The Urk World
Björn WALLSTEN

The Urk World
Hibernating Infrastructures & the Quest for Urban Mining
Abstract

This PhD thesis concerns urban mining, an umbrella term for different recycling strategies aimed to recover materials from the built environment. More specifically, it focuses on hibernating urban infrastructures, that is: cables and pipes that have been left behind in their subsurface location after they were disconnected. I term this subsurface urban realm of system rejects the “Urk World”. “Urk” is short for “urkopplad”, the Swedish word for “disconnected”, an abbreviation often found on old infrastructure maps denoting discarded system parts. Since urks contain high concentrations of copper, my normative stance is that the Urk World should be “mined” as a contribution towards diminishing the persistently wasteful handling of mineral resources in society.

The thesis has three focus areas. The first of these discusses how the Urk World has emerged, that is: how the creation of urks is sustained in sociotechnical processes related to infrastructure’s provision. The second concerns the potential of urk mining, how much copper the Urk World contains, where these quantities are located and by which implications they could be recovered. The third focus area is devoted to the politics of urks, and is concerned with the political embeddedness of infrastructure and where politics might intervene for the sake of increased urk recovery.

Five papers complete the thesis. The first paper investigates how much copper, aluminium and steel there is in the Urk World of the Swedish city of Norrköping, and how these quantities are spatially dispersed in the urban environment. The second paper is based on interviews with system owners and repair crews, and investigates how urks come into existence in relation to three different infrastructural processes: maintenance, larger installation projects and shutdown. The third paper describes how environmental systems analysis can be beneficially coupled with theories and methods from the social sciences to create knowledge useful to aid the development of urk recycling schemes. The fourth article makes use of the inherent ambiguities of urks to investigate a spectrum of locations where politics aimed for increased urk recovery can intervene as well as what is at
stake there. The fifth and final paper investigates urks in Linköping’s power grid in spatial and weight terms, and analyses the implications of urk recovery from several different viewpoints.

In overall terms, the major contribution of the thesis is how it improves the knowledge of societal stocks of materials, thereby giving an increased recognition of the built environment as a resource base. In overall scientific terms, it sets an example of how a coherent interdisciplinary research design can provide knowledge useful for the implementation of urk recycling schemes as well as for political decision-making for increased urk recovery.

Keywords: urban mining, hibernating stocks, infrastructure studies, urban metabolism, material flow analysis
“Urkarnas Värld: infrastrukturer i dvala och staden som resursbas” – en populärvetenskaplig sammanfattning

Min avhandling handlar om “urban mining”, ett samlingsbegrepp som innefattar olika strategier att tillvarata och återvinna material från våra städers byggda miljö. Mer specifikt fokuserar avhandlingen på urban infrastruktur i ”dvala”, dvs. de skrotade ledningar och rör som ligger kvar under städernas gator efter att ha kopplats ur, och som innehåller ansenliga mängder koppar (men även stål och aluminium). Jag föreslår ”urkar” som term för dessa urkopplade systemdelar, och ”urkarnas värld” som en karaktäristik för städernas underjord. ”Urk” är en förkortning för urkopplad som länge användes på svenska infrastrukturkartor för att beteckna de systemdelar som inte längre var i bruk men fortfarande låg kvar i marken. Min forsknings normativa utgångspunkt är att den mängd koppar som finns i dessa ledningar och rör bör plockas upp och återvinnas för att minska resursslöseriet i vårt samhälle.

Avhandlingen har tre fokusområden. I det första förklaras det idiomatiska branschuttrycket ”lagd kabel ligger” i en analys av hur praktiker och regelverk fungerar i samband med infrastrukturens underhåll och ny–anläggning. Dessa processer drivs av en inre logik som kontinuerligt kopplar ur och lämnar kvar de systemdelar som inte behövs för att uppfylla systemens funktion. Det andra fokusområdet behandlar återvinningspotentialen från urkarnas värld. Dels består denna del av kartläggningar av urkar med avseende på vikt och rumslig utbredning i städerna Norrköping och Linköping, dels en analys av förutsättningarna att återvinna dem med hjälp av olika strategier. I det tredje och avslutande fokusområdet diskuterar jag urkarnas politik, dels utifrån hur infrastrukturens politiskt beslutade ramverk påverkar deras tillblivelse, men även utifrån det politiska handlingssutrymme som urkarna själva spänner upp till följd av sin mångtydiga karaktär.

På ett övergripande plan är avhandlingens främsta ambition att förbättra kunskapen om samhälleliga materialförråd och att öka förståelsen för att den byggda miljön bör betraktas som en resursbas. Vetenskapligt är desse
största poäng att visa hur miljösystemanalytiska verktyg och samhällsvetenskapliga teorier och metoder kan sammanfogas i en gemensam forskningsansats, och hur detta möjliggör skapandet av kompletterande sorters kunskaper som är av betydelse för utvecklandet av systemlösningar och politiskt beslutsfattande på återvinningsområdet.
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**Kommentar [25]: OTAKTISKT TRAMS!!
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dedicated to the memory of my father Göran Berglund
(January 9, 1948 – October 2, 2015)
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By now the ancient earth disappears under the relics of man or of his industry. You can already count a series of strata, where you can read the history of human generations, as before you could read in the amassed bottom of the seas the history of ancient faunas. – Antonio Stoppani, 1873

1. Mining in the Anthropocene

Since prehistoric times, mankind has physically modified the landscape. Humans have deliberately excavated rock and soil and created different kinds of artificial grounds, built structures and generated waste material. We are geological agents that affect the composition of rock formations and thus the geological configuration of planet Earth (Szerszynski, 2012).

Since the Industrial Revolution began in the 1700s, both the impact and rate of the material transfer process from the Earth’s crust to our built environments have changed dramatically. Widespread industrial activity and far-reaching urbanization have increased the material needs of human society and thereby also the scale, magnitude and significance of mankind’s geological activity (Price et al., 2011). Lewis Mumford described the modern process as one of mining, blasting, dumping, crushing, extracting and exhausting (1934, p. 74), and it goes on with increased frequency, as we carve out a gigantic “hole world” underneath the planet’s surface (Bridge, 2009). In this process, natural wealth is excavated from the planet’s depths and piled up on its surface in “inverted minescapes” of skyscrapers in financial districts (Brechin, 1999), “ores” of infrastructure systems (Article 2) and “upside–down department stores” such as landfills (Clark and Hird, 2014). It has been noted that planet Earth would have a completely different geological configuration were it not for human activity (Ellsworth and Kruse, 2012).

Regardless of whether one determines the magnitude of the material transfer in terms of impact (quantity of material moved) or rate (the time over which this occurs), the current human–induced flows are more significant than ever. It has been argued that the planet has entered into a new geological era: the Anthropocene (cf. Robin and Steffen, 2007; Zalasiewicz et al., 2011; Palsson et al., 2012). In the Anthropocene, mankind is the most prominent force of geological change (cf. Steffen et al., 2007), which is indicated by our global impact on the Earth’s ecosystems and that there is essentially no environment left that is completely free of
anthropogenic effects (LeCain, 2009, p. 10). Although it is still debated whether we have actually yet entered the Anthropocene and if so, when this happened (cf. Lewis and Maslin, 2014), there are plenty of indices that suggest a geological shift on a significant if not global scale (Johansson, 2013). A few of them are worth mentioning to exemplify the material impact that we have had on the Earth’s crust:

The worldwide deliberate annual shift of material by human activity has been estimated at 57,000 million tonnes, which is three times larger than the amount of water transported to the oceans by all the world’s rivers (Douglas and Lawson, 2000). Over the past 200 years, the people of Great Britain alone have excavated, moved and built up at least six times the equivalent volume of its highest mountain: the 1344 meter high Ben Nevis (Price et al., 2011). The city of Paris, as a final example, has in a metaphorical sense become a major lead reserve in France due to its material build-up process since Roman antiquity. There is now more lead in Paris than in the reserves in all French mines combined (Barles, 2010).

The observation of lead in Paris is just one example of how urban environments are metallic entities. In fact, most of the raw material that we extract from the Earth’s crust ends up in cities which, added together, are the heaviest things humanity has ever built. It has been estimated that the accumulation of metals in urban areas might be more than a hundred times higher than in rural areas (van Beers and Graedel, 2007), and Lewis Mumford (1934) already suggested that cities should indeed be understood as extensions of mines.

The possibility of regarding the material build-up of cities as a resource base was realized in the late 1960s by the urban theorist Jane Jacobs (1969), who argued that cities would be the mines of the future. She claimed that cities will always be inefficient due to their chaotic density of people and material flows, and continuously generate surpluses such as waste paper and restaurant garbage, which can be recycled. Unlike mineral veins found in mountains that will be exhausted at some point, these urban overflows could in Jacobs’ optimistic view “be retrieved over and over again”, as new and formerly overlooked veins are continually opened (ibid. p. 111).

Since Jacobs’ day, the term “urban mining” has been increasingly used in reference to her vision, both in connection with the manufacturing industry (Chai and Gao, 2014), and the recycling business (cf. urbanmining.org, 2015), and it has received increasing attention in the media (cf. Beard, 2014). There is no agreed-upon definition of the term within the scientific
community, where it has been used to refer to inorganic recyclables, metal scrap, organic wastes (Li, 2015) and even energy recovery (Brunner, 2011). In this thesis, “mining” is understood literally and the term is thus used to denote the recovery of metal stocks in the urban environment.

Researchers who agree with this understanding have made intense efforts to explore how metals are transferred through society (cf. Baccini and Brunner, 1991; Bergbäck and Lohm, 1997; Wittmer et al., 2003; Tanikawa and Hashimoto, 2009; Graedel, 2011; Nakamura and Halada, 2015), and have found that approximately half of the amounts of certain base metals that have been extracted to date are no longer in use (Spatari et al., 2005; Müller et al., 2006; Zittel, 2012). In largely unknown quantities and concentrations, these metals are most often found in different kinds of waste deposits but have also dissipated into water and air (Brunner, 2007). Certain amounts accumulate in various sinks in the built environment, and constitute what researchers describe as “hibernating stocks” (Lohm et al., 1997). This classification denotes accumulated quantities of a certain resource “that has previously been consumed for a technological purpose, is not now being used, and has not yet been discarded” (Kapur and Graedel, 2006, p. 3136). Or put differently, they consist of artefacts that have been “abandoned in place” (Glöser et al., 2013). In reference to Bergbäck and Lohm (1997), many scholars assume that the recycling potential of hibernating stocks is significant (cf. van der Voet, 2002; Ayres and Ayres, 2002), and highlight their state of not being in use as a particularly interesting feature since it indicates that they are available for recovery. In general, however, the state of knowledge on hibernating stocks is meagre (Brunner, 2004), which is mostly due to scarce or unavailable data and the stocks’ relatively high dependence on consumer patterns (Kapur and Graedel, 2006). Studies of hibernating stocks have most often targeted consumer products such as obsolete television sets (Milovantseva and Saphores, 2012) or disused mobile phones (cf. Murakami et al., 2009; Ongondo and Williams, 2011) in household closets and drawers.

1.1 Why Study the Urk World?
The object of inquiry of this thesis is also an example of a hibernating stock: the left–behind sections of urban infrastructure systems. Ever since the first urban infrastructure systems were laid out during the 19th century, enabling what historians of technology refer to as “networked cities” (cf. Tarr and Dupuy, 1988; Williams, 2008), infrastructure parts have for a variety of different reasons been taken out of service, creating significant
amounts of disconnected cables and pipes that remain under the urban streetscape (cf. Hashimoto et al., 2007).

I term this largely unknown subsurface realm of system rejects the “Urk World”. “Urk” is short for “urkopplad”, the Swedish word for “disconnected”, an abbreviation often found on old infrastructure maps denoting discarded parts\(^1\). The spatiotemporal relation between urks and the Urk World is similar to how scrap relates to a scrapyard: while urks/scrap denote disused items, the urk world/scrapyard refers to the location where urks/scrap items are stored for a certain sequence of time.

Due to their high concentrations of base metals such as copper, aluminium and steel, urks and the Urk World have been suggested as a resource base for secondary extraction (Krook et al., 2011). The metal in particular focus in this thesis is copper, which is present in high amounts and concentrations in the infrastructure systems for electricity and telecommunications. Given that half of the world’s mountainous copper has been estimated as having already been exploited and since we are using the “red metal” in ever-increasing degrees (Kapur and Graedel, 2006), recycling has been predicted as the main source of copper within the next thirty years (Sverdrup et al., in press).

As a recycling strategy, copper mining in the Urk World should be understood as one of many plausible responses to the planet’s altered geologic configuration. The longer-term prospects for the traditional mining sector have been deemed a steady decline (Ayres, 1997) and in a not too distant future, the value of low-grade ores in the Earth’s crust will “no longer economically justify the expenditure of solar energy needed to extract and refine them” (ibid. p. 158). In other words: we will run out of the energy and money needed to produce copper using traditional means of extraction, before the planet runs out of copper (Sverdrup et al., in press).

When that happens, urban mining should preferably already be practised or at least be shovel-ready. This is the rationale for the present thesis.
2. The Objectives of the Thesis

The aim of this thesis is to develop several kinds of knowledge that can advise and suggest alternative pathways for the copper quantities found in the Urk World. It focuses on the characteristics of this infrastructural *subterranea incognita*, how it has emerged as a phenomenon in a context of work practices and regulatory frameworks, and how the provision of infrastructure could be re-arranged for the purpose of exploiting the Urk World as a secondary resource base.

To inform the design of well-functioning recycling systems, knowledge of the size, spatial distribution and characteristics of the resource that is to be recycled is just as necessary as the disposal practices of the actors and organizations involved (Lane, 2014). Historically, the success of secondary resource recovery in Sweden has been dependent on political interventions (SEPA, 2012), suggesting that knowledge of how tools and instruments of policy are involved in the creation of surplus material (Gille, 2010) is also useful for the forming of recycling interventions.

To achieve a research design that is able to provide all of these knowledge components for the case of urban infrastructure mining, I have combined two academic bodies of literature that are explicitly interested in urban worlds and their infrastructure networks: urban metabolism (UM) and infrastructure studies (IS). While scholars in these two fields have a shared interest in the material configuration of cities, they approach their research subject from different perspectives (see Brunner and Rechberger, 2004; Otter, 2010). The tools used in UM research allow for quantitative assessments of biophysical exchange processes of cities (cf. Barles, 2010), while IS scholars scrutinize the urban condition as a process in which human actors and urban technologies create the networked city together (cf. Guy and Karvonen, 2012). The combination of these two fields has allowed me to shed different lights on the Urk World phenomenon and the prerequisites to engage in mining there. In this cover essay, I therefore synthesize my research in three knowledge “clusters”, which separately focus on the three research questions that have guided the PhD thesis as a whole.
2.1 Knowledge Cluster 1: The Dawn of the Urk World

The first of these knowledge clusters concerns the emergence of the Urk World, i.e., how human actions and the infrastructural urban environment co-create dynamics of urk accumulation. My focus is here on how the creation of urks is arranged in infrastructural practices, and I scrutinize the sociotechnical processes in which urks occur. Knowledge of such aspects has been argued for as valuable for the design of successful recycling schemes (Bulkeley and Gregson, 2009; Lane, 2014), together with matters of ownership (Pongrácz and Pohjola, 2004) which are also addressed herein. The analysis of this knowledge cluster is guided by the first research question and its two sub-questions:

**RQ 1: How did the Urk World emerge and how is its continued existence ensured?**

Why are urks disconnected?

Why are urks left behind?

To answer these questions my co-authors and I performed one study on how infrastructure maintenance and repair is practically organized for a series of different systems in the Swedish city of Norrköping (Article 2), and one study that investigates how the Swedish regulatory framework allows urks to accumulate (Article 4). These studies are based on interviews with infrastructure actors in the local context of Norrköping and actors with thorough knowledge of infrastructure and/or waste matters in Sweden generally.

2.2. Knowledge Cluster 2: Mining the Urk World

The second cluster concerns the feasibility of mining the Urk World. Here I focus on how the Urk World can be prospected using a simplified two-phase approach (cf. Lederer et al., in review), which is similar to how the potential of mineral ore deposits is determined in traditional mining. The first phase regards the physical capacities of the Urk World and develops spatially informed knowledge of urk copper quantities, which is advised as necessary to determine the recycling potential of a secondary resource reserve (Brunner, 2007; Graedel and Allenby, 2010). The second phase deals with the spatially and contextually dependent conditions to recover such reserves, and I assess different strategies that urk mining can be engaged with. The analysis of this knowledge cluster is guided by the second research question and its two sub-questions:
RQ 2: What is the potential of Urk World mining?

How much copper does the Urk World contain and where is it located?

How can these quantities practically be recovered and by which implications?

To answer these questions, we used Geographical Information Systems (GIS) software to spatially analyse the Urk Worlds of the Swedish cities of Norrköping (Article 1) and Linköping (Article 5). While the Norrköping study performed a spatial characterization on several infrastructure systems, the Linköping one focused only the electricity system but specifically assessed the conditions of urk recovery as well.

2.3. Knowledge Cluster 3: Do Urks Have Politics?

The last cluster concerns the politics of the Urk World, and adheres to Nikhil Anand’s (2011) understanding of infrastructures as being both embedded in politics that ensure their functioning, and capable of spurring and suggesting political actions. This cluster thus deals with how political ramifications of Swedish infrastructure are involved in the systems’ creation of surplus material (see Gille, 2010). Also, I analyse how urk recovery might be made into a matter of concern (Latour, 2004) by outlining issues to be resolved for increased urk recovery. The analysis of this knowledge cluster is guided by the third research question and its two sub–questions:

RQ 3: How is politics involved in the Urk World?

How does the current political embeddedness of infrastructure affect urks and the Urk world?

Which urgent issues must be debated for urk recovery to occur?

These questions are approached in Articles 2 and 4, which both present interview–based studies in a Swedish context. In those, we examine how processes of maintenance and repair have been affected by how the current infrastructure configuration has been politically decided (Article 2), and outline the fault lines that appear between different actors and priorities where interventions can be made for increased urk recovery (Article 4).
2.4 The Structure of the Thesis

In Chapter 3, I make the case for increased copper recycling as the environmental rationale of the thesis. I present the research framework design in chapter 4, together with an outline of the appended articles and the methods used. Chapters 5 and 6 introduce the research approaches of Urban Metabolism and Infrastructure Studies and how previous work in these two fields relates to my thesis topic. Chapters 7, 8 and 9 rely on the results of the appended articles, and here I answer the research questions by presenting the three clusters of knowledge. Chapter 10 presents my reflection on how urban metabolism and infrastructure studies might be developed as research areas given the knowledge presented, while Chapter 11 concludes the thesis’ major contributions and suggestions for future areas of research.
Metals are gifts from the stars that were generated over billions of years; we should treat them with the awe and respect they deserve and devise ways to recycle them over and over.
– Thomas Graedel, 2011

3. The Rationale of Studying the Urk World

Early advances in radical mineral extraction strategies suggest that actors in several sectors are looking for alternative pathways to solve the mineral challenges of the upcoming century, rather than continuing last century’s battle to ensure profitable extraction from ever-decreasing ore grades. Increasing amounts of investments are for example made in environmentally risky alternatives such as ultra–deep mining below 2.5 km (Diering, 2000), mining the depths of the oceans (Cronan, 2000) or asteroids in outer space (Lewis, 2014), as well as in exploring non–conventional secondary reserves in societal stocks such as landfills (Johansson, 2013; Frändegård, 2014) or infrastructures (Hashimoto et al., 2007).

3.1. Why the Focus on Cupriferous Urks?

Copper is the third most–used metal in the world after steel and aluminium. It is a malleable and ductile metal that performs exquisitely as a conductor of electricity, evidence of which is seen in how it transmits nearly all the world’s power (LeCain, 2009). The geographical context of the thesis is Sweden. As elsewhere, copper has historically been the preferred Swedish choice for the cable–based infrastructure for electricity and telecommunication, which are the systems in major focus in this thesis (see Figure 1). In the early 20th century, the expansion days of the national power grid for some time transformed Sweden from a net exporter to a net importer of copper (Vikström et al., forthcoming) and as late as 1999, 28% of Swedish copper use was still devoted to the construction of infrastructure systems (Landner and Lindeström, 1999, p. 76). The in–use copper accumulation in the Swedish electric and telecom grids is by now equivalent to the reserves in Aitik, Sweden’s and one of Europe’s largest copper mines (Krook and Baas, 2013). Their sheer size is thus one reason for why copper stocks in infrastructure systems have been targeted as a resource base for the secondary extraction of metals (UNEP, 2010).
Figure 1. The Global Copper Machine (adapted from Glöser et al. 2013). A depiction of how this thesis' objects of inquiry relates to the global flows of copper.
As cables and pipes are comparatively large objects with significant concentrations of metals, they are easily aggregated for the sake of recycling (Ayres, 1997). This implies that if they are recycled, which however is difficult given their inaccessible location (Graedel, 2011), they could likely increase recycling percentages significantly for a certain period of time.

Cities are infrastructural, and they rely on sinks, i.e., repository sites, that store, filter and process different kinds of surplus materials (Tarr, 1996; Gabrys, 2009). The urban underground provides such a sink for disconnected components of infrastructure, which become theoretically available for recycling as they are taken out of service. While the majority of urban infrastructure components are in use, many infrastructure systems have started to reach the end of their service lives, especially in the Western parts of the world where they have been installed the longest. That a lot of components must soon be replaced suggests these systems to be an even more interesting source of secondary copper in the near future. In general, copper recovery from societal stocks can be motivated from environmental, degrowth and social perspectives.

3.2. The Environmental Argument for Copper Recycling

Copper is mostly extracted in open–pit mines, a mining technology developed and perfected to supply the world with copper through the mass destruction of mountains (LeCain, 2009). The ore grades from which copper is mined are steadily declining (Bridge, 2000), and at an average of 0.8% (Crawson, 2012), the production of a single tonne of copper nowadays requires the mining of 125 tonnes of ore. Only the mining of the fuel minerals coal and uranium are worse in terms of magnitude of material displaced (Ayres et al., 2002).

The environmental damage related to the energy– and resource–intensive copper production process is significant in terms of the deleterious effects on ecosystems and the surrounding landscapes (see Figure 2). The surplus refuse from copper mining is often chemically reactive (Bridge, 2004), and the process is in its entirety associated to environmental problems such as water pollution due to the leaching of toxic heavy metals like arsenic, molybdenum and lead, and airborne sulphur dioxide emissions from smelting (Ayres et al., 2002). Depending on the quality and kind of scrap, between 25–85% less energy is required for secondary production of copper in comparison to primary production (Kapur, 2006). The potential environmental benefits of copper recycling are thus significant.
Figure 2. Environmental Impacts of Traditional Mining (adapted from Warhurst and Noronha, 1999). The potential hazards in the upper red box increase with decreasing ore grades and are theoretically avoided if traditional mining is replaced by metal recycling.
3.3. The Ethical/Degrowth Argument for Copper Recycling

The case for copper recycling differs from that of steel and aluminium since copper (unlike iron and bauxite ore) is not abundant in the Earth's crust. Analyses indicate that the global future production rates of copper will continuously increase together with planetary welfare levels, and might reach a peak of production before 2020 (Ayres et al., 2002; Zittel, 2012). As 550 Mt of copper were extracted globally between 1930 and 2011 (and are thus in use or wasted), and 530 Mt remains for the future to be exploited (Zittel, 2012), estimates suggest that half of all the copper that will ever be produced has already been extracted (Spatari et al., 2005; Müller et al., 2006; Kapur and Graedel, 2006). The size of the remaining copper deposits do not call for any immediate supply risks in a short-term perspective (Alonso et al., 2007), but the possibility of scarcity in future supplies creates room for a discussion of the global societal copper stock's unequal distribution between regions. In 2000, the per capita in-use stock of copper varied from 30–40 kg per person in countries in the Global South to 140 to 300 kg per person in the Global North (Gerst and Graedel, 2008), amongst which Sweden was found at 189 kg of in-use copper per person (Rauch, 2009). Based on a future global population of 10 billion as projected by the UN, and the numbers provided by Zittel et al. (2012), Exner et al. (2014) arrive at an approximate average of 100 kg per person if the planetary copper stock was to be distributed equally, implying a net export of copper from rich countries to poorer ones. If Sweden wants to contribute to the goal of equal access to copper for all nations, this would mean a significant degrowth of the country's in-use copper stocks. The size of the hibernating stock of urks determines the extent in which urk mining could contribute towards realizing such an ambition.

3.4 The Social Argument for Copper Recycling

A final argument for increased copper recycling is the social impact of traditional copper extraction, which includes issues ranging from worker safety and occupational health, to matters of community stability, cultural integrity and indigenous rights (Bridge, 2004). Social conflicts, almost without exception, accompany mining projects (see Ali, 2003; Bebbington, 2012), and tend to be framed around issues of ownership and exercise of rights to land and water, and the often conflicting legal rights of the state and moral rights of affected local communities (Bridge, 2004 p. 217). Sweden is no exception in these matters. Ever since the significantly increased metal prices resulted in a proliferation of prospecting activities between 2004 and 2008, a long series of controversial concessions and
projects have arisen. During the fall of 2015, no less than four highly contested mine allowances were up for decision by the national government (Sveriges radio, 2015). All of these are examples of the long-standing conflicts of the rights to the land between mining interests and the indigenous Sapmi population in the Swedish north, which is also the underlying reason for why Sweden has not ratified ILO Convention 169 on the rights of indigenous and tribal peoples (SOU, 1999:25).

In comparison to traditional extraction, recycling does not immediately threaten the livelihoods of local communities in the same way that primary extraction does. Nor does it hurt other branches of industry such as tourism or hydropower. Furthermore, it is a univocally accepted activity, as evidence shows in the form of high public support and participation, for example in municipal recycling schemes (see MacBride, 2012). For social reasons then, while tentatively leading to increased amounts of traffic shut–offs and other disturbances in the urban environment, the mining of Urk World ore is preferable to traditional mining.
The truth of the Anthropocene is less about what humanity is doing, than the traces that humanity will leave behind.
– Szerszynski, 2012

4. The Scientific Underpinnings of the Thesis: The Interdisciplinary Study of Infrastructures

Infrastructures are peculiar, Brian Larkin writes, in being both “things and also the relation between things” or, put differently: “the objects that create the grounds on which other objects operate” (2013, p. 329). In this capacity, infrastructures operate as systems, allowing scholars interested in their complex functioning to draw a multitude of heterogeneous components into their academic analysis. The diversity of applicable perspectives for the study of infrastructure systems ranges from natural science-oriented systems analysis assessments found for example in material flow analysis (e.g. Drakonakis et al., 2007) to the relational parlance in Jane Bennett’s notion of the infrastructural assemblage, in which the electrical grid is “a volatile mix of coal, sweat, electromagnetic fields, computer programs, electron streams, profit motives, heat, lifestyles, nuclear fuel, plastic, fantasies of mastery, static, legislation, water, economic theory, wire, and wood – to name just a few of its actants” (Bennett, 2005 p. 448).

4.1 Introducing Urban Metabolism and Infrastructure Studies

While there is plenty of academic work on infrastructure systems in many disciplines, the previous research on urks is meagre. There are publications and conceptualizations that touch upon the existence of urks and the Urk World but I have not found any study that engaged with them as a sole and explicit object of inquiry. In this thesis, I make use of two bodies of literature that share an interest in infrastructure systems and have at least come close to urks as a research topic: Urban Metabolism (UM) and Infrastructure Studies (IS). These fields have inherently different views on how the world works, which they have inherited from their respective larger academic disciplines; Industrial Ecology and Science and Technology Studies (STS)³.
Many industrial ecologists, it can be argued, regard the world as something that is out there for us, as human scholars, to study, measure and understand. The frequent use of concepts such as “anthroposphere” (cf. Graedel et al., 2004), “biosphere” and “technosphere” (cf. Palm and Östlund, 1996), as distinguishable and separable entities is evidence of this. STS, on the other hand, has an entangled worldview in which humans and non–humans, i.e., technologies, things, animals and so on co–constitute the world, implying that this is also how the world must be studied; as a process in the making.

The different underpinnings of these two academic disciplines can be further exemplified by how urban metabolism and infrastructure studies regard cities. Urban metabolism scholars understand the city as a biogeophysical entity in which material flows over time accumulate into an urban fabric (cf. Douglas, 1983; Wilburn and Goonan, 1998). They purposefully simplify the urban fabric into a device for the accounting of material accumulation, while its existence as a result of actors engaged in sociotechnical processes is left outside of the analysis. The latter is on the other hand the explicit focus in urban–oriented infrastructure studies in which the configurative process of the urban fabric is particularly emphasized. These scholars give actors, politics, coordinating mechanisms and so on, a central position in their research designs (cf. Aibar and Bijker, 1997; Gullberg and Kaijser, 2004), while the materials science understanding of the urban fabric’s biogeophysical capacities on the other hand tends to be neglected5.

Scholars of urban metabolism and infrastructure studies thus share a common point of interest in networked cities and the urban fabric, but they operate in different conceptual territories. My central methodological argument in this thesis is that the different perspectives of these two approaches can interact and create a mutual modus operandi that makes use of their internal diversities. Rather than merging them into a consensus on how the urban fabric should preferably be addressed, or emphasizing one over the other, I argue that it is possible to find a trading zone in which both can operate without compromising their respective core qualities (Article 3).

4.2 The Urk Worlds Assessed in the Thesis
This thesis consists of studies of the urban infrastructures of the Swedish cities Norrköping (Articles 1 and 2) and Linköping (Article 5). The reason for why these cities were chosen is because the division where I have been
employees had established contacts with key actors in both of them when the research project started, which provided relatively easy access to relevant sources of data material as well as respondents. Norrköping and Linköping are relatively similar in terms of population (≈90,000 inhabitants) and geographical location in the Östergötland region of Sweden, and they display few if any residential areas that are uninhabited, as neither one of them have experienced longer periods of population decreases. There are some noteworthy infrastructural differences between them, one of them being that the German company E.On operates Norrköping’s grids for electricity and district heating, while Linköping still has its own municipally owned utility company, Tekniska Verken. The two companies have furthermore solved their maintenance and repair services differently: Tekniska Verken still has an in–house maintenance division, while E.On has outsourced theirs based on procurements for three to five–year contracts. In the case of electricity, this has been allowed ever since the sector was deregulated in 1996 (Källberg och Fransson, 2012).

Given that “mining” is understood vertically in this thesis, the assessed infrastructures are all subterranean. The systems were delimited to enable both a decontextualized quantitative assessment as preferred by UM and allow for recontextualization in qualitative process terms from the IS perspective. For example, I chose a significantly smaller spatial as well as material scope in comparison to most urban metabolism studies (Articles 1 and 5), and have kept the assessments local and with fewer included material entities than is normally the case (cf. Drakonakis et al., 2007). The twofold purpose behind this delimitation was (1) to reach a fine–grained understanding of the material capacities and spatial patterns of the Urk World and (2) to allow for qualitative analysis of how the Urk World has occurred and continues to occur, based on interviews with people that were either involved in urk accumulation processes, or had knowledge of the arrangements that allow this to happen.

4.3 The Appended Articles and Methods Used

An implication of designing my research approach in this way was that my use of the tools and methods in the two fields had to be reconfigured and apply slightly new means. The implications for both of the research approaches are described in sections 5.3 and 6.2–3. As an integrated whole, the research design benefited from the fact that the two perspectives interacted and were complementary, as it enabled me to cover aspects that would not have been possible by applying the perspectives one at a time.
Following from the mix of approaches, my epistemological stance is not consistent throughout all the appended articles and neither is the understanding urks and their Urk World habitat. Alternating the epistemological stance from one study to another created a certain kind of leeway for the thesis as a whole in providing me the possibility of developing different kinds of knowledge that in sum increased my understanding of the backstage world of infrastructure systems as well as the Urk World. For a more in–depth description of the theoretical under–pinnings of the interdisciplinary research design, see Article 3. In the following, I briefly describe the five articles, the methods used and short sections of who did what.

**Article 1:** To Prospect an Urban Mine: Assessing the Metal Recovery Potential of Infrastructure “Cold Spots” in Norrköping, Sweden  
**Journal:** Journal of Cleaner Production 55 (2013) 103–111.  
**Corresponding Author:** Björn Wallsten.  
**Co–Authors:** Annica Carlsson, Per Frändegård, Joakim Krook and Stefan Svanström.  
**Status:** Published.  
**Description:** In this article, we investigate copper, aluminium and iron in the infrastructure systems for AC and DC power, telecommunication, town gas and district heating in the city of Norrköping, Sweden. In size and spatial terms, we analyze the copper, aluminium and iron content for all the included infrastructure systems and estimate total tonnages for Norrköping’s infrastructure (urks as well as in–use components). We also assess how these quantities are spatially dispersed throughout the city.  
**Method:** We perform a bottom–up material flow analysis (MFA) of a purposefully delimited study object, which enabled a spatially informed analysis made with very few estimates and generalized assumptions. The quantification is based on a rigorous, time–consuming collection of local data from many different source materials: historical statistics and archived maps in the Norrköping City archive, and data and digitalized maps from the infrastructure system owners. The data was compiled using Geographical Information Systems software (GIS), in which the weights of all urks were calculated and then spatially analyzed using a map of Norrköping’s 36 official city districts and information on land use and the average age of buildings.  
**Who did what?** I collected most of the spatial data and manually digitalized the disconnected sections of the AC power grid together with
students Simon Andersson and Johan Pettersson. All the authors participated with Stefan Svanström at Statistics Sweden to assemble maps of the DC power and town gas grid, which were not retrievable elsewhere. Joakim Krook calculated the metal content per system meter while I did the GIS work. I wrote chapter 2, 3 and the conclusions, Joakim Krook and I co-wrote chapter 1, while Annica Carlsson wrote chapter 4. We all co-wrote chapter five. I re-worked and edited the text before submission, and was solely responsible during the review process. The maps were designed by Stefan Svanström.

Article 2: A Cable Laid Is a Cable Played: On the Hibernation Logic Behind Urban Infrastructure Mines


Corresponding Author: Björn Wallsten.

Co-Authors: Nils Johansson and Joakim Krook.

Status: Published.

Description: In this article, we analyze the underlying mechanisms of urk accumulation in different infrastructures in the Swedish city of Norrköping. We explicitly focus on the socio–technical processes in which urks are born, i.e., when system sections are disconnected and left behind. For this particular article, Norrköping was a good choice of study object based on the previous infrastructure–related research done on the city. Two empirically thick dissertations on gas and electricity (Kaijser, 1986), and water and sewage (Hallström, 2002) were particularly important.

Method: The empirical material was gathered using semi–structured interviews. Half of these were done with maintenance and repair workers to get as close to the micro–level of work practice and infrastructure disconnection process as possible. The other half were done with white–collar employees involved in infrastructure management at the local level who could complement the picture further with insights of the provisional, often contractual, aspects of maintenance and repair. In total, nine interviews were conducted. All were transcribed in full and then analyzed on the basis of three spatial disconnection patterns that we had detected during the work with Article 1. Theoretically, we took the conceptualization of infrastructure “cold spots” as a point of departure (cf. Guy et al., 1997, see section 6.1), and made use of previous infrastructure studies literature on the decline of Norrköping’s town gas system to be able to describe system obsolescence (Kaijser, 1986).
Who did what? I participated in all of the interview occasions except one where Nils Johansson did the interviewing alone. I transcribed six of the interviews and assembled the maps made from re-used GIS layers from Article 1. I wrote all of the chapters except for chapters 6 and 7, the first drafts of which were written by Joakim Krock and Nils Johansson respectively. I revised and edited the text before submission, and was solely responsible during the review process. The maps were designed by my brother Erik Berglund.

**Article 3:** Toward Social MFA — On the Usefulness of Boundary Objects in Urban Mining Research  
**Corresponding Author:** Björn Wallsten.  
**Co–Authors:** None.  
**Status:** Published.  

**Description:** In this article, I argue that research approaches that do not share the same epistemological convictions can be aligned and work together without a consensual understanding of the world, if their efforts are orchestrated towards a purposefully limited object of inquiry. I suggest that such a research design can be centred on what Star and Griesemer (1989) term a “boundary object”, i.e., an object capable of inhabiting several social worlds simultaneously while satisfying “the informational requirements of each of them” (Star and Griesemer, 1989, p. 393). Explicitly, I suggest the combination of quantitative assessment of material flow analysis (MFA) with the qualitative scrutiny performed in infrastructure studies (IS), and give concrete example of how to engage with such a research endeavor by describing how Article 1 and 2 were carried out in an orchestrated research effort. The article denotes how the applied approaches had to be slightly adjusted to make a good fit with each other, and the results achieved by using such an interdisciplinary approach in comparison to previous research in both fields respectively.

**Method:** Since the article is a re–write of the methodology sections of the cover essay of my licentiate thesis (Wallsten, 2013), no empirical material was explicitly collected. As such, the article synthesizes the main methodological arguments of my licentiate thesis with the ambition to inspire future researchers to engage with similar approaches.

Who did what? I wrote, edited and re–structured the licentiate thesis text to fit the article format, and was solely responsible during the review process.
Article 4: Urks and the Urban Subsurface as Geo–Social Formation
Journal: Science, Technology and Human Values.
Corresponding Author: Björn Wallsten.
Co–Author: Joakim Krook.
Status: Re–submitted after an initial “revise and resubmit” verdict.

Description: Our starting point in this article is that there is a certain non–stagnant capacity of waste–like entities such as urks, and that their resistance to categorization is crucial to encapsulate their political potential (cf. Hawkins, 2006; Moore, 2012; Hird, 2013). We investigate how this indeterminate capacity has implications in terms of where future trajectories for urk recovery are conceivable, and examine perceived fault lines between actors and priorities in urgent issues that must be resolved for increased urk recovery.

Method: The article is based on interviews, and we chose the respondents to cover a wide spectrum of actors, from maintenance and repair workers to national legislators, with explicit insights in Swedish infrastructure and/or waste–related matters. In total, twelve interviews were conducted, transcribed in full and then coded on the analytical basis of identifying the respondents’ exploratory interpretations of urks and their political consequences.

Who did what? Because of parental leave I participated in only two of the interviews, most of which were performed by Annica Carlsson. External help was used for the transcriptions. Annica Carlsson did the first thematic structuring of the material, while I developed the theoretical apparatus of the paper and wrote the article text in its entirety. Joakim Krook provided significant help in structuring the arguments, while I was solely responsible during the review process. Since 2014 Annica Carlsson has been working for the Swedish Environmental Protection Agency, and refrained from co–authorship of the paper.

Article 5: The Economic Conditions for Urban Infrastructure Mining: Using GIS to Prospect Hibernating Copper Stocks
Corresponding Author: Björn Wallsten.
Co–Authors: Dick Magnusson, Simon Andersson and Joakim Krook.
Status: Published.
Description: In this article, we present a study of urks in Linköping’s power grid that calculates their weights and spatial dispersion. In comparison to Article 1, the number of systems and metals assessed are fewer. Instead, we take the analysis one step further by performing several assessments of the conditions for secondary resource recovery.

Method: We again combined GIS and MFA into a prospecting tool for secondary reserves in a prospecting approach characterized by a high-resolution assessment of data from system owners and scanned infrastructure maps. The approach is two-phased and couples spatially informed size estimates of Linköping’s Urk World (phase 1) to the equally spatially contingent efforts required to recover urks from it (phase 2).

Who did what? Simon Andersson assembled the core dataset of urks for his master’s thesis. He collected the data from the archives of Tekniska Verken and digitalized them manually. Graduate student Jenny Rignell (2014) tried out the GIS–based method in her master’s thesis, which was thereafter extensively developed by the article authors. Joakim Krook calculated the urks’ metal contents while Dick Magnusson was responsible for the GIS work. I wrote the majority of the first article draft, except for the GIS method section and supplementary data, which were written by Dick Magnusson. Joakim Krook provided the majority of the strengths–and–weaknesses discussion, while I wrote the conclusions. Dick Magnusson developed the maps and tables, with some graphic editing by myself.
5. Urban Metabolism – An Introduction

The quantitative framework of this thesis is based on the understanding of urban metabolism found in the academic field of industrial ecology. The starting point for this field is that industrial and ecological systems share certain traits, and that nature can function as a key inspiration when improving the environmental performance of industrial as well as urban processes (Lifset and Graedel, 2002). Within industrial ecology, an array of different environmental assessment approaches have been developed, of which the study of urban metabolism is one. Urban metabolism is a diverse and broadly applied concept dealing with how cities transform and integrate raw materials, including energy and water, into the built environment (Decker et al., 2000), and can be defined as “the sum total of the technical and socioeconomic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” (Kennedy et al., 2007, p. 44).

There are four assessment tools commonly used within industrial ecology for the study of urban metabolism: Material Flow Analysis (MFA), Substance Flow Analysis (SFA), Energy Flow Analysis (EFA) and Environmental Footprinting. These are all quantitative tools to assess biophysical exchange processes of cities, but they fulfil different purposes that for example depend on whether one’s interest lies in flows of resources, substances or energy (Barles, 2010, p. 444). Since the focus of this thesis is the mineral resource–intensity of cities and the stocks of metals that constitute infrastructure systems, MFA was chosen as the most suitable approach.

5.1 Material Flow Analysis – An Introduction

MFA is to a large extent an accounting exercise aimed at quantifying the stocks and flows of a certain material in a certain geographically defined context and time period (Kennedy et al., 2011). The geographical context is most often an administrative region such as a nation, as MFA is an analysis of the throughput of different material processes of industrial society.
Examples of MFAs done with different scales and scope are assessments of
the global flows of nickel (e.g. Reck et al., 2008), the flows of steel and
copper in Japan (e.g. Daigo et al., 2007) a set of different metal flows in a
particular city such as Stockholm (e.g. Bergbäck et al., 2001) or the flows of
steel through the construction sector (e.g. Moynihan and Alwood, 2011). There are two basic ways of engaging with MFA, and they depend on
whether one collects data using a top–down or bottom–up approach.

Top–down MFA is the more common of the two, generally used to paint the
bigger picture of a material flow, and thus especially useful at the (inter–)
national if not global scale (Chen and Graedel, 2012). It relies on the basic
principle of “inflows equals outflows” (Kleijn, 2000), which is used to
compare the input flows of natural resources, the internal material flows
inside the area chosen for the assessment, and the output flows of emissions
and waste. Typically, a top–down MFA uses flowcharts for accounting of
the material at hand, and the central task is “to generate self–consistent
quantitative flow numbers for all the arrows on the diagram” (Chen and
Graedel, 2012). Data that is not directly available in different kinds of
statistics must be approximated mathematically. The top–down method
relies on comparing the flows over a distinct moment in time (often a year),
and is thus not fully adjusted to assess local repositories that consist of all
the accumulated amounts of a material from its first use to the present.
Mathematically, it is of course possible to calculate the accumulated stock
by integrating the mass balance between inflows and outflows over longer
time periods. Such operations however rely on gathering a thorough set of
historical statistics, which is a precarious but not impossible achievement to
engage with.

The bottom–up approach, which the MFAs in this thesis make use of, relies
on inventories of items (e.g., buildings, vehicles and infrastructure) instead
of flowcharts, and is often used in order to obtain comprehensive, detailed
information on specific material stocks. Bottom–up MFAs are suitable for
the scale of cities and might be calibrated to assess study objects as small as
a single house (Hedbrant, 2003). The material contents in a geographical
area chosen for assessment are estimated based on data from product
declarations, multiplied by the estimated number of units in use in the area.
To arrive at metal content per capita, the total quantities of the study are
divided by the area population. GIS–based census information can be used
to approximate the stocks’ spatial distribution (see van Beers and Graedel,
2007). A weakness of the bottom–up approach is that it yields less useful
data on waste deposits, because accessible and reliable information on the
content and extent of such repositories is hard to find (Graedel and Allenby,
This lack of readily available information is present also in the case of hibernating stocks such as urks. However, in-depth archive searches and other sources of historical statistics can alleviate these issues, so that in the end it boils down to the hours devoted to data collection.

5.2 Previous MFA Studies on Hibernating Stocks

The concept of hibernating stocks originates from the field of MFA, or more precisely from a Swedish research project focusing on Stockholm in the 1990s. Several scholars mistakenly refer to a publication from this project (Bergbäck and Lohm, 1997) as the first to describe hibernating stocks and how these “may be very large” and “cannot be ignored” (cf. van der Voet et al., 2000; Ayres and Ayres 2002). Instead, the first mention of “hibernating stocks” that I have found is in Lohm et al. (1997). Hibernation is there described as both a state and an amount, consisting of products that are no longer in–use but have not yet reached waste management either (Lohm et al., 1997). Several years after the concept was coined, Paul Brunner (2004:5) claimed that “amazingly little” was known about where and how large hibernating stocks actually are.

Before this thesis project started, some studies had targeted hibernating stocks at the household (Hedbrant, 2003) as well as societal level (Chan, 2004), with several studies focused on electronic gadgets such as mobile phones and TVs in household closets, drawers and attics (cf. Ongondo and Williams, 2011; Milovantseva and Saphores, 2012; Murakami et al., 2012). Out–of–use pipes still in the soil were amongst the first entities to be characterized as hibernating (Bergbäck and Lohm, 1997), for which some initial, sector–specific estimates had also been done in two consultancy reports (Designnine, 2006; Neuendorff, 2008) and a master’s thesis by Johan Wendell (2005).

Generally however, MFA researchers explain the difficulty in determining hibernating stocks as a combination of limited data availability and their heavy dependence on consumer behaviour patterns (Kapur and Graedel, 2006). Some studies estimate their hibernating stocks indirectly on the basis of the differences between the inflow and outflow of materials (Chen and Graedel, 2012), while others do not distinguish between hibernation and other stock categories due to data unavailability (cf. Spatari et al., 2005; Haas et al., 2015). Furthermore, hibernating stocks have not only been neglected within the research community but also in statistics and account ledgers where information is rare if it exists at all (Brunner, 2007).

Recent MFA research overviews that explicitly mention hibernating stocks
of urban infrastructure do not describe them in much detail (Alwood and Cullen, 2012, p. 267) and regard it as highly unlikely that they would ever be recovered (Graedel, 2011, p. 48).

5.3 Previous MFA Studies that Use GIS

The two MFA studies in this thesis use GIS software to spatially inform their analysis (Articles 1 and 5). While GIS is not an absolute necessity for spatial MFA assessments (cf. Zhang et al., 2011; 2014), such a combined approach is recommended due to its capacity to provide a spatial database and analysis tool for comprehensive accounting of a certain material in a given area (Zhu, 2014). A few previous studies have made use of GIS to do MFA (Tanikawa et al., 2002; van Beers and Graedel, 2003; Tanikawa et al., 2004; van Beers and Graedel, 2007; Tanikawa and Hashimoto, 2009; Tanikawa et al., 2009). Both the scale and scope of these studies is quite different from the ones presented in this thesis, as they present visualizations of summated material stocks at the aggregated level of city districts in large metropolitan areas9, whereas our studies focus on only “one” empirical object: the hibernating stocks of infrastructure, in the relatively small cities of Norrköping (Article 1) and Linköping (Article 5). The previous MFA study that is most comparable and similar in terms of size to the ones of this thesis is a detailed study of the city district of Salford Quays in Manchester, UK, in which Tanikawa and Hashimoto (2009) assess how the stocks for different construction materials grew between 1849 and 2004. That study is based on estimations of demolition rates of buildings and infrastructure, a method that is fairly imprecise if accurate estimates on hibernating stocks are sought. If we had used a similar model, complementary percentage statistics on the share of infrastructure left behind upon disconnection would have been needed to arrive at our desired level of detail.

5.4 Material Flow Analysis Done Differently

5.4.1 GIS–based MFA with a Delimited Study Object

In our studies, we had the deliberate intention of keeping close to the objects of inquiry and the local context and scale. Our zoomed–in focus on infrastructure systems was intentional since we perceived that high resolution and spatial sensitivity was necessary to acquire useful knowledge about the conditions for the mining of Urk World ore. We therefore also tried to avoid statistics–based assumptions to the furthest extent possible, since they would have affected the analysis of the object–specific local
conditions of urk recovery negatively. With our limited scope, the object of inquiry was not, like in most other MFAs, lost in inventories; the urks and the Urk World were not reduced to numbers and then resolved in aggregated estimates. Precisely because the MFA was framed to keep the individual objects in play, it was possible to connect the results to the social arrangements that are involved in creating these specific material stocks.

5.4.2 Using Historical Data to Quantify Hibernating Stocks
The limited scope allowed for time-consuming data collection to retrieve local infrastructure data, archive material and scanned paper maps, which enabled an assessment of the Urk World without making generalizations other than at the very local level\(^\text{10}\). Municipal statistics and historical maps dating back to the 1850s were used to identify systems disconnected in their entirety in Norrköping (Article 1), while 400 digitalized maps of the power grid were screened and transferred into GIS to be able to detect urks in Linköping from 1970 to the present (Article 5). In principle, we digitalized the urks’ material capacities and spatial location at the zoomed-in level of singular objects (see Figure 3). This is a major strength in terms of reliability and validity in comparison to other MFAs that model their estimates based on proxy indicators such as weighing factors for material amounts related to household income levels (van Beers and Graedel, 2004), or copper content per dwelling type (van Beers and Graedel, 2007).

Figure 3 (next spread). A Scanned Paper Map of an Electric Grid. In total, urks from 580 maps like this one were digitalized into GIS to provide the underlying data for the thesis. The urks are marked in yellow. Their copper content is possible to calculate based on product data for different cable types (see EBR, 2013) and the urk objects’ length.
5.4.3 Economic Analysis of Urk Recovery

The acquired level of detail was absolutely necessary to do estimates on the economic conditions of urk recovery. In comparison, the analysis done prior to this thesis that comes closest to our achievement had highlighted certain areas as more interesting than others from a strict stock perspective without also considering the costs of their extraction (cf. van Beers and Graedel, 2003). The economic analysis of our study (Article 5) combined the revenues one would receive from selling an urk, to the costs associated with extracting it from the urban underground. The revenue calculations were based on how much a large Swedish recycling company would pay for urks of different kinds, which is for example dependent on the copper content (determined by object length multiplied by the number and widths of cable cores) as well as the urk's coating material (paper or plastic result in different recycling efforts in terms of either machine or manual work hours). The costs on the other hand were associated to both the process of excavation (based on project length, machine and man–hours etc.) as well as spatially contingent variables (such as the urk's central or peripheral location in the city and the surface material it is located beneath). In the Linköping study (Article 5), all of these parameters were calculated at the level of singular urks, and relied on combining object–specific urk data with spatial information on the city using GIS.

5.5 Issues With the Applied MFA Approach

A few problematic aspects of doing material stock estimates using data with this level of detail and specificity should also be raised. First, the assessed archive maps are representations of a reality that might have changed since they were drawn (see Figure 3). A cable inscribed as “urk” on a map is of course not evidence that it still remains at that particular location: it might for example have been recovered, moved or re–connected to the grid. There is however little reason to think that our results have been greatly affected by this source of error, since we know from interviews that urk removal has very rarely been engaged with historically. Some method of triangulation, for example using a geo–radar device or the like (see Wang et al., 2011) would nevertheless have been beneficial to validate our findings in even greater detail. Second, we also found some inconsistencies in how urks are denoted; specific details such as information on cable type might have been either lacking or undetectable (in these cases we used copper content averages). During distinct periods of time, the common practice seems to have been to use an eraser to eradicate urks from the maps rather than
denoting them with the “urk” signifier. This might have led to some urks going under the radar during the very time-consuming detection process.

On the level of city characterization, the results are dependent on their local context, that is, the historical particularities of Norrköping and Linköping, their respective infrastructure configuration and so on, which make generalizations for other contexts somewhat precarious. The two studies could of course be compared and used to test the validity of each other’s results (or as a point of entry to discuss their differences), but we avoided statistical generalizations about whether the quantitative results were also valid for other cities in both articles (Articles 1 and 5).
6. Infrastructure Studies – An Introduction

Since the mid-1980s there has been a consistent flow of research within the social and humanistic sciences that can be identified as “infrastructure studies”. The authors are predominantly scholars within the fields of STS, history of technology, and geography that share an interest in infrastructure systems\(^1\). From their perspective the world is sociotechnically arranged, which means that humans and technologies should be conceived of as mutually constituting the world rather than as differentiable entities (MacKenzie and Wajcman, 1999, p. 41). As an example, a sociotechnical understanding of an infrastructure system is not possible without taking into account its context of politics, organisations, regulatory frameworks and so on (Hughes, 1983), and if one for example is interested in the workforce responsible for an infrastructure system’s development, they should be understood as more or less heterogeneous, i.e., work not only with technology as such, “but on and through people, texts, devices, city councils, architectures, economics and all the rest” (Law, 1991, p. 9). While the exact functions of the co-constitutive mechanisms between the social and technical spheres are still heavily debated in the field (Guy and Karvonen, 2012), it has been noted that there is more that connects than separates these researchers epistemologically (Graham and Marvin, 2001).

Several authors have particularly addressed urban infrastructure systems, and come to understand cities as being saturated with a large variety of old and new technologies, functioning as they do on the basis of a dense palimpsest of infrastructure systems (cf. Latour and Hermant, 1998; Graham and Marvin, 2001; Hommels, 2005)\(^2\). From the viewpoint of this “networked condition” (cf. Tarr and Dupuy, 1988), urban technologies such as infrastructure systems configure and are reconfigured by how decision makers and citizens engage with the built environment (cf. Coutard, 1996; Graham and Marvin, 2001). The city is accordingly perceived as an enormous artefact in which the “size and distribution of its streets, sidewalks, buildings, squares, parks, sewers, and so on can be interpreted as remarkable physical records of the sociotechnical world in which the city was developed and conceived” (Aibar and Bijker, 1997, p. 23).
6.1 (The Lack of) Previous Infrastructure Studies of Urks

Similar to previous MFA research, the urban infrastructure research community has so far not emphasized the Urk World as a phenomenon worthy of academic scrutiny. A few conceptions and studies have come close, but I have not found anyone who has explicitly targeted urks as objects of inquiry. A tentative reason for this negligence is that urks are part of an often forgotten narrative: one of reactions in response to forces such as declining demand. Making such an argument would be to adhere to a classic line of criticism voiced since the early days of the field, namely of having an overly narrow focus on the supply side of infrastructure provision and being too oriented towards development–biased descriptions (Bijker and Law, 1992). Even in later years, several authors have continued this line of argument and observed (1) how a knowledge gap still exists regarding underutilized network spaces (Moss, 2008, p. 439); (2) that relatively little is known about infrastructure system decline in general (Gandy, 2005); and (3) that we are seldom if ever served explicit accounts on how infrastructure systems are discontinued or unmade (Weber and Salehabadi, 2012).

Now, while these observations might be true in a relative sense (there is more knowledge on the development than decline of infrastructures), there are several studies that have dealt with infrastructure decline explicitly (Hughes, 1987; Gökalp, 1992; Kaijser, 1994; Ekman, 2003) and others that have dealt with related concepts such as breakdowns and interruptions (Bennett, 2005; Nye, 2010; Silvast, 2013).

There is also the literature on infrastructure “cold spots” (Guy et al., 1997; Moss, 2003, 2008; Naumann and Bernt, 2009; Coward, 2015), the concept within infrastructure studies that has come the closest so far to making the Urk World into an object of analysis. Cold spots are defined in these studies as “parts of technical networks where demand is weak and/or declining” (cf. Moss, 2008, p. 438). They occur when system services are underutilized following for example shutdowns in industrial areas, and their increased prevalence challenges the somewhat dogmatic view that infrastructure systems must always be planned for continuous growth. Situations where the planning of infrastructure is facing reversed challenges are for example found in connection with the European electricity supply (Högselius, 2007), the declining water supplies in the former East Germany (Naumann and Bernt, 2009), and in Swedish factory towns with decreasing populations (Häger and Thell, 2014).
None of the abovementioned studies follow infrastructure parts beyond their rejection, and a tentative reason for this can be related to their invisibility. Many scholars have asserted that as long as infrastructure systems perform their function they are the least apparent: their static components mediate the flow of system services in true silence, and catastrophic failures seem needed to bring them attention (cf. LaPorte, 1994; Guy et al., 1997; Star, 1999; Mau, 2004; Graham, 2009; Nye, 2010). But invisibility is equally present in relation to waste and other overflows that our technological societies produce. Like many other kinds of waste materials, urks are “kept from view, hidden in a back region” (Goffman, 1971, cited in Chappells and Shove, 1999). And so, while scholars of infrastructure might recognize infrastructure’s relative invisibility, this does not automatically mean that they are sensitive to the material wastes that the provision of those very same infrastructures result in. The Urk World is in a sense veiled behind double curtains of invisibility, as both infrastructure systems and wastes have repeatedly been argued as backstaged, or “hidden” urban entities (see Figure 4).

![Figure 4. A Backstage within a Backstage. A depiction of how the topic of this thesis relates to examples of research in urban infrastructure studies and urban waste studies.](image)

### 6.2 Infrastructure Studies Done Differently

#### 6.2.1 An Explicit Interest in Material Disconnection Processes

The extension of infrastructures is ensured through connecting ever more customers to the system and supplying them with services, a process that has been central for their study. As Martin Coward (2015, p. 97) writes: “The ontopolitical imaginary of infrastructural urbanism is one in which life is defined by connectivity. The loss of connectivity (or the threat of such loss) is thus seen as a threat to life itself. This ontopolitics is thus
constitutive of a political dynamic of inclusion and exclusion: connection and disconnection”. However, infrastructure studies seldom engage with the latter half of this dualistic conception, which coincides with how the predominant interest of social theory has been to study matters of connection and assembly, rather than disconnection and disassembly (Graham and Thrift, 2007, p. 7). While there are infrastructure studies on disconnection, these are with merit engaged with from the social perspectives of users (cf. Amin and Graham, 1998). The obvious example would be the conceptualization of “network ghettos” by Nigel Thrift (1995), entailing places characterized by low system access and social disadvantage, and where users run a high risk of becoming disconnected due to having trouble paying bills and so on. Given its highly motivated perspective on matters of social justice, the network ghetto conception nevertheless disregards the material disconnection of system parts. To study disconnections with a material sensibility was thus a first step towards shifting the gaze of infrastructure studies to fit my interest in analyzing urks and the Urk World. In concrete terms, a consequence of this was to not let the non–functioning system entities that are the results of disconnection processes out of sight. As Graham and Thrift (2007) remind us, decay and non–functioning are omnipresent and ever–consistent features of all infrastructure systems. They cite Henry Petroski (1985), who stresses that many infrastructure systems are premised on a certain degree of failure or breakage as a normal condition of their existence.

Like all material wastes, urks must be collected from (or in this case left at) their points of production by people (Jacobs, 1969, p. 111). My interest in socio–material processes of disconnection and their non–functioning material residues thus called for an approach comprised of respondents from different actor categories than those that are the traditional focus in infrastructure studies. The first of these is the workforce most intimately associated to urks; the repair crews, who perform a kind of technical backstage work that is rarely recognized and/or commented upon (cf. Shapin, 1989), and is represented as subordinate in most bureaucracies and thus actively hidden from view (Graham and Thrift, 2007, p. 4). In accordance with the recently emerging body of literature on infrastructure repair and maintenance issues (cf. Castán Broto and Bulkeley, 2013; Jackson, 2014; Ureta, 2014; Denis and Pontille, 2014), and by picking up Susan–Leigh Star’s plea on the surfacing of invisible work as a major research challenge in the social sciences (1999), the repair crew workers were invited as respondents in our studies (Articles 2 and 4).
A second previously neglected category of actors within infrastructure studies that was included are those that can be broadly defined as having regulatory as well as practical insights in matters of waste and recycling. To the extent that infrastructures are part of the Swedish system of waste management, there are recycling actors that deal explicitly with their afterlife as well as those that influence the formulation of regulations and societal goals that dictate the waste creation of infrastructures. Inviting interviewees from the Swedish Ministry of Environment, the Swedish Environmental Protection Agency, the Recyclers Association and metal recycling companies for the interviews (Article 4), enabled the possibility to further develop an environmental understanding of infrastructures and the regulatory arrangements that currently allow for the continuous accumulation of urks.

6.2.2 A Geo–Social & Volumetric Understanding of Infrastructure

Understood from the infrastructure studies perspective, the machinery of an infrastructure systems predominantly takes place within the socio-technical realm, i.e., between the providers of system services, the user recipients and the system itself. Placing the human–technology relationship at the centre of analysis, which is indeed at the core of a sociotechnical perspective, can result in the human–nature dimension being decentred or even rendered peripheral. Such a claim is voiced by Monstadt and Naumann (2005, p. 16), who state that “the traditional analytical categories of a sociotechnical system are unsuitable for portraying adequately the metabolism between nature and society structured by large technical systems or the socio–ecological ramifications of this”. Sociotechnical studies mostly omit how “infrastructures constitute a – if, not the – central interface between nature and society” (Monstadt, 2009, p. 1935).

Several studies exists that are concerned with infrastructure’s environmental impact and their key role in low carbon transitions (cf. Bulkeley and Betsill, 2003; Bulkeley et al., 2010). Typical for these studies is that they focus on the environmental consequences stemming from the (most often energy– and emissions–related) flows of systems services rather than the resource–related matters that concern infrastructures’ material build-up. Without explicitly going into dialectic with infrastructure studies scholars, contemporary media theorists argue that technologies can rewardingly be seen as aggregated and “made out of the raw materials of the earth” (Parikka, 2014, p. 5). Adding such a geo–social dimension to the sociotechnical understanding of urban infrastructures is a shift in perspective that enabled me to overcome the distance between our modern
technological society and environmental first sources of our material world, as Timothy LeCain (2009) writes. In a sense, my stance is a reversal to the early history of technology studies that could have a very material focus of infrastructure’s nuts and bolts as primary targets for assessment (see Berner, 2013), but with an added analytical dimension towards their depths as mineral objects.

The use of a geo–social perspective also implied a complementary vertical gaze towards infrastructures, which are often understood as horizontal phenomena. By combining these two, I could analyse infrastructures both in their aspects of vertically connecting different parts of the world, and in their capability of enacting a vertically stratified stack of layers (Bratton, 2015). Graham and Hewitt (2012, pp. 37–38) have argued for a “volumetric urbanism” to address “the ways in which horizontal and vertical extensions, imaginaries, materialities and lived practices intersect and mutually construct each other within and between the subterranean, surficial and suprasurface domains”. In this thesis, the analysis was much informed by such a volumetric standpoint. I wanted to assess infrastructures, not so much in their capacity of dictating the speed and size of system flows, but also and in particular as continuous accumulators of material stock weights in geo–social urban sediments. The interplay between horizontal urban processes at the street level and their vertical effects underneath the urban fabric became a focal point of the analysis, making the arrangements involved in excavations in city streets especially interesting to scrutinize.

6.3 Issues with the Applied Infrastructure Studies Approach

The infrastructure studies performed in this thesis were all based on interviews, which is somewhat precarious given that an ambition was to study maintenance processes in which practices play a major role. Early on in the research process, I considered applying an ethnographic approach for the maintenance–related scrutiny, but came to the conclusion that interviews were a preferable method that better suited my research questions. This was since I was not primarily interested in closely following the everyday maintenance work but rather in the respondents’ accumulated knowledge based on an abundance of experience from different situations and projects in which urks occur. I favoured the interview–based approach, since I was interested in the respondents’ reflections on their practices.

The selection of respondents is always a delicate matter, and could of course have been done differently. This became especially obvious in Article 4, because as we conducted the interviews we realized that the respondents’
answers verged into unknown territory. This was apparently the first time the respondents were asked specifically about urks. It became clear that they did not phrase official statements from the organizations they represented, but rather formulated their answers as preliminary thoughts that developed as the interviews proceeded. In our analysis, we therefore did not emphasize the respondents’ backgrounds, nor did we position the respondents’ claims in relation to one another. It should furthermore be noted that the article’s list of suggestions for where politics for urk recovery could intervene is not exhaustive. Had we chosen other respondents, the spectrum of answers might have been different and the suggestions fewer or more. Since the analysis made was engaged with as a way to open up rather than close down a debate, this was not regarded as problematic.

During the course of this thesis, I have interviewed people ranging from workers with hands–on experience of urks to top–level decision–makers. This array of respondents in positions with varying degrees of influence, comes with challenges of creating a sound interview environment in very different ways. In one arena, me being an academic was thought of as an advantage, while it was met with some degree of skepticism in others. I handled this challenge through adjusting my way of appearance, speaking and dressing to comply with the interview situation.
7. The Dawn of the Urk World

This chapter presents the first knowledge cluster, and depicts how the Urk World emerged and continues to emerge as the accumulated result of actions repeated over long periods of time.

7.1 Why Are Urks Disconnected?

In our study of Norrköping (Article 2), we observed how urks are created on an everyday basis as geo-social leftovers from two urban processes: infrastructure maintenance and repair, and larger infrastructure projects. In two ways, our observations suggested a refined understanding of the theoretical concept of infrastructure “cold spots”. First, they implied the existence of “colder than cold” or “frozen spots”: locations where system flow demands are non-existent. Second, and given the different spatial patterns in which urks congregate, a “frozen spot” is not merely a “spot”, but a multi–scalar phenomenon that for different reasons can be spatially differentiated between. Thus, we denoted different types of this phenomenon.

The first of these were “dormant cells” of infrastructure, which appear as leftovers from maintenance and repair work. These consist of singular disconnected infrastructure system parts that are granularly spread out under the entire city (see Figure 5). Most often, dormant cells are the result of repair crews’ everyday handling of breakdowns, maintenance and replacements, and their efforts to adjust failures, bad component performance, age–related deficiencies, accidental cut–offs and so on (Article 2). Second, in infrastructure “paralysis”, clustered urks appear in flaky cohorts in certain zones of the city, and as a result of project–managed processes such as urban renewal and densification when larger urban areas are re–developed (see Figure 5). As an example, paralysis can be the result of when an energy–intensive industrial facility shuts down and causes an entire power substation to be disconnected together with all of its adjoint cables due to vanished system flow demands (Articles 2 and 5).
Both of these patterns are guided by what we termed an underlying “disconnect and leave behind” logic of infrastructure systems (Article 2). Given that this logic is discernable both when the total flow of system services increases (e.g., when feeder routes are replaced with thicker parts to provide extended services to new urban areas), as well as decreases (e.g., firms relocate and their former supply chords are disconnected), it is complementary to the often–exemplified expansionist logic of “extend and supply” (cf. Moss, 2008), rather than its counterpart. The “disconnect and leave behind” logic is closely related to daily infrastructure operations, and detectable in all the different infrastructure systems that we scrutinized. It continuously freezes urks in time and space when infrastructures are horizontally re–arranged to meet new system service conditions.

At a more encompassing level, infrastructure systems can become obsolete and be disconnected in their entirety, resulting in what we termed
infrastructure “coma” (see Figure 5). This is a more rare and disruptive phenomenon that most often occurs as a competing system emerges that can provide better, more reliable or cheaper system services. As an example, this happened when the town gas deliveries were superseded by electricity in Norrköping (Kajjser, 1986). Infrastructure “coma” tentatively follows a kind of “contract and seize supply” mechanism as disconnecting and leaving behind is then the purpose of the process as the system is shut down.

7.2 Why Are Urks Left Behind?
Given how the “disconnect and leave behind” logic introduced above is two-staged, it is not enough to be disconnected for a piece of infrastructure to become an inhabitant of the Urk World: it must also be left behind. In the following, several reasons for why urks are left behind are presented.

7.2.1 Left Behind for Practical Reasons
In a hands–on sense, urks are left behind as the practices of maintenance and repair of subsurface infrastructures do not always equal visual access to the systems (Article 2). First, a part that is to be replaced (destined to become an urk) might be located further down or at the side of the digging shaft, or follow a completely different route than its replacement. In such cases, which are very common, the (part that is to become an) urk is never unearthed during the maintenance process and therefore left behind without much notice. Second, when system parts are upgraded and as users are sensitive about shut–off times, the installed systems should preferably be in service for as much of the replacement process as possible. Because of this, the excavation and refilling of longer sections is commonly done in sections with the installed part still connected to the system while its replacement is prepared. When it is time to switch over to the replacement part, the old one (soon to be an urk) lies underneath tonnes of soil and is thus impossible to recover. A third reason for why urks are left behind is that infrastructures might be located in such close proximity to one another that removing them is not advisable in order to avoid doing unnecessary damage. A final observation is that whenever repair crews actually encounter the Urk World, no sign of its larger presence is revealed. Given that the Urk World is the long–term result of insignificant day–to–day actions, it is difficult to perceive the magnitude of it as a phenomenon.

Two observations indicate that the system owners also seem to regard urks as insignificant items that are okay to leave behind (Article 2). First, they most often only have rudimentary waste management systems installed to
handle disconnected infrastructure parts. Their efforts to take care of surplus material are altogether quite limited, which for example can be seen in how their contracts with subcontractors and landowners only on very rare occasions are written in a way that involves the mandatory removal of disconnected parts. Second, until quite recently, system owners seldom kept track of urks in the GIS systems used to operate the infrastructure; the main focus of these has naturally been the connected, in-use system that provides the customers with flows of system services. The lack of reliable Urk World documentation might be a result of how the national Swedish agencies do not require system owners to report Urk World statistics, and thus encourage a systematic neglect in terms of relevant bookkeeping (Article 2). As an example, the existing information that we collected for our Linköping study was found on paper maps in obscure corners of Tekniska Verken’s archives or had at best been scanned as image files (Andersson, 2014).

7.2.2. Left Behind for Economic Reasons

Another reason for why urks are left behind is that their recovery is not economically motivated. Together, the high excavation costs and comparatively low recycling revenues make the economic incentives for urk recovery next to non-existent (see Figure 6).

![Figure 6. The Uneconomic Endeavour of Digging Up Urks (adapted from Article 5). This graph plots urks in Linköping (each represented by one dot), and their copper content (deciding the revenues of their recycling) vs. the site-specific costs of digging them up (such as surface material, where in the city they are located, etc.).](image-url)
One the expense side, excavation work is costly in terms of the workforce and machinery hours needed. Furthermore, the system owners have their utilities located in the streetscape owned by the municipality, and so whenever maintenance is being done, there is a series of time-related as well as fixed costs that the system owner has to pay, including the costs to reroute traffic, the rented space for excavated soil masses and re-paving the street surface. Essentially, such costs mean that a repair crew during the current conditions would never dig an extra meter to pick stuff up, even if they could (Article 2).

On the revenue side, metal recyclers pay relatively little for urks because of a range of factors such as global scrap prices, the available recycling technologies and their own profit margins (Article 5). The case of paper-coated cables, the most common urk type in the cities we have studied, can be used as an example of how urk recycling to an extent is trapped in a Catch 22–like logic:

“[S]uch cables seldom end up in the recycling sector because there are no companies willing to pay well enough for them, while the reason for these low revenues partly is that such cables have not yet come in large enough quantities to motivate investments in large-scale, automated recycling facilities” – Krook et al., 2015

7.2.3. Left Behind for Reasons of Legislative Ambiguity

A last set of reasons for why urks are left behind is the difficulty to categorize them according to existing Swedish legislation (Article 4). Our observations in Article 4 point towards how the involved actors are either unaware or uncertain of how the relevant parts of Swedish legislation should be interpreted in the case of urks and the Urk World. We could also observe that the legislative ambiguity of urks can even be used to avoid the responsibility of taking them up.

Key in this respect is that urks as well as the Urk World are pluralistic entities, that is, based on which of their material capacities is emphasized, urks can be interpreted as being many things at the same time. Given that urks are omnipresent in the urban underground, they are also capable of contributing to different interpretations of what the urban underground is, and some of these possible interpretations actively contribute to why urks are left behind (Article 4).

For example, some urks contain environmentally hazardous fluids and substances that might dissipate to nearby surroundings, creating the
possibility of interpreting the urban underground as contaminated soil. As there are many sites in Sweden that are much more polluted than urban undergrounds and therefore prioritized for soil remediation initiatives, the interpretation of the Urk World as contaminated soil is convenient for all actors that might be delegated the costly responsibility for urk recovery. This is since it defines the Urk World as a jurisdictional entity, but parks the matter at the bottom of the list of polluted sites in Sweden in a way that makes it no one’s explicit responsibility to engage with (Article 4).

Then, there is also the factor that the Swedish legislation performs waste with intentionality, i.e., the owner must have an expressed will to get rid of an item for it to be classified as waste, which causes three kinds of problems in relation to urk recovery. First, the system owner can always claim that an urk is a spare part that could be re–connected if needed (the reason why an urk was created is not always that it was broken). If such a claim is voiced, the urk cannot be regarded as waste and then the legislative support for its obligatory removal disappears. Second, even if an urk were regarded as waste, there is a loophole in Swedish environmental law stating that environmental measures such as resource recovery must be “economically reasonable”, i.e., the environmental benefits shall be significant enough to motivate the costs for the action. Since the recovery of urks has not been regarded as that, any actor who would want to enforce it by invoking Swedish waste laws would be powerless. Third, urks cannot in any practical legislative sense be regarded as waste, because if they were, then the Urk World would be a landfill. If landfill legislation came into play in all of Sweden’s urban undergrounds, that would create a situation where large–scale environmental measures would either be required to for example prevent leakages (which is far–fetched and practically impossible), or this piece of legislation would have to be re–written (Article 4)\textsuperscript{15}.

Concerning urks, the current legislative configuration of infrastructure provision in Sweden is a stalemate affair since they are not economically feasible to extract and since Swedish legislation is neither clear nor strict enough to demand their recovery (Article 4).
8. Mining the Urk World

Having outlined the geo-social dynamics that sustain the Urk World, I now turn to the second knowledge cluster, which concerns the accumulated effects of the above outlined dynamics and emphasize the magnitude and spatial dispersion of the Urk World phenomenon. Such a characterization of the Urk World equals the first phase in a two-phase prospecting approach suggested in Article 5, while the second phase aims at assessing the conditions for urk recovery. The results of our studies of Norrköping and Linköping (Articles 1 and 5) are in the following presented according to the two-staged nature of this prospecting approach, to outline the conditions for mining the Urk World.

8.1 Prospecting Phase 1:
The Urk World as a Spatially Dispersed Stock

Our study of the Urk World of Norrköping included seven infrastructure systems, and we found 5,000 tonnes of urk–metal equalling one-fourth of the weight of the city’s infrastructure. This number disclosed a distinct significance of the Urk World as accumulated evidence of the built-in resource inefficiencies in the current infrastructure configuration.

At 560 tonnes, we determined that every tenth tonne of Norrköping’s Urk World was copper, distributed between the four systems for electric power included in the study (see Figure 7). A noteworthy observation was that the two large infrastructure providers in the city are in charge of Urk Worlds of similar sizes. As E.On has 250 tonnes of urk copper in their AC power grid and the municipality of Norrköping has 230 tonnes in their obsolete DC power grid, the (dis-)incentives for copper mining from Norrköping’s Urk World are shared equally between them. In our Linköping study (Article 5), we found 125 tonnes of urk copper in Tekniska Verken’s AC power grid (see Figure 8).
Figure 7. Cupriferous Parts of Norrköping’s Urk World (adapted from Article 1). 560 tonnes of urk copper are here seen spread amongst the city’s 36 districts.
Figure 8. Cupriferous Parts of Linköping’s Urk World (adapted from Article 5). 125 tonnes of urk copper from the in–use power grid are here seen spread amongst the city’s 27 districts.
Comparing the results of Articles 1 and 5, some general observations can be made concerning the spatial dispersion of these copper quantities that might suggest some areas as more interesting than others from an urk recovery perspective.

First, the Urk Worlds of both Norrköping and Linköping are heavier in central urban areas than peripheral ones (see Figures 7 and 8), which correspond to how these areas are also the oldest. Central city districts have had infrastructure installed for the longest period and thus urks have had more time to congregate here than elsewhere. Another underlying reason for the urban centrality of Urk Worlds is that systems often start with supplying central urban areas and then expand outwards. Traces of such developments can be observed in Norrköping where the now obsolete systems for town gas and DC power never reached the outskirts of the city before being taken out of service (see the pattern of infrastructure “coma” in Figure 5). The city has also grown further since then.

Second, the age of city districts is also a factor when comparing more peripheral urban areas: older residential neighbourhoods for example have larger Urk Worlds than newer ones. The Norrköping numbers are most precise on this, where copper in single–family housing areas decreased on a kg/building basis from 15 kg in areas built before 1945, to 9 kg in areas built between 1945–1978 and to 1 kg in areas constructed after 1978 (Article 1).

A final commonality relates to the functioning of city districts, as we could conclude that urks are more prevalent in industrial areas than residential ones (Articles 1 and 5; compare Figure 8 and 9). The reason for this is likely found in the higher fluctuations of infrastructure system demand in industrial areas, as the number of activities is more flexible here than elsewhere. Industrial actors have more variable needs for system services than households and shops, and they move, open and shut down their activities more often. This brings difficulties of dimensioning the supply of services to areas where industrial activities are predominant, and corresponds therefore to a higher urk accumulation.

Both studies, and the Linköping one in particular (Article 5), however raise a certain caution towards how generalizable the local observations are. The summated stocks for any particular city district can namely be relatively small in comparison to the size of particularly heavy urks found there. In other words, the underlying reason for why an area has a big share of urks might be because it is inhabited by a few particularly heavy ones (see Figure 10), rather than this having to do with any general characteristic of the district.
Figure 9. The Characteristics of Linköping’s 27 City Districts (adapted from Article 5).
The reasons for why such urks were disconnected might furthermore be that very specific infrastructure events happened that affected this particular city district. This is for example the case with the city district of Ryd in Linköping (district five in Figure 9), where two of Linköping’s heaviest urks contribute to one–fourth of the copper stock. These two were disconnected when Linköping’s exurb Malmslätt was expanded in the 1980s, and resulted in such significant increases in electricity demand that the thick feeder cables to the newly built area were replaced (see Figure 10). This observation suggests that detailed knowledge of the local infrastructure history can be more important than the overview characterization of the city for anyone interested in engaging in urk recovery initiatives.

Figure 10. Urks in Ryd: A Zoomed–in Detail (adapted from Article 5). Ryd is a district with multi–unit student housing. The two heaviest urks in Linköping are marked in yellow.

8.2. Prospecting Phase 2: The Conditions for Urk Mining

Early STS scholar Langdon Winner (1977) differentiated between two archetypical ways for societies to engage in technological development. They can either decide on goals that they want to achieve and then steer technological development towards those, or they can adjust the goals so that they comply with the technologies available at hand, so–called reverse adaptation. Archetypes such as these might be translated to the Urk World insofar as society can either set an ambitious goal of urk recovery within a certain amount of time and then design the recovery processes and technologies to fulfil those goals. Or it can opt for recovery processes that more easily comply with current practices and adjust the societal ambitions in terms of recovery percentages and the time required accordingly. In Article 5, we assessed two strategies of urk mining that can be understood as versions of these two archetypes: “excavation for the purpose of urk recovery” and “integrated maintenance and recovery”. Our assessments of them are depicted in the following.
8.2.1. Urk Mining as Specific Project: Excavation for the Purpose of Urk Recovery

From a strict resource perspective, the argument for why urks should be recovered is that their copper content is better needed elsewhere. Mining the Urk World could then be seen as a strategy that should be engaged with to increase the recycling percentage of copper regardless of whether it can be done on commercial grounds or not. If the sole purpose to excavate a city street is to recover urks, it makes sense to extract as much of the stock with as few interventions as possible. We assessed the Urk World of Linköping’s power grid from this perspective, trying to characterize the stock’ ore veins, i.e., spatially locate and assess urks with especially high copper quantities (Article 5).

Figure 11. The Weights and Lengths of Linköping’s Urks (adapted from Article 5).

In a first analysis, we concluded that length was an important factor. While short urks outnumbered long ones, the 400 longest urks out of the total of 2,175 detected in Linköping equalled 70% of the Urk World’s weight in this city (see Figure 11). We then used GIS to seek out the 25 heaviest urks and spatially identified their locations (see Figure 12). Representing 1% of the urks in the Linköping power grid, these 25 specimens equalled nearly one–fourth of the entire Urk World’s weight and could thus be interpreted as ore veins from the perspective that they would yield a significant amount of recovered copper from relatively few interventions.
Figure 12. The 25 Heaviest Urks in Linköping (adapted from Article 5). It can be noted how the majority of these are found in districts with large shares of the total stock (see Figure 8, p. 49).
From the view of traditional mineral prospecting, an ore vein is however not an ore vein unless it is economically feasible to extract. Unsurprisingly, this turned out to be very far from true. Using conventional excavation and recycling technologies (excavators, trucks, cable recovery machinery, etc.) and following the regulatory framework for excavation practices (paving requirements, traffic shut-off costs, etc.), the recovery of the approximately 30 tonnes of copper in Linköping’s 25 thickest urks would return losses of 6.5 million SEK. The scrap prices of copper would have to experience a tenfold increase to make the approach of excavation for the purpose of urk recovery an economically feasible strategy.

Reduced costs for excavations or increased revenues from recycling must thus be thought out and implemented, to make the excavation for the purpose of urk recovery approach more viable. Suggestions in line with how Langdon Winner (1977) envisioned technological development could for example be the further advancement of so-called non-digging technologies such as Kabel–X (Article 5) or improved recycling technologies for paper–coated cables (see section 7.2.2).

8.2.2. Urk Mining as Reverse Adaptation: Integrated Maintenance and Recovery

To go out and excavate for the sole purpose of urk recovery is a strategy detached from the practical and economic conditions according to which infrastructure is currently organized in Sweden. Approaches more in tune with the current configuration of infrastructure were assessed from different perspectives in Articles 1 and 5. As these are related to either larger infrastructure projects or the everyday maintenance and repair processes, both of them start from the viewpoint that urk recovery can be integrated with regular practices and be considered an added value whenever the streetscape is dug up for any purpose. Urk recovery would thus not be the primary cause for why a project is engaged with, but instead be adapted to fit the already existing infrastructural arrangement. Accounting–wise, such “integrated maintenance and recovery” approaches would imply that the costs for urk recovery would solely be related to the extra work needed to unearth and extract urks (and not to the entire work process, which was the case in the “excavation for the purpose of urk recovery” approach).

In Article 1, we assessed integrated maintenance and recovery in relation to the transportation hub that is planned in connection with a new high-speed rail development in Norrköping. This presented an interesting case
since the project relied on the conversion of a centrally located industrial area, in which urks are particularly widespread (see section 8.1). We assumed that all existing urks, as well as the parts to be replaced and become urks, could be extracted as an added value to the planned soil remediation, and found that 51 tonnes of copper would become available in an area equivalent in size to 2% of Norrköping. While we did not particularly assess the recovery economics of the case, we could suggest such projects as opportunities to recover urk copper based on how the tonnage would equal one-tenth of the urk copper in the entire city\textsuperscript{16}.

In Article 5, we assessed the conditions for re-arranging the everyday maintenance and repair of Linköping’s power grid so as to be accompanied with urk recovery as an added value. That is, we stipulated and assessed that whenever a subcontractor is excavating the streets, they should make sure to recover any urks found during the process. In comparison to the excavation for the purpose of urk recovery, this integrated maintenance and recovery approach shifted the economics of urk recovery to become economically feasible in eight locations in Linköping (see Figure 13). These eight detected “hotspots” contain 2.2 tonnes of urk copper. Two of them are cases of thick singular cables, while the remaining six consist of two to five parallel urks. Close to 200 urks yield losses of less than 100 SEK if recovered, and if copper prices rose by 30%, the economically feasible cases to extract would increase from eight to 48, and the available copper amounts from 2.1 to 10.4 tonnes (Article 5).

![Figure 13. The Economic Conditions for Integrated Maintenance and Recovery (adapted from Article 5). The recovery “hotspots” are depicted in beige, and in comparison with Figure 6 (p. 44), quite a few urk sections are now not too far from breakeven results.](image-url)
8.2.3 Further Comparison of the Approaches

In our analysis, the “integrated maintenance and recovery” approach thus outperformed the “excavation for the purpose of urk recovery” in economic terms. The 25 heaviest cables are ten times less expensive to extract using integrated maintenance and recovery, and would yield losses of about 600,000 SEK instead of 6.5 million, given the current scrap prices for copper. We could furthermore conclude that the approach made more environmental sense in terms of avoided CO$_2$ emissions (Krook et al., 2015)$^{17}$. The average Swedish maintenance or repair work releases 25kg CO$_2$ per excavated and restored meter, most of which is related to the restoration of the surface material which is predominantly asphalt in Sweden. By integrating urk recovery as a standard procedure, between 3–15kg CO$_2$ are avoided per meter (dependent on the kind of urk). If more than one urk would be recovered in a singular project, these numbers naturally increase further. The amounts of avoided CO$_2$ are thus significant and might convince an environmentally aware system owner of urk recovery as a way to lower their environmental impact.

However, the integrated maintenance and recovery approach comes with three distinct and important objections. First, a mere 61.7% of the existing urks in Linköping are located sufficiently close to the in–use electric grid to be uncovered during the everyday processes of maintenance and repair. This means that if the ambition is to extract the entire Urk World, the integrated maintenance and recovery approach can only be part of the answer. Second, and given the current rates of maintenance excavations done on a yearly basis, only approximately 1% of the Urk World is uncovered per year, implying that it would take approximately 100 years for the 61.7% to be recovered (see Table 1).

<table>
<thead>
<tr>
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<td>0,6</td>
<td>2,3</td>
<td>3,3</td>
<td>1,1</td>
<td>9,4</td>
</tr>
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Table 1: Accessed Urks During Maintenance Work in Linköping 2003–2011 (adapted from Article 5). The general assumption is that the maintenance needs will increase during the upcoming years, due to that a significant share of the installed systems will reach their expected lifelengths.
Third, the approach is difficult to steer towards “hot spots” with large quantities of copper, since maintenance and repair is done to ensure that the system is functioning (and not for the sake of urk recovery). Since the maintenance work process is dictated by where the grid breaks down and malfunctions, etc., an urk “hotspot” must wait until a system event that requires maintenance or repair occurs in its direct proximity, before it will become extracted.

Bringing matters to a head, the “integrated maintenance and recovery” approach is less costly but recovers only a share of the Urk World and over a very long period of time. Being able to extract some 60% of the Urk World over the course of 100 years seems like a very unambitious intervention. The “excavation for the purpose of urk recovery” approach is advantageous insofar as it can be directed towards urk hotspots and potentially recover a larger percentage in fewer projects, but comes with very large costs. It is not reasonable to suggest urk copper mining at losses of 220 SEK/kg by enforcing practices that are ill equipped to the everyday procedures of infrastructure provision.

Making an effort to further stimulate and develop either one of these two strategies is a delicate matter, not the least since they likely will involve extra costs that will have to be allocated to a certain actor. Then, it is not merely a matter of cost allocation either, since any intervention for the sake of urk recovery would affect the practices and relations between the different infrastructure actors and possibly require changes in contracts, business models, regulations and so on. It is thus possible to ask: where can decisions for increased urk recovery be taken? It is in relation to such matters that things get political.
9. Do Urks Have Politics?

This chapter presents the third knowledge cluster and is divided in two sections that approach the politics of urks in different ways. The first (section 9.1), is based on an assessment of how processes of maintenance and repair, and thus the accumulation and continued presence of urks, are embedded in an infrastructural configuration formed by political decision-making (Article 2). The second (section 9.2–3), focuses on the ways in which possible interpretations of urks are political, not in the sense that any eventual tensions between them must necessarily be resolved, but rather since their inherent ambivalence they can be used “as a lever for discerning the relationships between the different parties involved” (Woolgar and Cooper, 1999 p.443). Rather than providing a discussion of how politics should intervene, this section outlines a spectrum of where politics can (or even must) intervene to create trajectories for increased urk recovery (Article 4).

9.1 Urks and the Deregulated Infrastructure Configuration

During the 1990s, regulatory changes were implemented in several Swedish infrastructural sectors to stimulate their efficiency. Measures were for example taken to decrease the overall cost of maintenance by introducing the possibility to choose between different suppliers of subcontractor services for the system owners. In practice, the implemented policies made it possible to outsource maintenance and repair crews, and such new companies were set to compete for procurement contracts based on price (Källberg and Fransson, 2012)18.

Ever since these principles were introduced in Norrköping, repair crews in several infrastructure systems have experienced significantly increased time and cost pressures in their work environment, resulting in stressful installation processes with ticking costs for shutoffs, machinery hours and rents for land to store dug-up earth masses (Article 2). They could also see indications of the cost pressures in the way that cheap, lightweight replacement parts with shorter life expectancies were installed, and they in
general terms questioned the set-up for maintenance and repair with procurement contracts that stretch over five–year periods at most. As the estimated life spans of infrastructure parts are counted in decades, they pointed out that the replacement part is likely not the installer’s responsibility by the time it breaks down. Hence, they perceive the configuration as more or less rigged for careless installation, which can be interpreted as an indication that any eventual economic efficiency gains in the “here and now” by this procurement–model are contradictory to resource efficiency in the long run. The outsourcing policies thus seem to increase the rate of urk accumulation, as components installed during the deregulated infrastructure paradigm might not last as long and break down simultaneously with those installed before it (Article 2).

With limited certainty, our quantitative results support the critique voiced above. In our study on Linköping, where Tekniska Verken has kept repair crews in–house, we found 125 tonnes of urk copper in the in–use power grid (Article 5; see Figure 8). The power grid in Norrköping is of similar length, but is run by E.On with outsourced repair crews and has twice the quantity of urk copper at 250 tonnes (Article 1; see Figure 7). Further scrutiny of when urks were disconnected is needed to determine if there is actual leverage to this observation, and our data on the age of urks is unfortunately not consistent enough to confirm these indications. Evidence of such a trend will be easier to detect in the longer time perspective, and a systematic analysis may be able to tell if parts installed with outsourced repair crews have shorter lifespans than those installed before. Nevertheless, given the picture painted by the respondents on how the accumulation rate of the Urk World is increasing, the procurement model should be regarded as one of the contributing factors to urk accumulation along with other ones such as age, topography or the size of maintenance and upgrading budgets.

9.2. Further Ways of Conceptualizing Urks and the Urk World

The likelihood of urks as a phenomenon on the rise, is further emphasized by the fact that many Swedish infrastructures are ageing and have started to reach their life expectancy to quite a high degree (Article 2). An infrastructure configuration that makes better use of its required resources, would thus both be arranged to prevent urks from accumulating as well as for the recovery of those parts that have already become urks. Given that the moment in time when old infrastructure parts are replaced is the best window of opportunity to engage in urk prevention/recovery that is likely to
ever occur, there is reason to engage in preventive measures before the major upgrading projects commence on a larger scale.

The purpose of the fourth article was therefor to activate the political urgency of urks by investigating claims concerning what urks are, made by a set of respondents. In total, we identified five different interpretations of urks and five corresponding geo-social formations of the urban underground. In section 7.2.3, I outlined how three of these interpretations (urks as pollution sources, waste or spare parts) create a legislative ambiguity concerning urks that contribute to why they are left behind after being disconnected, and prevent urk recovery from happening. The remaining two interpretations from Article 4 are explained in the following. All of the them were based on the urks' physical characteristic and contents, and in turn suggested different matters that needed to be resolved if increased recovery were to occur that is outlined in section 9.3.

The fourth aspect that was emphasized is that urks contain valuable resources in the form of metals that could potentially be recycled (Article 4). The Urk World could thus be characterized as a mineral deposit that could potentially be “mined”. As mentioned, the recycling of urks in Sweden is currently done in a market setting19, and this is a reason for why it so seldom occurs, since the excavation costs outweigh the relatively low revenues from recycling (see section 7.2.2). The only current case when urk recycling happens to any substantial degree is in connection with bigger redevelopment projects, as cables are unearthed in shafts of larger sizes, and the costs for excavations are paid regardless of whether urk recovery happens or not. In these occasions, the subcontractors reap the benefits since they write the contracts directly with the urban developer, and with larger degrees of freedom than the “if feasible: recycle” terms that dictate the contracts for everyday maintenance and repair that they write with the system owner.

The final interpretation was that urks are occupiers of subsurface urban space. Following from this, the Urk World is thus a congestion: a geo-social clutter of functioning as well as nonfunctioning parts that affect infrastructure's overall efficacy by inserting uncertainty, risk, inconvenience and additional costs to the maintenance processes (Article 4). In Article 2, it was pointed out that the deregulation had made these matters worse, since the level of complexity in the infrastructural set-up had increased. There are now more actors (diggers, subcontractors and so on) present in the urban underground than before and an increased number of systems in which urks can occur. Accordingly, it was believed that this had resulted in
more street excavations and decreased the possibilities to synchronize maintenance and repair work\textsuperscript{20}. These observations seem to imply that the outsourced maintenance–and–repair procurement model leading to continued accumulation of urks will eventually cause enough obstacles and increased costs to require change. The diminishing amounts of available underground space in Swedish cities is occasionally already sufficient to motivate the removal of particular urks, but this happens only in central urban areas that have had infrastructure systems installed the longest. One of the system owners argued that mandatory urk removal to prevent further congestion would not be impossible for them, but would require revised and updated business models to fit such new circumstances (Article 4).

### 9.3 Urks as Matters of Political Concern

The five different urk interpretations made by the respondents of Article 4 are not passive: some of them contain seeds for change (waste, resources and occupiers), while others enforce the status quo (pollution sources and spare parts). As long as the latter prevails, the Urk World becomes incrementally more hazardous and crowded with resources, waste, spare parts and occupiers. Since urk mining is currently not economically profitable and no existing regulation is powerful enough to demand urk removal, the task for politics aiming to increase urk recovery is to locate where interventions are possible and settle the plausible controversies found there. Using the parlance of Bruno Latour (2004), there is reason to transform urks from matters of fact (concerning their quantities, internal composition and so on), to matters of concern by highlighting the aspects that prevent increased urk recovery from happening. As long as such issues are not opened up for debate with the intent of resolution, changes will arguably not occur and urk recovery will continue to be a non–issue (cf. Marres, 2007). Several such matters to be debated could be associated with how urks and the Urk World were interpreted.

In the respondents’ answers, the “urks as resources” interpretation was connected to a larger context of Swedish politics and the lack of consistent, all–embracing national resource policies in Sweden. Several indices they claimed supported this, e.g., the failure to mention infrastructure reserves in the recently developed national Mineral Strategy and the Swedish absence on the steering committee of the International Resource Panel of the UN Environmental Programme. The latter example was found to be in sharp contrast to Sweden’s strong position and significant role in the initiation of the UN panels on climate issues and chemical legislation. In terms of how the urks’ plenitude indicates a wasteful handling of mineral
resources, a matter to be resolved that surfaced during the interviews was the prioritization between primary production of metals and secondary recovery. Swedish mineral resource politics have long been arranged so that recycling is massively under-supported in comparison to primary extraction (Johansson et al., 2014). The key negotiation at stake here concerns whether Sweden should be known as a mining country (as emphasized in the Mineral Strategy) or for its metal recycling ambitions, as well as what the prospects of these two strategies are for the future.

A second matter to be resolved could be observed in the regulations that influence the contract agreements between the infrastructure system owners and the municipal landowners, as there are different ways to create incentives for urk recycling that may have different implications for these two types of actors. A sharpened waste regulation based on a forceful urk–as–waste interpretation would mean that the costs now avoided by all parties (since the Urk World in practice is regarded as contaminated soil), would be assumed by the system owners and in the end likely paid for by higher user tariffs. Another way of approaching the economic relation between these actors would be to lower the costs associated with street excavations now paid by the system owner, with the result that the municipal landowner would lose significant revenues from for example traffic shutoffs and street restoration. The task in this particular issue is thus to negotiate the economics involved in a way that is acceptable to the concerned actors, and weigh short–term economic efficiency gains against longer term resource efficiency ones. In these negotiations, the environmental benefits of urk mining in terms of recovered copper and avoided CO2 emissions can preferably be mentioned as a way to motivate either increased costs for the system owners and/or lost revenues for the municipal landowner. In the long run, an expense today does not need to be perceived as a cost but rather as an investment for the future, which is a line of argument that is increasingly referred to in for example climate ambitions made by municipalities and companies alike.

At the ground level of everyday infrastructure operations, a third issue to be resolved for increased urk recovery could be detected in the relationships between the system owners and the maintenance subcontractors. This matter has two aspects. The first is if whether the deregulated arrangement with outsourced repair crews is the best set–up for urk recovery. As was argued by several respondents in Article 2, the outsourcing of maintenance has been accompanied by increased time and cost pressures that prevent urks from being recovered. Given the statements from these actors, it is worth debating whether the current maintenance practices could be
improved, a debate that is for example ongoing in the case of the Swedish national railroads (Nyberg, 2011). The second aspect is of an economic nature, as it can be debated if it is the owner of the system parts or the subcontractors who should reap the rewards if recycling becomes, or indeed is made, profitable? As mentioned, the only instance when urk recycling occurs to any significant degree is when the subcontractors themselves reap the recycling benefit, which happens only under certain circumstances, i.e., larger city redevelopment projects. The main issue to be resolved with regards to this matter of urk concern is how recycling initiatives could be arranged to either fit the business models of the system owners, or be a formalized part of the subcontractors’ operations.

A fourth matter of concern is the contradictions implied by how market logic dictates the functioning of the metal recycling sector. As mentioned in the case of paper–coated urks, factors such as global scrap prices and available recycling technologies affect the recyclers’ profit margins and hinder them from paying enough for certain urks to make their recovery profitable. Because urks cost too much to recover and are worth too little on the recycling market, only small amounts of them have been recycled, preventing necessary investments in cable recycling technologies that would decrease the costs of recycling. As the recycling sector today is engaged in this matter from a profit interest perspective, a key problem is that economic incentives guide their actions to a greater extent than environmental or ethical ones.

The fifth and last issue detected in the material relates to how different environmental concerns might be in conflict with one another, and if so, how prioritizations are achievable between them. Historically, Sweden’s position as a front–runner on issues of climate change and chemical legislation has not been coupled with thorough policies concerning our natural resource use. Urk recovery could contribute to the Environmental Objective of designing a built environment with a less extensive use of resources and limit the effects on climate that stem from infrastructure maintenance operations. Contrary to the importance given to protecting the environment from hazardous material that dissipates from industrial activities, measures for decreased resource intensity find no support in the Swedish regulatory apparatus. This becomes problematic in the case of urks, as the Environmental Objective of a non–toxic environment can be seen as preventing urk recovery from happening insofar as the legislation on contaminated soils can be invoked to hide urks at the bottom of the list of polluted sites to be remediated. The key question that arises in regard to
this matter is how different environmental objectives should be prioritized between and on what basis such a prioritization should be grounded.

Engaging in political interventions for increased urk recovery can be conceived of as a form of navigation along the fault lines between actors and non-negotiable standpoints in the abovementioned matters. The suggested spectrum where such politics can intervene and must navigate, range from the International Resource Panel of the UN, via the national Swedish Environmental Code and Quality Objectives, to the locally engaged actors and contracts in Swedish infrastructure configuration. While all the matters of concern have a relationship to the Urk World, it is arguably insufficient to intervene only in one or two of them. For example, it is tentatively not enough to only develop new cable recycling processes, to reverse the outsourcing of repair crews or lower the restoration costs when digging in the streets to achieve increased urk recovery. Rather, an orchestrated effort seems needed that consists of a multitude of combined and aligned changes to achieve consistency. National and municipal metal recycling targets should preferably be anchored in legislation and imply concrete, practice-related changes in business models, budgets, and contract formulations. Finding trajectories along the fault lines associated with the concerns suggested in the interviews, is a central task of any techno-political achievements in this matter. In the larger perspective, urk politics boils down to a matter of what kind of society we want to create for ourselves, and the significance we appoint to urk recovery for the achievement of that society.
[We have to practice] a deeper ecology than that of input–output or systems analysis. We have to listen to infrastructure and bring imagination to understanding its components and how they work. – Lampland and Star, 2008

10. Reflections
10.1 Towards Political Industrial Ecology

Repeatedly, scholars doing urban metabolism assessments of material flows are criticized for being too distanced from the reality they aim to describe. The human practices that are actively involved in societal material flows are often left untouched by the scrutiny, as for example the MFA approach might leap from one extreme (with an emphasis on the atomic level) to the other (e.g., the in-use stock of 200 countries). As Erik Swyngedouw notes (2006, p. 35), urban metabolism scholars too often uncritically pursue “the standard industrial ecology perspective based on some input–output model of the flow of ‘things’ [and] while insightful in terms of quantifying the urbanization of nature, it fails to theorize the process of urbanization as a social process of transforming and reconfiguring nature”. This thesis provides an example of the contrary, insofar as it thoroughly accounts for material flows but lets them remain connected to the “processes, elements and structures of society” that sustain them (Anderberg, 1997, pp. 197 and 199).

In its desire to also discuss the political embeddedness of the Urk World, this thesis furthermore adheres to recent geography scholars who suggest “political–industrial ecology” as a concept and research approach which, instead of keeping environmental politics out of the equation in a “post–political” industrial ecology stance, deliberately connects the results of quantitative assessments to their political implications using a theoretical lens from the field of political ecology (see Cousins and Newell, 2012; Newell and Cousins, 2014; Murray–Mas, 2015). Political ecologists adopt an explicit stance of social transformation, and make use of a plethora of theoretical approaches to understand and explain the socio–political dynamics related to the production of nature (Murray–Mas, 2015). Newell and Cousins (2014) for example suggest “boundary objects” (similar to Article 3), as a way to make this theoretically driven political science approach interconnect with the perspectives found in the industrial ecology toolbox. On the overall level of combining environmental assessment tools
with social science research methods, their approach has similarities to the one engaged with in this thesis. The apparent difference is that my co-authors and I engaged in MFA in the twin cities of Norrköping/Linköping (instead of doing an LCA in Los Angeles like Cousins and Newell [2015]) and used infrastructure studies rather than political ecology as the accompanying social science research approach.

The point of these authors’ suggestion as well as that of this thesis, is that achieving a fuller delineation of the object of study relies on industrial ecologists complementing their quantitative achievements with other societally relevant perspectives. For example, they can ask politically more active questions than “Where has all the copper gone?” (Lifset et al., 2002), refrain from framing sustainability matters “without the hot air” (MacKay, 2012), and investigate the criticality of metals in ways that also include questions of for whom the metals of study are critical and the geopolitical power relations involved in such matters (cf. Graedel and Nassar, 2013). Urks can be considered an example of how material stocks and flows are inherently political, as the Urk World is not only a matter of spatially distributed cable lengths and copper weights, but also and in very concrete terms the accumulated remainders of the techno–political events throughout the history of any networked city.

Insofar as cities rely on a hierarchy of urban infrastructures whose systemic throughput as well as repair and maintenance needs must be prioritized, this thesis conclude with observations of how cities are inherently inefficient (Jacobs, 1969) and obdurate (Hommels, 2005). Such inter-related and contested aspects must be further incorporated into the industrial ecology analysis of material stocks and flows, I argue, rather than avoided for the sake of reducing the matter at hand to a computable set of numbers and statistics.

10.2 Towards the Study of Infrastructures Unmade
McFarlane and Rutherford suggest (2008a) that whenever infrastructures are concealed or backgrounded, this is always done from actors with influential positions in society. This thesis shows that observation to be valid also for urks, as urk removal would imply extensive costs for any of the actors involved in infrastructure configuration (owners, municipalities or even the state). For example, it makes sense for the system owner to demarcate urks as external to the sphere of economic relationships in which they operate (cf. Callon, 1998). Consequentially, urks are configured as outside of the infrastructural property using mechanisms that are in turn
tangible (the urk is cut and left behind), inscriptional (deleted from maps, not reported or digitalized) and mental (forgotten). The observations of this thesis comply with Andrew Barry’s suggested notion (2001, p. 17) that the way these kinds of boundaries are continuously drawn and re-drawn is an inherently techno-political matter.

For social scholars of infrastructure, a lesson to be learned from this thesis is to refrain from infrastructural boundary demarcations in terms of functioning/non-functioning, and instead regard waste materials such as urks as integral to the infrastructure system to reach a fuller environmental understanding of them (see Gabrys, 2009). There can perfectly exist both insides (functioning parts) and outsides (urks) within phenomena (infrastructures), as Karen Barad (2007, pp. 148–175) for example has pointed out. Lately, steps towards realizing such a research stance have been taken by researchers who have given increased attention to infrastructure maintenance processes, and denote how these systems accrete (Anand, 2015), rust (Jackson, 2014) as well as leak and crack (Schwenkel, 2015). With merit, such observations are often accompanied by analytical scrutiny of how infrastructures require repair to ensure their normalized state of functioning (Urêta, 2014), re-instate their credibility (Henke, 2000) or assert their eventual experimental qualities (Castan Broto and Bulkeley, 2013). However, these different instances of infrastructural fixing and mending are only one side of the maintenance coin. The other is to set aside parts that do not ensure functioning in processes of sorting things out. There is a research task to follow also the “non-actors” in these socio-material processes (see Galis and Lee, 2012), that is, the recipients of overflow material (e.g., the urban underground) as well as the overflows in themselves (e.g., the urks). Engaging in such a research endeavor is justified by the quantitative assessment performed in this thesis, as the Urk World’s sheer magnitude qualify it as worthy of social science scrutiny. Tentatively, there are plenty of other infrastructural overflows that deserve the same treatment.
11. Concluding Remarks and Future Research

Explicitly designed for such an endeavour, this thesis gives concrete examples of what can be achieved if an urban metabolism assessment tool (material flow analysis) is coupled to a social science research approach (infrastructure studies): an understanding of societal stocks of materials that involves static knowledge of their size, spatial distribution and economic conditions of recovery, as well as processural knowledge on how they accumulate in socio-technical processes and are politically embedded. If there is an overall lesson to be learned from this thesis, I believe it is the contribution to regard society’s material build-up as a resource base. The preposterous amounts of minerals that we have dug up and continue to dig up from the Earth’s crust simply do not disappear once we have extracted them, but are instead stocked in different societal supplies that are more or less obvious for us and that might eventually be mined for the sake of the environment. A thorough understanding of the geo-social relations in our societies will be key when facing the mineral resource-related challenges in the century to come. Then there are, I believe, several more precise remarks to be made from the presented material as well.

11.1 The Quantitative Contribution in Terms of Society’s Wasteful Use of Copper

While for reasons of contextual variety we advised caution towards scaling up the quantitative results from our local studies (Article 1), it serves a purpose to perform a crude aggregation exercise to be able to compare them to other relevant figures and stats. Comparing only the local electric grids in the two quantitative studies of this thesis (Article 1 and 5), there is something like 5–7 kg of urk–copper per Swede. Those numbers do not include regional or national electric grids or any telecommunication figures, where the latter have been estimated at approx. 20 kg per capita due to the initiated upgrading process to fibre optics (Wendell, 2005). Nor do they include the approx. 25 kg per capita of electric cables still in–use in ageing local grids, destined to soon become urks and replaced by aluminium cables according to current common practice (Article 1).
If the prevention of urk accumulation during the future upgrading of Sweden’s infrastructure does not occur, these results indicate that the Swedish Urk Worlds will harbour disused copper quantities that are of the same order of magnitude per person (approx. 50 kg) as the in–use amounts of copper in countries in the Global South, which were at 30–40 kg fifteen years ago (Gerst and Graedel, 2008). Urks are in this sense thus not only an example of the Swedish society’s persistently wasteful use of mineral resources, but also highly problematic from a global justice perspective as well. On the other hand, and if Sweden wants to diminish its in–use copper stock to contribute its share to equal access to copper for all and comply with the estimated 100 kg of available copper per person globally (Exner et al., 2014), urk mining as well as preventive measures towards further urk accumulation can contribute significantly to realizing such an ambition.

11.2 The Contributions to Material Flow Analysis
The results of this thesis have contributed to fill parts of the detected gap concerning hibernating stocks in general (see Brunner, 2004), and have reached a new level of spatial detail concerning suitable locations for urban mining initiatives. I furthermore believe that the studies show how there is much to be gained for MFA researchers in avoiding the temptation of always wanting to explain the abstract interconnectedness of the broader picture, in favor of looking down to the heterogeneous complexity found in the details of the specific locale (Article 1). When assessing a purposefully delimited study object and geographical scope, it is easier to connect the MFA to the level of localized practices and perhaps resource politics as well. Since they also enable the analysis of the (economic) conditions of engaging in recovery activities, such approaches seem crucial for installing properly designed recycling schemes.

More in particular, this thesis has developed and refined the ways that GIS allows bottom–up MFAs to not only function as a summation device for city districts (which generally leads to rather predictable conclusions of “where there are buildings there are also stocks”), but as a two–phased prospecting tool based on in–depth spatial categorizations of stocks and assessments of their recovery.

11.3 The Contributions to Infrastructure Studies
In relation to previous infrastructure studies research, a key lesson is that infrastructure systems must be understood not only as the key mediators of material and energy flows between humans and nature as Jochen Monstadt
(2009) put it, but also as being constituent and part of such flows in and of themselves. This thesis makes the connection that the environmental impact of infrastructures is related to the materials upon which their construction depends, which has so far been under–emphasized within this field of research. Such a perspective furthermore enables the combination and co–functioning of this social science approach with locally scoped MFA studies.

Another contribution is the observation of the Urk World as an infrastructural phenomenon, without which any understanding of infrastructure systems can only be partial. The existence of this infrastructural shadow world stresses the importance of not letting the dichotomous relationship between their functioning and non–functioning realms dictate how infrastructures are perceived. Indeed, it serves the interest of certain actors to do so, which further stresses the political importance of the Urk World’s existence. Foregrounding the role of repair crews and the regulatory configuration of maintenance processes cannot be stressed enough for such assessments.

More specifically, the thesis has presented a theoretical contribution to the field in terms of three suggested kinds of “frozen spots” of infrastructure: “dormant cells”, “paralysis” and “coma”, to denote the diverse patterns of parts, zones and wholes of systems which have been taken out of use and left behind underneath urban streetscapes due to non–existent system demand.

11.4 Contributions Related to Urk Recovery Interventions

Last, the thesis has provided several suggestions on how increased urk mining might be engaged with in practice, and where interventions might be conceived of in political terms.

First, it assessed and discussed the pros and cons of different urk recovery strategies in terms of costs, information needs and recovery potentials. The recovery conditions of excavation for the purpose of recovery were for example compared with approaches integrating urk recovery with the everyday work of repair crews. Furthermore, large urban re–development projects when streetscapes are dug up and re–purposed were emphasized as a window of opportunity for urk recovery, since urks might then be exposed in quite large numbers.

Second, it provided an analysis of the politics of urks and the Urk World and delineated how interventions for increased urk recovery are possible at
several levels of decision–making. The conceivable political action space stretches from the different kinds of contracts engaged in by the maintenance subcontractors to the International Resource Panel of the United Nations. The possible ways of creating consistent regulations for urk recovery rely on navigating contested grounds where actors’ interests and priorities must be weighed against each other. Urks and the Urk World can in this way be connected to political visions for creating our future society.

11.5 Areas of Future Research

There are several ways of continuing the research done in this thesis. Theoretical, empirical as well as methodological achievements are conceivable, both related to the involved areas of research as well as other ones.

To further advance the field of MFA, the two–phased approach in Article 5 could be re–calibrated to perform a thorough environmental assessment of urk recovery, connecting avoided CO₂ emissions to the spatially contingent economic costs of urk recovery. Such an assessment could provide the system owners with more information on how to take further responsibility in environmental matters. There are also plenty of other hibernating stocks studies to be made, both for different metals and stocks. The MFA community furthermore still awaits the first comprehensive study on hibernating stocks on a country level.

To further advance the field of infrastructure studies, ethnographic maintenance and repair studies would tentatively be useful to further depict the processes and settings in which urk recovery can practically be engaged with. As a suggestion, such studies could for example be done in relation to pilot studies of recently developed urban mining technologies such as Kabel–X or different HDD techniques. Since this is a quite recently discovered actor group within infrastructure studies, plenty of insightful angles on their socio–material interactions with the systems are still available for scrutiny.

Further stressing the subterranean as a possible realm for different kinds of urban studies seems to be another rewarding continuation from this study. For example, the underlying machinery of the Urk World is clearly related to concepts such as “drosscape” (Berger, 2007), which denote derelict leftover areas as a contemporary feature of the surface urban realm. Studies of the Urk World could thus complement previous “landscape infrastructure” studies on urban waste and wastelands along a vertical axis,
and present an intriguing geo-social urban netherworld full of dross and discards. There is also a continuation of studies to be written from the early “cities as mines” observations made by Jane Jacobs (1969). It could for example be further scrutinized how cities are not only networked entities that consume and circulate a large portion of the world’s resources, but resource bases in and of themselves due to their material build-up over the course of time. The networked society cannot only be conceived and theorized as consisting of spaces of flows, as Castells (1996) argued, but could be further understood as consisting of spaces of stocks as well.

Last, policy analysis can be suggested to come up with concrete suggestions for political actions for increased urk recovery. It is one thing to provide a spectrum of sites where urk politics might intervene (as this thesis does), and quite another to answer how politics should intervene and what that should look like. In this respect, there are cities and practices to possibly learn from, one example being the moratorium-based ways of regulating infrastructure excavations in the Norwegian city of Bergen. Furthermore, and at a higher level of decision-making, incentives to steer society away from traditional resource extraction must be further encouraged. Coming up with distinct alternatives to the currently hegemonic ways of extractivist thinking is one of the great tasks we have to solve for the sake of future generations. There is, as I see it, a great possibility to achieve some effective research-driven policies in this particular matter, which would be a refreshing alternative to the all too prevalent policy-driven research.
Notes

1 I use urk as a convenient shorthand for a “disconnected piece of infrastructure that remains in its subsurface location” and untranslated to keep its onomatopoetic qualities. Another reason for using the “urk” term is that as a value–neutral placeholder, it allows for a discussion with fewer presuppositions than if for example waste had been used.

2 LeCain (2009, pp. 5–11) suggests large–scale, open–pit mining operations as the mass destruction machinery needed to provide for the mass production and mass consumption of capitalist society.

3 Concerns of mineral resource scarcity are less a matter of actual physical depletion than they are a matter of the increasing amounts of energy required to extract decreasing ore grades (Diederen, 2009). Most minerals are bi–modally distributed in the Earth’s crust, with a large peak at very low concentrations and a much smaller one in higher concentrations (Skinner, 1979). The lack of concentrations between these two peaks is called the “mineralogical barrier” (see Figure 14, next page), and a debate is raging over whether we should transcend this barrier or not, or if it is even possible (Tilton, 2002). On one side of the debate are the “pessimist” supporters of the “fixed stock paradigm”, who start from the premise that the Earth is finite and argue that “mining the other side” (of the mineralogical barrier) should be deferred since it will destroy planet Earth for generations to come, and cost far too much in economic terms to ever be motivated anyway. Among this crowd, you tend to find environmentalists and geologists. On the other side of the debate are “optimistic” miners, prospectors and economists who adhere to the “opportunity cost paradigm” and argue that technological development should enable “mining on the other side” to ensure a mineral resource base that is forever infinite in comparison to any conceivable global demand. While empirical evidence over the course of the 20th century supports the optimists, this development has been intimately dependent on cheap and abundant energy supply in the form of fossil fuels. As the high concentration peak (the one to the right) has already been depleted or is currently being mined, and since we can not rely on a cheap supply of fossil fuels for the future (for environmental reasons, we should abstain from it even if it was possible), my stance is that the low concentration peak seems out of reach for both economically viable exploitation (see Diederen, 2009), as well as for reasons that have to do with the unrealistic energy demands, unacceptable social disruptions and enormous environmental consequences that such operations would imply (cf. Bardi, 2013).
The empirical focus in this thesis is obviously on technology rather than science, and so like Hommels (2005) I could have made an explicit demarcation and written only about technology studies (TS).

This is notably different from what can be seen in the field of environmental history where researchers such as Brechin (1999) and LeCain (2009) have actively sought out the connections between urbanization and mineral resource extraction. The same observation can be made concerning urban political ecology, in which several researchers have retheorized the city as a product of metabolic processes between society and nature (cf. Gandy, 2002; Kaika, 2004; Heynen et al., 2006).

Urks need not be subsurface entities as, for example, they have been detected in the aerial US telecom grid (Design Nine, 2006). Furthermore, urks of course also occur in infrastructure systems that do not contain copper, and can for example be disconnected concrete water pipes, or composite district heating pipes containing a plenitude of different materials.

For a literature review of all anthropogenic material cycles that so far have been assessed by the MFA approach, see Chen and Graedel (2012).
These two are archetypes depicted in industrial ecology handbooks (cf. Graedel and Allenby, 2010). Because of different purposes and data availability, MFAs in practice tends to divert quite a bit from these basic approaches (Chen and Graedel, 2012). Furthermore, combinations of the two might be engaged with for triangulation purposes (cf. Zeltner et al., 1999).

The exception is van Beers and Graedel (2007), which had a national scope with stocks analyzed at the regional level.

Admittedly, some estimates were done inside of the case study boundaries in Article 1. For example we made use of kilograms per capita assumptions to extrapolate findings that were relevant for one part of the city to hold for the city as a whole.


The introductory chapter of “Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition” (Graham and Marvin, 2001) provides an exhaustive survey of how the networked conditions of urban life can be understood from this viewpoint.

A longstanding criticism in IS has been voiced toward the focus on the workforce responsible for the technological development (cf. Law, 1991, p. 12; Graham and Marvin, 2001, p. 183), i.e., the “system builders” as the Nestor of the field, Thomas Hughes (1983), termed them. This criticism has often been noted in relation to the much less weight given to the users of infrastructure services (cf. Akrich, 1992; Summerton, 1998; Bladh, 2006), an imbalance that has leveled out in recent years as there are by now plenty of user–centered infrastructure studies (cf. Akrich, 1995; Oudshoorn and Pinch, 2003; Truffer, 2003).

A few notable examples are however Orr (1996), Downey (1998) and Henke (2000).
Interpreting waste incineration as a recycling measure, the very low percentage of waste (3%) that is landfilled in Sweden is often framed as a success story (Corvellec and Hultman, 2012).

Notably, this tenth is achieved by adding the weight of all existing urks and the weights of those parts that are prevented from becoming urks.

This result was quite expected as the environmental impacts of the “integrated maintenance and recovery” were accounted for as solely related to the extra work needed to unearth and extract urks, and not to the entire work process (which was accounted for in the “excavation for the purpose of urk recovery” approach).

In the parlance of Graham and Marvin (2001), such a process can be described in terms of vertical and horizontal segmentation (pp. 141–142).

Notably, urks are not part of the extended producers responsibility, which for example is implemented for e–wastes, vehicles and metal packaging materials in Sweden.

When municipalities “owned” the city’s entire infrastructure, systems could more easily be co–located in shafts and maintenance operations were easier to plan and coordinate in–house.
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Papers

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