice which includes recycling of society’s stocks of unused but not discarded metal, these unused amounts metal is part of a so called hibernating stock. An example of a very large stock is the infrasystems in the shape of power cables and pipes.

The objective of this thesis is to quantify the metal stocks of copper, aluminium and iron in subterranean infrasystems in the city district of Södra Butängen in Norrköping. Also, a quantification for Norrköping as a whole is performed but on slightly different infrasystems. An economical valuation of these stocks is also performed. The Municipality of Norrköping has the ambition to transform this small industrial area, that Södra Butängen is today, into a sustainability profiled residential and commercial area which opens up an opportunity to recycle the infrasystems when all buildings are removed and the ground is dug up.

To fulfill the objective of the thesis, and quantify the metal stocks, so called static quantification was used. The infrasystems to be included in this study were chosen and the data describing these systems was collected from the respective owner of the systems. The gathered data consists of maps which were digitalized with GIS-software using ArcMap 10 where the stocks then were quantified. The results show that the infrasystems in Södra Butängen holds almost 600 tons of metal with an economical value of 4.67 million SEK. For the Norrköping quantification the results shows that the stock contains about 30,000 tons of metal. The economical value is a little over 70 million SEK. The hibernating stocks in Norrköping equals to 5,100 tons of metal and a value of 9.5 million SEK.

There is a potential for urban mining in Södra Butängen that should be considered. However, there are some issues that also must be considered, like cost of extraction. There are large stocks of metal that not have been possible to identify in this thesis. This includes the power grid for Norrköping; a valuable stock due to its large copper content.

Keywords
urban mining; copper; iron; aluminium; hibernated stock; recycling; infrasystem
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Abstract

As the society’s demand for metal increases, the rate of mineral extraction will do the same. This contributes to environmental implications in the form of emissions and depletion of finite natural resources. Conventional recycling is a common practice used to reduce the need for extraction of metal ore and in turn reduce the environmental impact. Recycling is an important source to satisfy the metal demand; as much of 30% of the metal demand is covered by recycling in some markets. Another form of recycling is the practice of urban mining. A practice which includes recycling of society’s stocks of unused but not discarded metal, these unused amounts metal is part of a so called hibernating stock. An example of a very large stock is the infrasystems in the shape of power cables and pipes.

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1 Introduction

The extraction and processing of metals from earth’s crust is vital for the support of the technological development and standard of the human society of today (UNEP, 2010). In many aspects, the society has made itself more or less dependent on this constant flow of metals from the lithosphere\(^1\) into the antroposphere\(^2\). It has been established that the flow of metals into the antroposphere is larger than its corresponding outflows; which in turn leads to an accumulation of metals in the antroposphere (Wittmer, Lichtensteiger & Wittmer, 2007).

However, there are some issues related to this practice of consuming metals. The mining and extraction of minerals is, for instance, not performed without certain environmental impact. According to Norgate and Hauge (2009) the practice of mining and processing of ore both consumes significant amounts of energy and gives rise to various pollutant emissions.

The increasing usage of metals (Wittmer, Lichtensteiger & Wittmer, 2007), and therefore the increasing extraction and mining of these metals, contributes to consumption and depletion of the finite natural resources which the metals represents. The Swedish annual copper consumption did, for instance, increase to 532 tons from 239 tons between the years 1998 to 2005. (SCB, 2009). This is also a contributing factor to decreasing ore grades, which has fallen globally (Norgate & Hauge, 2009). This could in turn lead to higher prices and also a lower supply on the metal market. Also, the environmental impacts caused by mining could increase further when more ore has to be mined in order to produce a given amount of metal (Norgate & Hauge, 2009).

One way to treat and reduce the extent of these problems is to use conventional metal recycling in which scrap metal is recycled to reduce the need of new metal into the antroposphere. The environmental benefits consist of large energy savings; in the case of aluminium recycling, up to 95 % of the energy can be saved compared to mining of the said metal (Wernick & Themelis, 1998). Recycled metal represents a relatively large portion of the total metal demand in some parts of the world; approximately 30 % of the copper demand in Europe (Graedel et al., 2004) and 50 % of the iron demand in North America (Wang, Müller & Graedel, 2007) is covered by recycled scrap metal. However, there are other methods of recovering unused metal apart from this conventional recycling. An example of a recycling method with potential is the so called practice of urban mining. Urban mining is used to recover resources, including metals, that are located within the society and that have fallen into disuse. These resources could, for instance, be in the form of buildings or infrasystems that no longer are used but still not scrapped or removed. Unused, potential resources are in urban mining terms known as hibernating. Large stocks of hibernating metal can be found in infrasystems in the form of cables (Wendell, 2005; Krook et al., 2011) and pipes. However these stocks are expensive to extract since excavation within a build city environment is often required (Krook et al., 2010).

Considering this mentioned cost issue, an exceptional opportunity, from an urban mining perspective, has now emerged. This opportunity is related to certain municipal plans concerning the area of Södra Butängen. At present, the mentioned area consists of small-scale industries and commercials activities, but the Municipality of Norrköping is planning a transformation of the whole area; from an industrial district to a modern sustainability-profiled residential and commercial area (Norrköping Municipality, 2009). If these plans would be realised, all current buildings would have to be removed and this may possibly apply to the infrasystems below ground as well. This leaves an exceptional opportunity to consider; to extract and recycle the subterranean infrasystems of a whole city district, in this case Södra Butängen. This would be a possible way of avoiding some of the costs connected to the practice of urban mining as mentioned earlier. Also, not only the hibernating parts of

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\(^1\) All solid matter, which is part of the earth’s crust.

\(^2\) Everything that is part of the human society or made or modified by humans.
the infrasystems could be extracted; the parts that are currently in use could also become available if the buildings are demolished.

This leads to the objective of this thesis which has been conducted in collaboration with the department of Environmental Technology and Management at Linköping University as a part of the projects *Urban Mining* and *Sustainable Norrköping*.

### 1.1 Objective

The aim of this thesis is to investigate the potential for urban mining in subterranean infrasystems in Södra Butängen and the city of Norrköping. To fulfill this aim, the following questions should be answered:

- How much aluminium, copper and iron are contained in the subterranean infrasystems in Södra Butängen and Norrköping respectively?
- What is the economical value of these metal stocks in Södra Butängen and Norrköping?

The metal quantification for Södra Butängen is the main focus of this thesis, the quantification of Norrköping is used to illustrate a metal content for the whole city.

### 1.2 Delimitation and definitions

This thesis is delimited to examine subterranean infrasystems made of the metals aluminium, copper, and iron\(^3\). These metals were chosen because of their significant presence in the analyzed infrasystems and their economical value. Zinc was meant to be included in the quantification, but during the work progress it became clear that no systems contained any significant amount of this metal.

Infrasystems above ground, such as aerial cables or train- and tram tracks are excluded from the study. The reason to this is that infrasystems above ground often is taken care of and recycled when no longer used. Subterranean cables and pipes on the other hand are exposed to a higher risk to become forgotten and left hibernating below ground where a stock is built up. Pipes and similar infrastructure made of non-metal materials, like plastic and concrete, are also excluded. Since the focus is set to subterranean systems; all parts of the systems inside building are excluded from the examinations.

The quantification for Södra Butängen is geographically delimited to fit the planned area of the Municipality of Norrköping as seen in figure 1 (Norrköping Municipality, 2009). For the Norrköping quantification the study is delimited to the built urban areas of the city of Norrköping, see figure 2. The chosen infrasystems for both examined areas are the district heating system, water- and sewage system and street lighting. However, for the area of Södra Butängen additional systems are examined; power cables and telephone lines. There are also additional, completely hibernating systems that are studied for Norrköping as a whole and not detailed for Södra Butängen, these are the old town gas system, a cable-TV network and the subterranean parts of the old DC-power cables to the tram system. As a complement, the modern in-use DC-cables to tram system is also included.

Where possible, a distinction between so called hibernating system parts and in-use system parts is done. Hibernating system parts are those that no longer are in active use, have lost their intended function and are considered as scrap but not physically removed or discarded. There are also cables that are not in active use, but are meant as backup in case of broken cables. In the quantification, these cables are treated as a special case since these not actively in-use nor hibernating.

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\(^3\) Includes steel and similar ferrous alloys. In the results these ferrous metals are just called “iron”.

5 (35)
Figure 1. Geographic delimitation of the studied area of Södra Butängen is shown within the black marking. Based on the municipal plans for the area (Norrköpings municipality, 2009). Modified map based on Lantmäteriet (2003). © Lantmäteriet, Medgivande I 2011/0101

Figure 2. The black border represents the geographical delimitation for Norrköping for this study. The map is modified and based on Lantmäteriet (2003). © Lantmäteriet, Medgivande I 2011/0101
2 Theoretical framework

2.1 Industrial ecology

Industrial ecology is an approach developed to meet the environmental and sustainability issues created by the industry and the industrial society. These issues exist in the form of resource depletion, pollution and disturbance of natural ecosystems (O’Rourke, Connelly & Koshland, 1996). In order to allow for industrial development in a sustainable way, and avoid conflict with the natural environment, there are several goals that industrial ecology strive for. One of the major goals is to optimize the usage of natural resource and to minimize the creation of waste. To achieve this several strategies are used; material substitution, dematerialization, recycling and industrial symbiosis. The latter two are essential in the strife towards the closing of material flows in society which is central to the concept of industrial ecology (O’Rourke, Connelly & Koshland, 1996). This means that the waste of one industrial process should constitute the feedstock of another industrial process as far as possible (O’Rourke, Connelly, Koshland, 1996; Garner & Keolian, 1995), in essence this is an attempt to mimic natural ecosystems and their processes (Frosch, 1992).

In order to study the effects on, amongst else, the environment caused by industrial processes of the modern society, industrial or societal metabolism studies could be used (Anderberg, 1998). These studies could identify the flows of materials into, out from and within the society. For these studies material flow analysis is a useful method and tool.

2.2 Material flow analysis

An established method to investigate and quantify the flows of certain materials or substances in the society is the so called material flow analysis (MFA). MFA as a tool and method can be, and has been, used in many different ways. It has, for example, been used to quantify inflows, non-hibernating stocks and accumulation of heavy metals in Stockholm (Sörme, Bergbäck & Lohm, 2000). Another study by Spatari et al. (2005) makes use of MFA to investigate the flows of copper in North America. The study then estimates the accumulation of copper in landfills to examine the potential to recycle and use them as a source of secondary resources. Also, Wendell (2005) has used MFA to quantify the flows of metal into and out from the stock of power and communication cables where hibernating amounts of copper and aluminium was quantified.

According to Brunner and Rechberger (2004), MFA is based on the estimation of flows of certain substances or materials into and out from a defined system during a certain period of time. In short, the MFA process is described by Brunner and Rechberger (2004) as follows. The first step is to select which materials or substances to analyze; this depends on the aim of the study. The next step is to define the boundaries and delimitations in both time and space of the studied system. Then the relevant stocks and flows must be identified to thereafter determine the mass and concentration of these stocks and flows. When the size of the inflows and outflows of an analyzed system is known, the accumulation in the stocks can be estimated.

However, Kapur and Graedel (2006) suggest another approach to MFA that can be used in urban mining applications; the static or the bottom-up approach. This is in contrast to the previously mentioned MFA process where stocks and flows are investigated. Using the static method, the material content in a geographical delimited area and stock is directly determined and quantified. No material flows related to the system are considered. The quantification of the stock is done via collection of data describing the system, its material content and components. This static approach has not been used so much in earlier studies, and therefore not much is written about it in literature. It can in some ways be considered a relatively new method. This is the used method in this thesis because this method offers relatively high precision in quantifying the stocks.
2.3 Urban Mining

As an example of a state-of-the-art application related to the concept of industrial ecology is urban mining. Urban mining is used to study flows and stocks of metals in the society and to investigate the potential to “mine” this metal as a secondary recourse.

As the inflow of metals to society is larger than the corresponding outflow, a stock of metals is built up (Klinglmair & Fellner, 2010). This stock is often known as the employed stock (stocks are shown figure 3) (Kapur & Graedel, 2006), and consists of all the metal that is part of, and has a function in, the human society. This is distinguish from the other two main type of stocks; the geochemical stock from which new metal ore is mined in the lithosphere, and expended stock in which unused scrap metal ends up (Kapur & Graedel, 2006). This is where a complement to conventional recycling enters the picture; urban mining. The aim of urban mining is to extract and recycle metals from this employed stock. This is distinguished from the conventional recycling where only scrap metal from the expended stock is recycled (Klinglmair & Fellner, 2010).

However, all metal in the employed stock is not readily available for recycling; most of the metal is stuck in a part of the stock called in-use. This includes metals which are in active use in the society in the form of various metal products (Kapur & Graedel, 2006). The metal primarily of interest for urban mining is the metal which exists in the other of two employed stock component; the hibernating stock. This stock contains metal that is a part of society, but no longer in use (Kapur & Graedel, 2006). Examples of this are abandoned buildings, scrapped cars, old cell phones and disconnected power cables. A strict definition of urban mining is to extract metal from the hibernating stock and put it back into the in-use stock. The concept could include a lot more, but this definition is the one used in this thesis.

![Figure 3](image_url)

**Figure 3.** The three main types of metal stocks according to Kapur and Graedel (2006); the figure shows the metal flows created by urban mining, conventional mining and -recycling. Recreated and modified after Kapur and Graedel (2006).

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4Also, the stock component “distributed” is all natural, but non-mineable metal that is present in the lithosphere. Dissipated metal is metal that have been lost to the environment due to wear of metal product (Kapur & Graedel, 2006). None of these two stock components are concerned in this thesis.
The extraction of the metals from the hibernating stock in the antroposphere can be compared with conventional mining, where the McKelvey resource classification system is used to classify and distinguish so called reserves from other resources (see figure 4). Reserves are natural resources that are available for extraction since their locations are known and extraction is economically feasible. Resources on the other hand, are not primary available for extraction because of marginal economical feasibility (Smil, 2003). This view could also be applied for urban mining situation, where hibernating stocks could be considered for as a non-reserve because of uncertain economical feasibility and stocks location. Just like in conventional mining where prospecting is used to enlarge the reserve stock similar “prospecting”, in the form of urban mining studies, could be used to find and identify reserves in the employed stock.

![McKelvey resource classification system](image)

**Figure 4.** The McKelvey resource classification system shown in a so called McKelvey box. The reserves box represents the available resources for human extraction because of economical feasibility. The arrow is representing the potential prospecting for urban mining. The figure is based on work by Smil (2003).

To reduce the extent of the potential issues caused by falling ore grades (Norgate & Hauge, 2009; Klinglmair & Fellner, 2010) and rising raw material prices, urban mining can be a valuable measure. Urban areas, and their accumulated stocks of metals, could act as pools of secondary resources to reduce the need of primary resources. According to Kinglmair and Fellner (2010) urban mining even has the potential to become more important than traditional ore mining. Also, more scarce supplies of primary ore in the future could further increase need and importance of urban mining (Klinglmair & Fellner, 2010). An example of the consequences of rising metal prices on the market is the looting of power cables in Russia were miles of both live and disconnected power cables is stolen annually (Tyler, 2000). This could be seen as an extreme variety of urban mining.

The significance and possibility of urban mining as a potential secondary resource is illustrated by Kinglmair and Fellner (2010) who describes the raw material shortage situation in Austria during World War I. According to the said study no more than 10 % of the domestic copper demand was covered by primary ore mining at the time, while the supply from urban mining was approximately three times larger during 1917. Another urban mining study, which also is somewhat similar to this thesis, is Beers and Graedel (2003) who quantified the in-use copper stock in Cape Town, South Africa in order to evaluates its potential as a secondary resource. The study did, amongst else, quantify the copper content in
infrasystems like power cables and telephone lines, and investigated the potential in these stocks as a source of copper.

A hibernating stock of significant size is the infrasystems that consists of power- and communication cables, water-, sewage- and heat pipes etc. Wendell (2005) concludes that the hibernating stock of cables in Sweden has a mass of approximately 800,000 tons of copper and aluminium, which equals to an economic value of about 30 GSEK. Also, a study by Krook et al. (2011) estimates that the amount of hibernating cables in local power grids, in Gothenburg as an example, is as much as 17%.

The practice of extracting metals from the anthropogenic stock, and in particular built urban areas, is surrounded by several complications. These complications are mainly of economical character. This is highlighted by Krook et al. who investigates the cost associated to the extraction of different types of hibernating cables (2010). Common issues related to this include excavation, soil storage, land rental, shutting of the traffic and site restoration, which are relatively costly. These issues are primary related to so called separate recovery in built urban areas were only the hibernating cable itself is extracted. According to Krook et al. (2010) one could practice integrated recovery; which means that hibernating cables is recovered during other works, such as maintenance of existing active cables. The authors conclude that the economical feasibility of cable recovery in a built city environment is very low. At current metal prices the costs related to cable recovery often outweighs the revenues (Krook et al., 2010).
3 Material and Methods

The used method in this thesis is essentially based on MFA; more specifically, it makes use of the previously mentioned static quantification. It could also be mentioned that this method not has been used before in this context, as in quantifying infrasystems on this level of detail. This contributes to a higher quality of data and a more precise result compared to other studies in the same field using slightly different methods.

3.1 Identification and selection of systems

Since the aim of this thesis is to quantify the amount of metal in infrasystems, relevant, metal containing systems had to be identified. At first, well known systems like power, telephone, district heating, water and sewage was chosen. However, as work progressed additional systems was “found” and identified, such as cable-TV and the disconnected tram DC-power system. Some systems was planned to be included, but found to be of a non-significant size, e.g. district cooling. Also, other systems was meant to be included but was dropped because of lack of adequate data, e.g. DC-power grid for households. There are also infrasystems in Norrköping that does not contain any metal, fiber optical cables are one example, which were naturally excluded as well. Eventually, the following systems were chosen for the metal stock quantification:

**District heating**
Owned by *E.ON* and consists of steel pipes with different types of insulation. Also, small amounts of copper pipes are used (Sjögren, 2010, personal contact).

**Water and sewage**
Both the drinking water pipes and sewage pipes are included in this system. Copper, cast iron, galvanized steel, concrete and plastic is used as pipe material (Narveby, 2011, personal contact). The system is owned by *Norrköping Vatten*.

**Street lighting**
The municipal street lighting system; both copper and aluminium cables are used here. This system does also feature “inactive” cables which are cables that not are actively used and meant for backup in case of broken cables (Lundmark, 2011, personal contact).

**Power cables**
The power grid, owned by E.ON. Both copper and aluminium conductors are used in the cables (Johansson, 2010, personal contact).

**Telephone lines**
This system is owned by *Skanova*. All cables in the system use copper conductors. Traditionally used for telecommunication and nowadays also DSL-services (Schillerström, 2011, personal contact).

**Town gas system**
The old town gas system is an obsolete gas pipe network last used 1987. However, the pipes have been partly reused to hold cable-TV cables and later on optical cables. Today, the system is owned by *Tele2* who uses 25 km of the pipes to hold the said optical cable (Sahlin, 2010, personal contact).
Cable-TV
A cable-TV network that was owned and operated by *Hyresbostäder i Norrköping* and installed in the mentioned gas pipes. Nowadays the net is unused and therefore completely hibernating. The system uses co-axial aluminium cables (Sandell, 2010, personal contact).

Tram DC-power cables
Consists of two separate systems; a larger DC-system made of copper, and a new smaller system that replaced the older one in 2010 (Lundmark, 2011, personal communication). The newer system uses both aluminium and copper conductors, and transmits power through the regular AC-grid over some of the longer distances. The newer system is therefore smaller. The older system is completely unused.

### Table 1. A summary of the analyzed systems and their characteristics

<table>
<thead>
<tr>
<th>Type of system</th>
<th>System length (Butängen only)</th>
<th>Pipes or cables?</th>
<th>Type of metal</th>
<th>In operation or disconnected</th>
<th>Addressed stocks DN=Norrköping SB=Södra Butängen</th>
<th>Type of data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>District heating</td>
<td>400 (5.3) km</td>
<td>pipes</td>
<td>steel, copper</td>
<td>in operation</td>
<td>NK &amp; SB, in-use &amp; hibernating</td>
<td>GIS</td>
</tr>
<tr>
<td>Town gas</td>
<td>147 km</td>
<td>pipes</td>
<td>steel, iron</td>
<td>disconnected</td>
<td>NK, Hibernating</td>
<td>Historical sources</td>
</tr>
<tr>
<td>Power grid</td>
<td>(27) km</td>
<td>cables</td>
<td>copper, aluminium</td>
<td>in operation</td>
<td>SB, In-use &amp; hibernating</td>
<td>Physical maps</td>
</tr>
<tr>
<td>Telephone</td>
<td>(11) km</td>
<td>cables</td>
<td>copper</td>
<td>in operation</td>
<td>SB, In use &amp; hibernating</td>
<td>Physical maps</td>
</tr>
<tr>
<td>Old tram DC-power</td>
<td>12 km</td>
<td>cables</td>
<td>copper</td>
<td>disconnected</td>
<td>NK, Hibernating</td>
<td>Physical maps</td>
</tr>
<tr>
<td>New tram DC-power</td>
<td>4.6 km</td>
<td>cables</td>
<td>copper, aluminium</td>
<td>in operation</td>
<td>NK, In-use</td>
<td>Specification list</td>
</tr>
<tr>
<td>Cable-TV</td>
<td>4 km</td>
<td>cables</td>
<td>aluminium</td>
<td>disconnected</td>
<td>NK, Hibernating</td>
<td>Physical maps</td>
</tr>
<tr>
<td>Water &amp; sewage</td>
<td>967 (11) km</td>
<td>pipes</td>
<td>steel, iron, copper</td>
<td>in operation</td>
<td>NK, &amp; SB, In-use</td>
<td>GIS</td>
</tr>
<tr>
<td>Street lighting</td>
<td>767 (46) km</td>
<td>cables</td>
<td>copper, aluminium</td>
<td>in operation</td>
<td>NK &amp; SB, In-use</td>
<td>GIS</td>
</tr>
</tbody>
</table>

### 3.2 Data collection on the length and composition of the studied infrasystems

In order to fulfill the objective of this thesis, spatial and physical data describing the examined systems was collected. The respective owner of each system was contacted. The aim was to collect GIS-layers for every system to quantify their metal content. This since GIS is, according to Kapur and Graedel (2006), a valuable tool for this static quantification. The used method of static quantification is also very time-consuming since spatial data for complete infrasystems must be handled. To store and make use of data describing the location and physical attributes of every object in an infrasystem, GIS is an invaluable tool. Without GIS, this method would be practically impossible to use in any but a very small scale.

This collection of data was possible for street lighting and water and sewage systems. One significant weakness in this GIS data for the water and sewage and street lighting is the lack of data describing the hibernating parts. All hibernating objects are continuously removed from the GIS by the system owners and a static quantification is therefore not possible (Narveby, 2011, personal contact; Lundmark, 2011, personal contact).

As for district heating, no GIS-data was handed out since the data was considered to be of such critical nature that it could not be handed out. The quantification and calculations of the metal stock was made on-site at the system owner, E.ON, using their GIS system (Facil Plus). A distinction between in-use and hibernating system parts was possible for this system.

For most of the systems, however, GIS ready data was not possible to obtain. In the case of power cables, telephone lines, the old tram DC-power and cable TV analogue maps was
collected instead. These maps then had to be digitized by hand using GIS-software (ESRI ArcMap 10). The maps for the power cables, was used up until the year 2005 (Johansson, 2010, personal contact). Eventual changes in the system after 2005 have therefore not been observed. These maps are, however, the only source for hibernating cables since hibernating objects are not included in the superseding digital system (Johansson, 2010, personal contact).

Data describing hibernating cables are present in the maps for telephone lines. However, it was said (Schillerström, 2011, personal communication) that there are several complications regarding hibernating telephone lines; the cables themselves may be crucial for the support of concrete canalizations and that the occurrence of hibernating cables are rare.

For the town gas system and the new tram DC-power no spatial data was available. Instead, for town gas, different sources of historical data (Ekdahl, 1951; Norrköping, 1938-1965) describing the physical properties of the system had to be combined. However, as parts of this system are used as canalization for optical cable (Sahlin, 2010, personal contact), parts of the system is not truly hibernating.

The data for the new tram DC-power cables was available as listed specifications for the cables (Nilsson, 2011, personal contact). Also, no parts of this system are hibernating since it is recently installed.

Because of the lack of available GIS-data, a quantification of the metal stocks for power cables and telephone lines was performed for Södra Butängen only and not for the rest of Norrköping. This since manual digitalizing of analogue maps for a whole city is not possible within the scope of this thesis. In complement to all collected data concerning these systems, interviews with system owner representatives was performed to gather missing or complementary data not available in the data material.

3.3 Calculation of metal stocks
When all necessary data had been collected, the GIS-layers were imported into GIS and layered over a base map. These layers are in the forms of vector files, where each object, in this case cables or pipes, are represented by a single vector line. For those systems where no GIS-layers were obtained, copies of the physical maps were imported instead. On top of these maps, new vectors were created by hand. Each vector represented a single cable or pipe. Attribute data for hibernation state, dimensions and types were added to each vector. This data was acquired partly from the maps and partly from the interviews. With all the necessary data added, the respective attribute table for each system was exported to an Excel spreadsheet. To calculate the metal content, values for area and length were multiplied for each object to calculate the metal volume. The real metal concentration for each and every object separately was used in calculation. The volume was then multiplied with the density for each of the three metals. Equivalent calculations were performed for the town gas system and the new tram DC-cables. For more detail concerning the calculation for each infrasystem see appendices 1-5.

3.4 Economical valuation of the metal stocks
To perform the valuation of the metal stocks, scrap metal prices was acquired from Göran Thorsell (2011, personal contact) at the recycling company Stena Recycling.

3.5 Reliability and validity of the data and the calculations
Some issues are adhering in these calculations. All uncertainties and assumptions related to the calculations are more thoroughly presented in appendix 6 based on the ideas of Hedbrandt and Sörme (2000). This shows that most of the data uncertainties adhere to the calculations of the town gas system. This since the quantifications of the system is based on historical source and not on spatial data. However, as Hedbrandt and Sörme (2000) suggests, the data uncertainties should be quantified to achieve a total uncertainty interval, this has not been performed in this thesis.
Some of the more important questions regarding reliability are:

- For some systems, there are missing data for hibernating objects. For instance, street lighting where data regarding hibernating cables are missing in the system owners GIS-system.
- Attribute data regarding specifications for cables and pipes are missing in some GIS-layers. It is unknown if these objects contain metals. For water and sewage these objects have been left out from the analysis. For the other systems a mean value has been used instead.
- Some data is based on assumptions and estimations regarding the physical property of the system. This does especially apply to the town gas system where no GIS-files or maps have been obtained.
- For the systems where no GIS-layers were obtained, manual digitalizing of the objects was used instead. This is a potential weakness in the method since the accuracy is sometimes suboptimal. Physical paper maps are first scanned and then imported in to GIS-software where the vectors are drawn by hand in accordance to the appearance of the objects in the maps.
- For telecommunication cables, the thickest, most copper rich transportation-network cables have not been quantified since the metal content in these are unknown, even by the system owner (Schillerström, 2011, personal contact).
- However, despite a handful uncertainties and reliability issues the used method offers a fairly high precision compared to many other studies in the same field, like Beers and Graedel (2003). In this thesis a quantification of the metal content in more or less every object, using every object’s individual metal concentration, is performed.
4 Metal stocks in the infrasystems of Södra Butängen

The results from metal stock quantification are presented below and are divided between Norrköping as a whole and Södra Butängen. Each metal is presented separately and is divided on in-use, hibernating and “inactive” metal. Note the differing scales on the figures.

4.1 Aluminium stock in Södra Butängen

The quantified amounts of aluminium in the infrasystem stock for Södra Butängen shows that only two of analyzed systems contain any aluminium; power cables and street lighting cables (see figure 5). The total stock contains 9 tons of aluminium where the power cables hold 8.55 tons and the street lighting 0.45 tons. Since hibernating stocks not has been possible to quantify for street lighting, the only hibernating aluminium is found in the power cables and the amount is 0.7 ton.

Both these systems contain copper and aluminum. The share of aluminium in the system was found to be 17 % of the length and weight for the power cables. This indicates that aluminium is used in thicker cables compared to copper. The aluminium share for the street lighting is only 6 % of the length and 3.7 % of the total weight.

For the street lighting cables, inactive cables were identified. These are formally in-use, but not actively used since they are meant as backup only. For the aluminium cables 0.18 tons are considered inactive.

![Aluminium stock in southern Butängen](image)

**Figure 5.** The aluminium stock in Södra Butängen; the majority of the aluminium is situated in the power cables.
4.2 Copper stock in Södra Butängen

The copper stock in Södra Butängen holds 72.2 tons (see figure 6). The majority of this copper is contained within the power cables with 49.7 tons of copper. This is followed by street lighting with 14.5 tons; telephone lines with 7.1 tons the water and sewage system with only 1 ton. 6.85 tons of the power cables are hibernating and also a marginal 0.02 tons of the telephone lines. The hibernating parts of the street lighting and the water and sewage system could not be determined. As for the district heating; no pipes made of copper could be found in Butängen.

Just like for the aluminium stock, the copper cables of the street lighting does contain inactive cables. These cables equals to 0.6 tons of the total 14.5 tons.

![Copper stock in southern Butängen](image)

Figure 6. The total copper stock in Södra Butängen; all of the quantified systems except the districts heating pipes contains copper.
4.3 Iron stock in Södra Butängen

The metal quantification shows that only two of the analyzed systems contain any steel or iron but in relatively greater amounts than copper and aluminium (see figure 7). A total of 512 tons of iron could be identified in Södra Butängen. This is divided between district heating pipes and the water and sewage system with 174 and 337 tons respectively. No parts of the district heating pipes in Södra Butängen was found to be hibernating, while the hibernating water and sewage pipes not could be quantified. The used material in the district heating pipes is, beside copper, solely different kinds of steel and no cast iron or such. For the water and sewage systems on the other hand, the material consist of partly galvanized steel and partly iron. In Södra Butängen only the drinking water pipes was found to contain any metal; only iron and no steel. 54 % of the pipes are made of metal, the rest are mainly made of either concrete or plastic, and also 6 % of the pipes were made of an unknown material. The sewage pipes in Södra Butängen only use concrete or plastic.

![Iron stock in southern Butängen](image)

**Figure 7.** The total iron stock in Södra Butängen. Only water and sewage and district heating contain any iron or steel.
5 Metal stock in selected infrastructures in Norrköping

5.1 Aluminium stock in Norrköping

Since the quantification of the metal stocks in Norrköping is incomplete and looks on partly different systems, the results also look a bit different (see figure 8) compared to the Södra Butängen results. The total stock does for instance contain 10.7 tons, which is only marginally larger than the stock for Södra Butängen. The power cables in Södra Butängen is the system with the largest aluminium content, since this system not has been quantified for Norrköping as a whole the aluminium figures are as low as they are.

The quantified stock is divided on three systems; the tram DC-power, street lighting and cable-TV where the DC-power contains 2.4 tons, street lighting contain 7.9 and the cable-TV the remaining 0.4 tons. Hibernating parts of the street lighting system has not been quantified. The cable-TV system is, on the other hand, completely hibernating and make up the whole part of the identified, hibernating aluminum stock in Norrköping. Only the new part of the tram power cables contain any aluminium, since this system is completely in-use no hibernating aluminium is found in the tram power system.

The inactive street lighting cables of aluminium weights 0.24 tons, which is not much more than what is identified in Södra Butängen.

Figure 8. The total aluminium stock in Norrköping; only power cables and street lighting contain any aluminium.
5.2 Copper stock in Norrköping

As figure 9 presents, the quantified copper stock is 513 tons in Norrköping. Most of this copper is present in the street lighting cables; 227 tons, and in the district heating pipes; 201 tons. The other systems with copper content are the water and sewage system with 47.6 tons and the two tram DC-power systems; 33.3 in the disconnected one and 3.6 tons in the in-use system. Since the old tram power cables are disconnected, the whole system is hibernating and makes up the whole hibernating part in this system. The hibernating stocks in street lighting and water and sewage could not be determined. The district heating system was found to contain no hibernating copper parts. In the DC-power case, the hibernating part is completely made up of the old disconnected DC-power cables. The in-use part is on the other hand made up of the modern DC-power cables.

Compared to Södra Butängen, the quantification for Norrköping show a significant amount of copper in the district heating pipes. 16% of the length of the system uses copper pipes but only 2% of the metal mass is copper due to the lesser diameter sized used for the copper pipes compared to steel pipes.

The power cables are not included in the Norrköping quantification. Like for aluminium, the power cables are the largest container of this metal. Large amounts of copper are therefore left unidentified. The fraction of copper in the water and sewage system is relatively small; this is because copper only is used in the smallest of pipe diameters.

The inactive copper cables for the street lighting weights 25.5 tons of the total 227.

**Figure 9.** The copper stock in Norrköping. Street lighting and district heating contain the most of the copper. The only identified, hibernating copper is located in the old tram DC-power system.
5.3 Iron stock in Norrköping

Iron is, according to the quantification, present in significantly greater amount than the other metals (see figure 10). A total of 28,700 tons of iron could be identified. 13,867 tons of this metal can be found in the water and sewage system; 10,648 tons in the district heating system and somewhere between 4,200-5,350 tons in the town gas system depending on chosen parameters in the calculations. The whole town gas system is unused and is therefore considered hibernating. Of the district heating system 894 tons is in a hibernating state. A quantification of the hibernating parts of the water and sewage system could not be performed.

Both the town gas system and the water and sewage system are made from part steel and part iron. In the town gas case this iron-steel ratio is 62:38 in system length. The used materials are cast iron and welded steel respectively. There is also notable difference between water pipes and sewage pipes. The drinking water pipes contain 69 % metal of which less than 1 % is galvanized steel and the rest is cast or grey iron. For the sewage pipes concrete and plastic dominates; only a tiny fraction at less than 1 % consists of metal.

Figure 10. The iron stocks in Norrköping, divided between three systems.
6 Economic valuation of metal stocks

The actual economic value of the metal stock depends on several factors. According to Stena Recycling, the price paid for metals, is primary determined by the world market price. Other factors that influence the paid price are the quality of the metal, possible cable isolation and eventual PCB content in the cables (Thorsell, 2011, personal communication). The prices that Stena Recycling pays for various scrap metals are presented in table 1.

An examination of the Södra Butängen stocks shows (see figure 11), based on the prices for pure metals, that the copper stock has the highest economic value at 3.84 million SEK. The iron and aluminium stocks are worth 770,000 and 110,000 SEK respectively. Hibernating part of the copper stock is worth 364,000 SEK, and the hibernating aluminium is only worth 5,000 SEK.

Since a majority of the copper stock is made up from the power cables and telephone lines the largest value is concentrated to these systems.

<table>
<thead>
<tr>
<th>Types of metal</th>
<th>Pure metal (SEK/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>1,500</td>
</tr>
<tr>
<td>Aluminium</td>
<td>12,000</td>
</tr>
<tr>
<td>Copper</td>
<td>53,000</td>
</tr>
</tbody>
</table>

Table 1. The circa price Stena Recycling pays for each metal. Prices from: 2011-04-08

![Economic value of metal stocks in southern Butängen](image)

Figure 11. The economical value of the metal stocks in Södra Butängen.
Different systems have been quantified for Norrköping, therefore the economic value is distributed differently between the metal stocks (see figure 12). The aluminium does have comparably low value at 128,000 SEK, but the iron stock does hold proportionally large value at 64.5 million SEK which is twice the copper stock value for Norrköping. The metal content in power cables and telephone lines have not been quantified for Norrköping. The lack of these two systems is the reason for the differing figures.

Of particular economical interest for Norrköping are the hibernating stocks, this is because these stock are more readily available and not locked up in the in-use stock. This is in contrast to Södra Butängen where all metal could become available regardless of state. The hibernating stock in Norrköping is for iron worth 7.65 million SEK and for copper 1.77 million. The hibernating aluminium stock is only worth 5,000 SEK.

![Economic value of metal stocks in Norrköping](image)

**Figure 12.** The economical value of the metal stocks in Norrköping.
7 Discussion

As the presented results show, there is a sizable metal stock with a potential for urban mining in Södra Butängen. With a mass of almost 600 tons and a market value of approximately 4.7 million SEK there should be strong reasons for a consideration to recycle parts of these metal amounts. The largest share of this economic value is mainly related to the copper stocks, which is dominated by the power cables. These cables also hold the largest hibernating part of copper in Butängen; 16% of the weight in the power cables is hibernating. This could be compared with studies by Krook et al. (2011) who estimated a hibernation ratio of 17% and 3.6% in Gothenburg and Linköping respectively. Another study by Wendell (2005) suggests that the ratio of hibernating copper in cables on the Swedish national scales is 31%. Although, the results from these studies are not directly comparable to this thesis since only a single, industrial city district is analyzed here, and in the case of Wendell (2005) the figures are aggregated. However, there are high costs related to the extraction of these stocks in the form of infrasystems within a city (Krook et al., 2010; 2011). But since so called integrated recovery (Krook, et al. 2010) can be practiced in the Butängen case, the extraction can be done with less cost.

There are also some other complications that must be considered before an eventual extraction. There may, for instance, be system parts in Butängen that is vitally connected to other parts of the system; e.g. telephone lines in Södra Butängen may connect with lines in other parts of the city. Other complications could also be of environmental character; some cables may for instance contain toxic substances which could constitute a potential hazard (Thorsell, 2011, personal communication).

The quantification of the metal stocks made for the rest of Norrköping does also demonstrate significant amounts of metal with a total stock of almost 30,000 tons. However, the situation for Norrköping looks different; more or less the whole metal stock in Södra Butängen could be made available for extraction, an opportunity which is not possible to the same extent for the whole of Norrköping. To dismantle and extract a fully working infrasystem in-use for a whole city is neither desirable nor practically possible. The stocks of interest though, from an urban mining perspective, are the hibernating parts (Kapur & Graedel, 2006) of the infrasystems, as a possible secondary resource. This since these parts no longer are in-use and could be extracted without affecting the functionality of the in-use infrasystems. The calculated economical value for these hibernating parts is approximately 8.5 millions SEK. This economical value is related mostly to the hibernating town gas system; a system which is not completely hibernating though since parts of the system is used for hold optical cables. There is also a possible issue concerning the economical value of the stocks. Especially in the case of the partly 150-year old (Ek Dahl, 1951) town gas system, some pipes can have been exposed to corrosion, which would affect the prices paid for the metals.

However, sooner or later parts of the in-use infrasystems could become disconnected and hibernating, for instance when cables or pipes reaches the end of their service life. Through this, parts of the quantified amounts of the in-use metals could therefore in the long term become available for extraction.

In addition to this quantified amount, there is an unidentified potential for even larger stocks; several systems have not been possible to quantify, including the power cables and telephone lines which are systems with a major copper content. There is, in other words, a significantly larger economic value hidden in these non-quantified stocks. The economic valuation for Södra Butängen, with its copper rich power cables, shows this; the copper cables hold a proportionally large economic value. There are also probably much larger hibernating stocks too, stocks that have not been quantify due to scarcity of data concerning these systems; street lighting is one example of this.

Of significant interest to urban mining are also the relatively large stocks of hibernating metal that consists of whole obsolete systems that nowadays have lost their intended function.
Mentionable examples are the town gas system and the DC-power grid for households. As the town gas system proves, these systems can hold large amount of hibernating metal. What make these systems differ from the others is that they have no clear owner or other interested actors. This does also mean that there are few who have interest in keeping data and documentation describing these systems. The collection of data describing these systems is therefore very difficult and requires the use of historical sources. The town gas system is a notable exception to this since it has found a new use. This is an example how an old system can be reused for another purpose. This does also show that it is not necessarily determined that the recycling of the infrasystems is preferable; the infrasystems could also be reused instead of recycled. The telephone lines are another example of a system for that has found a new area of use; where the primary function of telephone services has been complemented with modern DSL-services (Schillerström, 2011, personal contact).

If these hibernating metal stocks are to be extracted as resources, like with traditional mineral prospecting their location and quantity must be identified (Smil, 2003). There is, however, one great obstacle that complicates this; the apparent disinterest to keep record of disconnected and unused cables and pipes of some of the system owners. During the data collection it became clear that this is not always the highest priority with the system owners. For the used static method, this leads to severe issues with the data availability as hibernating stocks not always can be fully quantified. Even if this data is available, it is many times sensitive information that is not easily obtained due to the criticality of infrasystems. For future studies using the same method, this is a problem that must be considered. Simultaneously, in those cases where digital GIS-data for the systems were available, GIS proved to be a very helpful tool for static quantification just as Kapur and Graedel states (2006).

This study clearly shows that there is a potential for urban mining in Norrköping, and especially for Södra Butängen. However, it may not be economically feasible to extract these metals today. But if the ore grades will continue to fall (Norgate & Hauge, 2009) and the metal consumption rise (Wittmer, Lichtensteiger & Wittmer, 2007), the metal prices, and in turn the attractiveness of urban mining, would increase. In other words the reserve, or the stock of extractable resources, could grow as prices increases and stocks are identified (Smil, 2003). Urban mining of city infrasystems seems to offer a promising opportunity to meet the future resource demands, especially in the case of city redevelopment projects like Södra Butängen. If this is to be made possible the various actors and stakeholders, such as system owners and the municipality, would have to cooperate. According to Krook et al. (2010) this is traditionally uncommon since this is located outside the actors’ primary sphere of interest.

Also, several opportunities for additional studies have been identified during the work with this thesis. Most notably is a quantification of the power- and telecommunication cables which not has been quantified for the whole of Norrköping. These cables most likely hold a great economical value since they are made out of valuable copper and could potentially offer urban mining possibilities. However if these infrasystems are to be quantified, an other method than the used static quantification would most likely have to be used due to the format and availability of data for these system.

There is also another system which not has been quantified at all; the DC-power cables for households. This is a completely hibernating system that also is made of valuable copper. A quantification of this system would require a supplementary data from historical sources to be made possible.
8 Conclusions

- The southern parts of Butängen have been quantified to hold a total metal stock of almost 600 tons of metal; copper, iron and aluminium included. The stock has an economical value of approximately 4.7 million SEK, mostly related to the copper content in the power cables.

- For Norrköping as a whole the total stock was quantified to almost 30,000 tons of metal. Most of this is iron or steel. The hibernating parts of this stock is in the size of 5,100 tons where the majority of this consist of the old town gas system. The stocks are in total worth over 70 million SEK, and the hibernating part approximately 9.5 million SEK.

- There are large metal stocks, mainly of copper, that not have been possible to quantify for the whole of Norrköping. This is due to the format of the available data which many times only are available in non-digital format. These unidentified stocks do probably hold the largest economical value due to copper content in, for example, power cables.

- The stocks that generally are of most interest for urban mining, the hibernating ones, are not always easy to quantify. The data needed to quantify these stocks are in some cases non-existent, which makes a quantification of these stocks nearly impossible.

- There seems to be a potential for urban mining in Södra Butängen, especially with the valuable copper stock and the redevelopment plans in mind. This opportunity for urban mining should be evaluated and considered.
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Lundmark, Paul (2011). Electricity engineer, Norrköping Municipality
Narveby, Per (2011). Inquiry engineer, Norrköping Vatten
Sahlin, Tony (2010). Planner, Tele2 Norrköping
Schillerström, Mats (2011). Net planner, Skanova Stockholm
Sjögren, Maud (2011). Distribution department, E.ON Norrköping
Appendix 1 - Town gas calculations

In order to calculate the metal content in the town gas system, several types of data describing the physical properties of the system had to be acquired. The following data was collected:

- Total pipe length of the system
- Inner diameters of the pipes
- Distribution of diameter types of the total system length
- Thickness of the pipes
- Pipe material and distribution of material types among the pipes.
- Service pipe diameter and total length

The maximum length of each diameter type of pipe was used for the calculations. The used diameter distribution up until 1950 is based on information from Ekdahl (1951). Between 1951 and 1970 the system expanded with another 25,092 meters (Norrköping, 1938-1985). The diameter of the pipes used for this expansion is unknown. In the calculations an assumption was made; the post-1951 expansion was made using the two most common diameter types only; 100 mm and 150 mm pipes. The length of each diameter type is presented in table A2:1.

According to Ekdahl (1951) all pipes installed before 1926 are made of cast iron and pipes installed after 1942 are made of steel. The pipes installed between these years make use of both steel and cast iron. In the calculations an assumption is done that the ratio of steel and iron between 1926 and 1942 is 50:50. Also, ratios of 90:10 and 10:90 are used to calculate the resulting weight interval.

The pipe wall thickness of cast iron pipes are, according to Karlsson (2010, personal communication), 12-15 mm and 10 mm for steel pipes for pipes with an inner diameter over 75 mm. To calculate the resulting interval, both 12 and 15 mm thickness was used for the iron pipes in the calculations. Pipe thickness is presented in table A2:2. The inner diameter used for the service pipes is, according to Karlsson (2010, personal communication) 50, 75 and 100 mm. In the calculations a distribution at 45:45:10 respectively was assumed. With the inner diameter and thickness known, the outer diameter could be calculated. Then, the area of the inner diameter was subtracted from the outer diameter area. This was done for each diameter type. The resulting difference was then multiplied with the corresponding maximum length of each diameter type to obtain the total metal volume of the system. The volume was then multiplied with the chosen density of 7.84 tons/m³ to receive the total mass of the system which is shown in table A2:3.
### Table A2:1. Pipe length of each diameter type.

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<thead>
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<th>Inner diameter (mm)</th>
<th>Cast iron pipes</th>
<th>Steel pipes</th>
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<td>38</td>
<td>777</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
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<td>0</td>
</tr>
<tr>
<td>64</td>
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<td>75</td>
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<td>0</td>
</tr>
<tr>
<td>81</td>
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</tr>
<tr>
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<td>75 (service pipe)</td>
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<td>3594</td>
</tr>
<tr>
<td>100 (service pipe)</td>
<td>1401</td>
<td>799</td>
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</tbody>
</table>

### Table A2:2. Pipe thickness of each diameter and material type.

<table>
<thead>
<tr>
<th>Inner diameter (mm)</th>
<th>Pipe thickness (mm)</th>
</tr>
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<tbody>
<tr>
<td>&lt;76</td>
<td>5</td>
</tr>
<tr>
<td>&gt;75</td>
<td>12-15</td>
</tr>
</tbody>
</table>

### Table A2:3. The differing results depending on the chosen parameters (iron:steel ratio & iron pipe thickness). The result is shown in tons.

<table>
<thead>
<tr>
<th>Ratio iron:steel</th>
<th>Iron pipe thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12</td>
</tr>
<tr>
<td>10:90</td>
<td>4203</td>
</tr>
<tr>
<td>50:50</td>
<td>4358</td>
</tr>
<tr>
<td>90:10</td>
<td>4513</td>
</tr>
</tbody>
</table>
Appendix 2 - District heating

The quantification of the metal stock in district heating pipes was made on-site at the system owner E.ON. The system owners own GIS-software (Facil Plus) was used from where an attribute table for all pipes was exported to an Excel spreadsheet. Data concerning pipe length and pipe water volume was present. From this, the inner diameter was calculated. Complementary data concerning thickness of the pipes was acquired from Sjögren (2011, personal contact). With this information it was possible to calculate the metal volume of the pipes which was multiplied which the density of 7.84 tons/m$^3$ for steel pipes and 8.96 tons/m$^3$ for copper pipes. The exact length and the dimensions of the copper pipes were not known. However, it was known that 16 % of the pipes are made of copper, that these pipes used thinner material and only the lesser diameter pipes uses copper. The copper has a metal volume that is 60 % of that of the steel pipes. A calculation of: “steel volume * 0.16 * 0.40” was used to obtain the copper volume. The quantification of the district heating holds one mentionable weakness, the system parts of Söderköping is included. However, the length of the pipes corresponds to less than 0.5 % of the total system length.
Appendix 3 - Cables

Power cables
Physical maps describing the location and specification of the power cables was collected from E.ON. The maps has not been updated since 2005 (Johansson, personal contact). With the maps acquired, they were imported into GIS (ESRI ArcMap 10) and adjusted to match a base map layer. For every single cable on the maps, a vector was created which was given attribute data for its specifications. The length of each cable was calculated with the built-in geometry calculator. The complete list of cables was exported to an Excel spreadsheet. Information concerning copper content was based on information from EBR (2009) for certain cables. For other cables not present in that source, the mean value of 0.0093 kg/m/mm$^2$ was used for copper cables and 0.0027 was used for aluminium cables. The value for kg metal/m was multiplied with the length of the cable. This was done for every cable to obtain the total mass of the cables. Some cables lacked information regarding specification on the cables; the metal content was therefore unknown. For these cables a mean value of 1.49 kg copper/m was used. They were assumed to contain no aluminium. All disconnected cables were separated in the calculation.

Cable TV
A map describing the main parts of the old cable TV net was acquired from Sandell (2010, personal contact) at HNAB. The GIS-procedure was then more or less equal to the one used for the power cables. The aluminium content in the cables was determined using product specifications from the cable manufacturer (CommScope, n.d.A; n.d.B). The mean conductor area based on the product specifications was 35.22 mm$^2$ in conductor area; this since the cable types was known but not the used ratio between the cable types. Cirka 50 % of the cable length was of an unknown type, the mean area was used for this cable as well. The cable conductor area was multiplied with the total cable length to obtain the total mass of the cables. The volume was then multiplied with the aluminium density; 2.7 tons/m$^3$, to obtain the total metal mass of the system.

Telephone lines
Maps and wiring diagrams for the telephone lines of Södra Butängen was acquired from the system owner Skanova (Schillerström, 2011, personal contact). The following GIS-procedure was the same as for all the previous systems. From conductor diameter and number of conductor pairs the total conductor area was calculated. The area was multiplied with cable length and copper density to obtain the total copper mass. So called transportation-network cable has not been included in the quantification because of unknown metal content in these cables.

The old tram DC-power
The metal quantification procedure was similar to the one used for cable-TV. Maps describing the location of the positive pole cables and the negative pole cables were collected from Lundmark at Norrköping Municipality (2011, personal contact). Like for the power cables and cable TV, the tram DC-cables were imported into, and hand digitalized in GIS. The total cable length was multiplied with the cable conductor area of 300 mm$^2$ (according to Lundmark, 2011, personal contact). The resulting volume was multiplied with the copper density; 8.96 tons/m$^3$ to obtain the total mass.

The new tram DC-power
For this system no maps or GIS-data was available. Instead a complete list of all cables, their conductor area and conductor material was acquired from Nilsson (2011, personal contact),
Göteborgs Spårvägar. The conductor area was multiplied with length and aluminium or copper density to obtain the total mass of the two metals.

Street lighting
GIS-ready data covering the whole street lighting system in the municipality was acquired from Lundmark (2011, Norrköping Municipality). The GIS-layers was imported into GIS where all cables outside the geographical delimitation were removed. The cable density was based on information from EBR (2009) which was multiplied with the cable length to obtain the total metal mass.
Appendix 4 - Water and sewage system

From Norrköping vatten, GIS-layers covering the whole municipality were obtained for these systems. In the GIS-software all pipes outside the geographical delimitation was excluded. The object attribute table in the GIS was exported to an Excel spreadsheet. This data contained information regarding inner diameter, the length of the pipes and material. Specifications for the pipe outer diameter were obtained from Per Narveby at Norrköpings vatten (2011). With this information the metal volume was calculated; multiplied with the densities of 7.84 tons/m$^3$ for iron or steel and 8.96 for copper pipes the mass was obtained. All pipes made of non-metal materials were excluded from the calculations.
Appendix 6 - Data- and calculation uncertainties

All sources used in the calculations for every variable used in the calculations are listed in table A6:2. The sources are then classified in levels (1-5) according to the liability and quality of the data. The levels and their explanations are presented in table A6:1. This model of data and information source valuation and classification was developed by Hedbrand and Sörme (2000) to be used for handling and quantification of data uncertainties. The model used here is a simplification since no quantifications have been used. However, it gives an overall picture of the data quality and reliability used for the calculations in this thesis.

Table A6:1. The uncertainty classification levels used for the classification of data sources.

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>Source of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Data describing the system:</td>
</tr>
<tr>
<td></td>
<td>Maps</td>
</tr>
<tr>
<td></td>
<td>Literature</td>
</tr>
<tr>
<td></td>
<td>Manufacturer specifications</td>
</tr>
<tr>
<td></td>
<td>GIS</td>
</tr>
<tr>
<td></td>
<td>Data from experts (DC-power)</td>
</tr>
<tr>
<td>2</td>
<td>Rescaling of known data</td>
</tr>
<tr>
<td></td>
<td>Hand digitalizing of GIS-maps</td>
</tr>
<tr>
<td>3</td>
<td>Information from experts (Town gas)</td>
</tr>
<tr>
<td>4</td>
<td>Assumptions based on mean values</td>
</tr>
<tr>
<td>5</td>
<td>Assumptions</td>
</tr>
</tbody>
</table>
Table A6:2. All data sources used for the metal quantifications in the thesis, classified according to the level description in table A6:1.

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>VARIABLE</th>
<th>SOURCE OF INFORMATION</th>
<th>LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Town gas</td>
<td>Total system length 1865-1950</td>
<td>Literature: Ekdahl (1951)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Total system length 1951-1970</td>
<td>Literature: Norrköping (1938-1983)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Used material in the pipes 1865-1970</td>
<td>Literature: Ekdahl (1951)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cast iron:steel ratio 1926-1942</td>
<td>Assumption</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Thickness of steel pipes</td>
<td>Expert: Lars Karlsson</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Thickness of cast iron pipes</td>
<td>Expert: Lars Karlsson</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Diameter type distribution 1865-1950</td>
<td>Literature: Ekdahl (1951)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Diameter type distribution 1951-1970</td>
<td>Assumption</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Service pipe diameter</td>
<td>Expert: Lars Karlsson</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Distribution service pipe diameters</td>
<td>Assumption</td>
<td>5</td>
</tr>
<tr>
<td>Power cables</td>
<td>Total system (cable) length</td>
<td>Manual digitalizing of GIS maps</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Metal content in cables</td>
<td>Literature: EBR (2009)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Metal content in cables</td>
<td>Rescaling of data: EBR (2009)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Metal content in unknown cable types</td>
<td>mean value</td>
<td>4</td>
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<tr>
<td>District Heating</td>
<td>The pipe dimensions</td>
<td>E.ON's GIS</td>
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<tr>
<td>Cable TV</td>
<td>Length of the cables</td>
<td>Hand digitalizing of GIS-maps</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Metal content for QR-cable</td>
<td>Manufacturer specifications</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Metal content for other cables</td>
<td>Assumptions based on mean values</td>
<td>4</td>
</tr>
<tr>
<td>Old tram DC-power</td>
<td>Length of the cables</td>
<td>Hand digitalizing of GIS-maps</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Cable dimensions</td>
<td>Expert: Paul Lundmark</td>
<td>1</td>
</tr>
<tr>
<td>New tram DC-power</td>
<td>Length of the cables</td>
<td>Expert: Stellan Nilsson</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cable dimensions</td>
<td>Expert: Stellan Nilsson</td>
<td>1</td>
</tr>
<tr>
<td>Water &amp; sewage</td>
<td>Total system (pipe) length</td>
<td>GIS-maps</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>The dimensions of iron pipes</td>
<td>Manufacturer specification</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>The dimensions of steel &amp; copper pipes</td>
<td>Manufacturer specification</td>
<td>1</td>
</tr>
<tr>
<td>Telephone lines</td>
<td>Total cable length</td>
<td>Hand digitalizing of GIS-maps</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cable dimensions</td>
<td>Internal documents from Skanova</td>
<td>1</td>
</tr>
<tr>
<td>Street lighting</td>
<td>Total system length and cable dimensions</td>
<td>GIS-maps</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Copper content in cables</td>
<td>Rescaling of data: EBR (2009)</td>
<td>2</td>
</tr>
</tbody>
</table>