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LANDFILL MINING

Institutional challenges for the implementation of resource extraction from waste deposits

Nils Johansson

LINKÖPING UNIVERSITY

Environmental Technology and Management
Department of Management and Engineering
Linköping University, SE-581 83 Linköping, Sweden

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ABSTRACT

Landfill mining is a term to describe the emerging field of exploring and extracting disposed material. The recovery of deposited resources may increase the flows of secondary resources and thereby replace a significant share of the primary production. The extraction of deposited materials may also be integrated with remediation and after care measures, to handle the many problematic landfills. Such unconventional recycling practices are, however, currently limited. The research in the field has mainly focused on technical evaluations of sorting efficiency, economic feasibility, and resource and environmental potential. Other issues of concern to institutions, markets, policy and conflict of interest have received considerably less attention.

This thesis consists of five scientific articles that have been synthesized. The overall aim of the thesis is to examine the institutional conditions for the implementation and emergence of landfill mining. This is addressed by three research questions. The first question concerns how policies come into play in a landfill mining operation and its consequences for the implementation and emergence of landfill mining. The second question is devoted to understanding these policies and why they look the way they do. Based on how policy influences landfill mining operators and how these policies can be understood, the third question seeks to formulate some overall institutional challenges for the emergence of landfill mining, and how the authorities' capacity to address the institutional challenges may increase.

The result shows that current policy makes it difficult for landfill mining operators to find a market outlet for the exhumed material, which means that landfill mining may result in a waste disposal problem. Regulations also restrict accessibility to the material in landfills. Therefore, it has generally been municipal landfill owners that perform landfill mining operations, which directs learning processes towards solving landfill problems rather than resource recovery. Landfill mining is not, however, necessarily to be perceived as a recycling activity. It could also be understood as a remediation or mining activity. This would result in more favorable institutional conditions for landfill mining in terms of better access to the market and the material in the landfill.

The regulatory framework surrounding landfills is based on a perception of landfills as a source of pollution, a problem that should be avoided, capped and closed. Extracting resources from landfills, challenges this perception and therefore results in a mismatch with the regulatory framework. On the other hand, the material in mines is typically regarded in the formal institutions as a positive occurrence. Mining activities are regarded as the backbone of the Swedish economy and therefore receive various forms of political support. This favorable regulatory framework is not available for secondary resource production. Based on the identified institutional conditions, institutional challenges are identified. The core of these challenges is a conflict between the policy goal of increased recycling and a non-toxic environment. Secondary resources are typically punished through strict requirements for marketability, while primary resources are supported through subsidies such as tax exemptions. The authorities lack capacity to manage the emergence of unconventional and complex activities such as landfill mining. The institutional arrangements that are responsible for landfills primarily perceive them as pollution, while the institutions responsible for resources, on the other hand, assume them to be found in the bedrock.

The major contribution of the thesis is to go beyond the potential-oriented studies of landfill mining to instead focus on how institutions relate to landfill mining. In order to move towards a resource transition with dominant use of secondary resources a new institutional order is proposed.

Keywords: Landfill mining, recycling, mineral policy, institutions, transitions, mining.

SAMMANFATTNING

Deponiåtervinning:

Institutionella utmaningar för resursutvinning från soptippar

Konsekvenserna av att bryta mineraler från underjorden blir allt allvarligare i takt med att allt otillgängligare gruvor måste brytas. Återvinning kan delvis erbjuda ett alternativ, men avfallsströmmarna är alltför begränsade för att täcka den ökade efterfrågan på resurser. För att öka återvinningsflödet behöver nya typer av återvinningsbara förråd exploateras. Avfallsupplag innehåller många gånger jämförliga mängder mineraler som de som finns i användning. Ett sätt att öka återvinningen skulle således kunna vara att återvinna deponerade sopor, vilket brukar gå under benämningen *deponiåtervinning*. Därigenom öppnas även möjligheter att hantera de många dysfunktionella soptipparna.

Den här avhandlingen behandlar hur myndigheter, institutioner och lagar relaterar till deponiåtervinning utifrån tre olika forskningsfrågor. Den första frågan syftar till att kartlägga de lagar och regler som påverkar aktörer som försöker återvinna deponerat material. Detta regelverk gör det svårt för aktörer både att finna avsättning för det uppgrävda materialet och att få tillgång till det i deponierna. Den andra forskningsfrågan syftar till att undersöka varför regelverket ser ut som det gör. Deponier ses allmänt som ett problem, en föroreningskälla, som ska kapslas in och stängas. Operationer som siktar mot det motsatta; att frigöra avfallet från soptippar möter därför regulativa hinder. Samtidigt finns det andra mineralförråd, traditionella gruvor i berggrunden, som framställs som en möjlighet, en resurskälla som ska utvinnas. Regelverket runt detta mineralförråd uppmuntrar till utvinning genom skattelättnader och direkta stöd vilka inte är tillgängliga för återvinning. Utifrån dessa iakttagelser kan några övergripande institutionella utmaningar formuleras i enlighet med den tredje forskningsfrågan.

Det finns en konflikt mellan miljömålen om *ökad återvinning* och *giftfri miljö*, eftersom avfall i regel inte är lika rent som jungfruliga resurser. De institutionella villkoren för återvinning och gruvbrytning av mineraler är obalanserade, då produktionen av sekundära resurser från avfall bestraffas medan primära resurser från berggrunden stöds. Detta beror delvis på att sekundära och primära resurser hanteras under olika institutionella regelverk. Idag har sekundära resurser blivit en miljöfråga, och ligger under

Miljödepartementet och Naturvårdsverket, medan primära resurser har blivit en näringslivsfråga och ligger under Näringsdepartementet och SGU.

I denna avhandling siktar jag mot att gå bortom potentialstudier av sekundära resurser och istället påvisa hur institutioner och intressekonflikter påverkar utvinningen av dessa resurser från deponier. För att nå en resursomställning mot en dominerande användning av sekundära resurser föreslås ett nytt förhållningssätt till dessa alternativa gruvor och en ny institutionell ordning där sekundära, snarare än primära, resurser sätts i främsta rummet.

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Elin, your ability to make things work at home, despite my extreme workloads at times, means that you more than anyone have been of utmost importance in the realization of this thesis. Thank you.

LIST OF APPENDED PAPERS

I. Johansson, N., J. Krook, M. Eklund, B. Berglund (2013) An Integrated Review of Concepts for Mining the Technosphere: Towards a New Taxonomy. Journal of Cleaner Production 55: 35-44.

II. Johansson, N., J. Krook, M. Eklund (2012) Transforming Dumps into Gold Mines. Experiences from Swedish Case Studies. Environmental Innovation and Societal Transitions 5: 33-48.

III. Johansson, N., J. Krook, M. Eklund (2014) Subsidies to Swedish Metal Production: A Comparison of the Institutional Conditions for Metal Recycling and Metal Mining. Resources Policy 41: 72-82

IV. Johansson, N., Krook, J., Frändegård, P. (2016) A new Dawn for Buried Garbage? An Investigation of the Marketability of Previously Disposed Shredder Waste. Accepted for publication in Waste Management.

V. Johansson, N., J. Krook, M. Eklund (manuscript) Is there Institutional Capacity for a Resource Transition? A Critical Review of Swedish Governmental Commissions on Landfill Mining. Is to be submitted to Environmental Science and Policy.

CONTRIBUTIONS TO THE PAPERS

All papers have been written and information collected by Nils Johansson. Joakim Krook and Mats Eklund have supported the research design and contributed comments to all articles, except Paper IV to which Eklund did not contribute. Per Frändegård participated in Paper IV by assisting in the collection of information. Björn Wallsten (Berglund) contributed comments to Paper I.

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1.

INTRODUCTION

This chapter highlights why new forms of resource extraction are needed and a new approach to landfills. The aim of the research is then presented and motivated.

1.1. Towards a circular economy: a new take on waste

Mineral resources have been important for human civilization throughout history, which has been manifested by naming eras after minerals, e.g. the "Bronze Age" or the "Iron Age." Today, minerals are even more fundamental. Virtually all metals in the periodic table are used, and those not in-use today probably will be in-use tomorrow (UNEP, 2010). At least four metals are of fundamental importance: iron for construction, aluminum for transportation, lead in batteries, and copper to conduct electricity. In advanced technologies additional metals are used, for example in circuit boards or hospital instruments. As a result of the growing utilization of minerals, mining production has increased exponentially. During the last 150 years, from the pre-industrial era around 1850 to 2010, world population increased by a factor of six (UN, 1999), while the production of copper increased by a factor of 400 (PGL, 1936; BGS, 1920-2016).

Minerals are non-renewable resources, therefore the concentration of minerals in active mines decreases gradually as the most accessible mines are extracted first. During the last 150 years, the average concentrations of copper in mines has fallen from 20% (Mudd, 2007: 64) to 0.8% (Crawson, 2012). The decreasing concentrations mean that both the energy consumption and waste generation increase for the operation. Today, the metal sector accounts for 20% of all energy use in global industry (UNEP, 2013). At the same time, mines alone (300 million tonnes) create more waste than all households in the European Union (UNEP, 2013; Eurostat, 2012). Mining waste can pose a serious risk to humans and the environment. For example, 96% of the arsenic (US EPA, 2016a) and 92% of all mercury (US EPA, 2016a) that is released by US industry has its origins in mining, primarily leaching mining waste. The growing problems of the current mode of mineral production has led to a request for alternatives (e.g. European Commission, 2015; Gudynas, 2013)

One potential alternative that could address these problems is the concept of *circular economy*. This concept aims to leave the dominant linear economic model based on "take, make and dispose" (Ness, 2008) towards a circular economic model that acknowledges a more environmentally sound bio-based and renewable resource use. Circular economy is a broad concept embracing many dimensions including how products are designed, produced, consumed, and essentially handled as discarded waste. As the name suggests, the aim of circular economy is "the realization of closed-loop material flows" (Geng & Doberstein, 2008) where resources through various practices of circulation such as sharing, leasing, reusing, and recycling are kept "within the economy whenever possible" (European Commission, 2016).

By circulating materials instead of discarding them, the hope is that the availability of resources, especially non-renewable resources, will not only be secured in the long run but also bring environmental and economic benefits while doing so (Ellen MacArthur Foundation, 2013; Club of Rome, 2015). The environmental savings come from an assumption that circulation avoids some of the severe consequences of extracting minerals from the Earth's crust, but are different depending on the material. For example, recycling of aluminum leads to 90-97% energy savings and steel 60-75%, compared to primary mining (Chapman & Roberts, 1983; UNEP, 2013). The energy savings of recycling other materials such as plastic and paper are considerably lower. Circulation practices are generally regarded as more labor intensive than the resource-intensive mining sector (Ayres, 1997), at least in the initial stage of a transition towards a circular economy. Therefore, a circular economy is expected to generate both new work opportunities and economic growth (Stahel, 2013).

An important cornerstone of a circular economy is waste management, which perhaps is the area in which the concept has been furthest implemented. Waste management has for a long time typically been based on the simplest and cheapest way to deal with garbage, namely, to collect it in a landfill. Waste scandals, public protests, lack of new locations for landfills, and a changed perception of waste made waste a central policy issue during the 1970s (cf. European Commission, 1975). These policies were first formulated to protect the environment and humans. But in the 1990s, the EU waste policy started to promote recycling, re-use and energy recovery over the disposal of waste. For example, the principle of producer responsibility was introduced in Sweden in 1994 (SCS, 1994), the landfill tax in 2000 (SCS, 1999) and bans in 2002 (SCS, 2001).

These policy changes, which included both economic and regulatory instruments, had a decisive impact on the waste management system (Kemp, 2007; Hafkesbrink, 2007). For example, in Sweden, deposition of municipal waste has decreased by 97% by weight since 1994 (ASWAM, 2016), while over 70% of all landfills open in 1994 have been capped (ASWM, 2008).

Recycling of base metals has been going on for a long time. Today, however, recycling of metals in some regions is a more important source of metals than ore mining. In 2010, 78.4 million tonnes of secondary metals (Eurostat, 2013) and 21.7 million tonnes (BGS, 2010) of primary metals were produced in Europe. There are, however, large differences between EU countries. In Sweden primary production of metals is 10 times higher than the secondary production (BGS, 2013; Eurostat, 2013), while neighboring Denmark lacks mines. However, to meet the demand for metals in Europe, domestic production is rarely enough. Globally, primary production for most metals is much higher than secondary production. For copper, recycling accounts for 30% (ICSG, 2016), for steel 37% (BIR, 2013), aluminum 51% (Tsesmelis, 2013) and rare earth elements less than 1% (UNEP, 2011) of the total production, which means that the rest is produced by the mining sector.

There is a fundamental problem in relying on recycling. As long as the consumption of resources increases and are held in-use for a considerable time, the waste streams will always be smaller than the increasing resource demand. Hence, as long as consumption increases, recycling cannot even in theory meet the demand for resources. There will also always be losses in the form of, for example, abrasion, oxidation or dilution, which means that complete recycling is impossible (Georgescu Roegen, 1971), even within a steady consumption level. Furthermore, in practice, the recycling rate of some minerals such as rare earth elements is virtually nonexistent, while the recycling rate of base metals in some countries is already high and cannot increase significantly (Graedel et al., 2011; SGU, 2014).

1.2. Landfills as untapped resource reservoirs

One way to increase recycling would be to focus on a type of mineral stock that is often forgotten in discussions about resource availability and circular economy (cf. USGS, 2015; BGS, 2016; Swedish Government, 2013; European Commission, 2008), i.e., those excluded from the market and accumulated in different pristine waste deposits such as landfills, tailings, and slag heaps (Ayres, 1999). Some researchers claim that waste deposits (landfills, slag heaps, and tailing ponds) hold a considerable resource potential, e.g. globally the amount of copper in waste deposits is estimated to be comparable to the current in-use stock (Kapur, 2006). In some regions with well-developed district heating systems, such as Sweden, the amount of combustibles in municipal landfills alone may cover the demand for waste fuels for decades (Frändegård et al., 2013).

Given this potential, the extraction of deposited resources, i.e. landfill mining, has been proposed as a source for net addition of raw material (e.g. Krook et al., 2012; Jones et al., 2013). While the concept of circular economy focuses primarily on avoiding material being excluded from anthropogenic material cycles, landfill mining focuses instead on including materials previously excluded. In contrast to the material in-use, which only becomes accessible when the purpose is lost and becomes waste, deposited resources are in theory directly accessible since they serve no function. Hence, targeting deposit waste opens up possibilities for the recycling sector to control the inflow and create a more resilient flow of secondary resources. Although waste deposits are a finite resource reservoir, the extraction of disposed resources can nevertheless create opportunities for the recycling industry to expand and build necessary capacity for the growing waste streams.

However, since various materials have been deposited over time, including hazardous materials, waste deposits are also a source for significant environmental and health risks. The disposal of materials in waste deposits typically leads to greater emissions of heavy metals than the natural leakage from, for example, weathering and volcanic activity (Reimann & Garrett., 2005; UNEP, 2013). This is because most waste deposits originate from the past and lack proper environmental protection technology. As a result, in Sweden alone, around 700 municipal and industrial landfills have been identified by the EPA (2013a) as high risk subjects. In addition, landfills are one of the largest global sources of methane emissions (US EPA, 2016b). In Sweden, landfills are just behind the agricultural sector as the second biggest source of methane emissions (EPA, 2016a).

As the risks with landfills emanate from the deposited material, the recovery of those materials into resources has been proposed, similar to remediation and capping, as a way to manage problems associated with landfills (Cossu et al., 1996; Hogland, 2002). Potentially valuable materials like minerals and organics could be recycled and incinerated or composted, which would reduce the leaching potential. Furthermore, resource recovery could be integrated with remediation measures. The extraction of disposed material will not only bring resources to the surface but also, for example, hazardous waste. This opens up an opportunity to handle the hazardous waste in landfills according to regulatory practices and upgrade the landfill infrastructure according to current regulatory standards.

Landfill mining can also make other types of "resources" available, such as land surface. Although landfills normally have been placed on the outskirts of cities, to hide and forget the waste, due to urbanization landfills are increasingly in the way of urban development. Certainly, it could be legally possible to build on top of landfills, but considering the many accidents from building on top of disposed waste (cf. Cossu et al., 1996; Reith & Salerni, 1997), deposited material should in many cases be removed before the site can be exploited.

Moreover, in line with stricter legislation it has become increasingly difficult to get permission for new landfills. Therefore, existing landfill space has become a valuable asset, in other words the void in the landfill that results after disposed material has been excavated and recovered. Thus, recycling of deposited material can through creating more space extend the life time of existing landfills and thereby avoid or postpone the creation of new landfills, potentially preserving land for other activities (Spencer, 1990; Richard et al., 1996a, b; Dickinson, 1995; Reeves and Murray, 1997; Cha et al., 1997). Hence, there seems to be some potentially good reasons to utilize and manage the materials that over time have been buried in landfills.

1.3. Landfill mining as a social-technical activity

Today, landfill mining is an unconventional phenomenon, and when deposited materials are utilized it is typically in small-scale pilot projects. These pilot projects are usually undertaken by waste owners, exploring the possibilities to solve traditional landfill problems such as getting additional cover material or to increase the lifetime of the landfill, by extracting some of the deposited material (Krook et al., 2012).

Research on landfill mining can basically be divided into two different lines: (I) evaluations of pilot studies and (II) environmental and economic assessments. With a dominant focus on solving problems for landfill owners, landfill mining was initially a field of research that consisted of evaluations of pilot projects. These evaluations, often in the form of technical reports, highlighted aspects of the project that worked well and aspects that proved unsuccessful. Most of these studies concluded that the pilot studies only posed low risks and minimal emissions of health-hazardous substances (e.g. Cossu et al., 1995; US EPA, 1997), or that the operation was not economically feasible and the sorting equipment inefficient (e.g. Stessel & Murphy, 1991; Savage et al., 1993; US EPA, 1997; Hull et al., 2005).

In response to these rather limited technical assessments and perspectives, a new research focus has emerged. This emerging take on landfill mining is influenced by lessons from industrial ecology's strong focus on resource recovery, more advanced technologies for separation, and upcycling of material quality. Systems analysis tools are increasingly used to evaluate the resource, environmental or economic potentials of full-scale landfill mining operations. These studies have shown that landfill mining can potentially lead to environmental and social benefits, but has difficulties in making a positive turnover (Frändegård et al., 2013; Van Passel et al., 2013; Jones et al., 2013; Marella & Raga, 2014; Jain et al., 2014; Herman et al., 2014; Damigos et al., 2015; Danthurebandara et al., 2015; Frändegård et al., 2015; Winterstetter et al., 2015).

The evaluation of pilot studies (I) as well as the resource, economic and environmental assessments (II) have rarely touched upon aspects beyond the very projects in focus, such as policy, culture, markets, and organizational issues. This technical and quantitative focus on landfill mining provides a limited understanding of the challenges for the emergence and implementation of landfill mining. The restricted focus of landfill mining research has created a situation where assessments have to be based on assumptions about, for example, marketability of sorted fractions and how regulations relate to the extraction of disposed waste. Aspects such as mineral concentrations and avoided methane emissions are of importance for mining initiatives with an environmental profile. However, softer issues such as policy, culture, markets, and organizational issues will also prove crucial to understand the potential of landfills as mines. For realizing landfill mining, there must, for example, be a market ready to receive the excavated disposed waste, and a regulatory framework that does not pose major obstacles for such an operation.

Making ends meet is a common problem in many environmentally driven developments connected, for example, to renewable energy (Levidow & Papaioannou, 2013) and organic food production (DeLonge et al., 2016). The lack of profitability and competitiveness in comparison with the conventional (in this case traditional mining), means that learning, policies, regulatory and institutional dimensions are often emphasized to realize such environmental alternatives (Rotmans et al., 2001; Smith et al., 2005; Jacobson & Lauber, 2006; Elzen et al., 2011). The increased utilization of waste from household and industry as well as the emergence of renewable energy has demonstrated that political commitment through public institutions has played a crucial role for engaging actors (Freeman & Louçã, 2001; Jacobsson and Bergek, 2004; Jacobson & Lauber, 2006; Kemp, 2007). However, public institutions have also proved to hinder the emergence of radical innovation through their close relations with the dominant sector, an alliance Unruh (2000) called the "techno-institutional complex," which results in *lock-ins*. Institutions shall in this thesis primarily be understood in a traditional way as formal governmental agencies and related official documents in terms of regulation, requirements, rules, and guidance. Institutional conditions concern the influence of governmental structures, laws, rules, and policies on practitioners' possibilities for engagement.

1.4. Aim and research questions

The aim of this thesis is to assess the institutional conditions for landfill mining. By studying how institutions relate to landfill mining, conditions in terms of obstacles and opportunities for landfill mining operators will be identified. The interest is thus directed to governmental structures, laws, rules, and policies affecting practitioners' possibilities to extract secondary resources from landfills. First the institutional conditions for landfill mining, its consequences and underlying reasons will be identified. Based on these findings some institutional challenges are synthesized, i.e., questions of considerable importance for the implementation and emergence of landfill mining. In total, the amounts of disposed materials in terms of metals, combustibles, and construction materials are significant as demonstrated above and therefore motivated in a circular economy context. There are thus important reasons for continued evaluation and study of landfills as potential mines. This does not necessarily mean that all landfills should be extracted. Instead, the outcome of this thesis could prove useful if politicians decide to implement alternatives to the current resource policy. To reach the research aim, three research questions (RQs) have been formulated.

1. What are the current policies for the implementation of landfill mining activities?

The intention is to map the existing institutional conditions for actors engaged in landfill mining operations, emphasizing different types of policies such as regulations and taxes. This will be investigated by analyzing how the regulatory framework comes into play in a landfill mining operation. In particular, the laws and rules will be in focus that influence operators' possibilities to access the disposed material and find a market for the excavated, previously deposited waste. The consequences of the current laws for operators and learning processes in the field will also be in focus. Since landfill mining is not a common practice a clear definition of how such practices shall be governed and regulated is lacking. Therefore, possible alternative regulatory frameworks that may come into play in a landfill mining operation will also be described.

2. How can the current formulation of policies be understood?

The second research question seeks an understanding of why the institutional conditions for landfill mining look the way they do. This will be examined by visualizing how the perception of waste and resources influences the formulation of policy, and thereby controls how activities should be performed in relation to landfill mining. The formulation of policies will also be connected to the institutional arrangement and the governmental structure responsible for the regulations. Approaching the foundations of the regulatory frameworks with potential relevance for landfill mining opens up possibilities for a deeper understanding of the institutional challenges for landfill mining.

3. What institutional challenges can be identified for the emergence of landfill mining?

By identifying policy barriers for landfill mining, their consequences and underlying causes, institutional challenges for landfill mining to emerge into a feasible and conventional practice can be identified. The challenges will be formulated from a general perspective, for example conflicting objectives, based on a synthesis of the observations from the previous questions. The institutional challenges will partly be related to other similar areas where alternatives such as biofuels challenge the dominant approaches. By relating the institutional challenges of landfill mining with challenges faced in other fields, lessons could also be learned for how the institutional capacity can increase to handle the emergence of unconventional, complex and uncertain phenomena such as landfill mining.

The thesis will end with a forward looking reflection on what is missing in the current discussions about resource management and how the findings from this thesis can address this gap.

1.5. Scope

This cover thesis is a synthesis of five papers written during my PhD period. My study of landfill mining during the PhD period has been limited to a specific sort of waste deposits, namely those containing obsolete and discarded things. This excludes waste from mining or metallurgical processes, but includes waste from households and industry in landfills. The reason for focusing on landfills is that they occur in all regions, in cities and villages, and contain material once valuable, which potentially could be resurrected.

Municipal and industrial landfills typically contain a variety of materials, basically more or less everything once in use. Hence, many different types of waste categories such as combustibles, fines, plastics, and metals will be relevant. However, metals will be emphasized because this type of disposed material has proven possible in real-life projects to utilize and is also one of the few secondary resources that brings any revenue to the landfill mining practitioner (e.g. Cobb & Ruckstuhl, 1988; Obermeier et al., 1997; Zanetti & Godio, 2006; Kurian et al., 2007; Wagner & Raymond, 2015). But other materials will also be recognized, not least since the extraction of metals from landfills will bring a variety of other materials and contaminants that must be handled.

My main focus during the PhD period has been on the relationship between landfill mining and institutional conditions. This attention comes partly from my project's close relationship with recycling operators, who have identified policies as a major obstacle to the implementation and emergence of landfill mining. Institutional conditions with relevance for implementation in the form of policies, taxes, regulation and requirements will be in focus.

The starting point of practitioners also brings a specific perspective on policy. Policy in this thesis will be studied from a business-oriented perspective, i.e., the perspective of landfill mining operators aiming to extract disposed material. I do not attempt to map all possible conditions of relevance for landfill mining but rather seek to emphasize a few policies with significant relevance for the implementation and emergence of landfill mining. Hence, this thesis is not a comprehensive study of the institutional conditions for landfill mining. Institutional conditions relevant for other stakeholders such as policymakers in the form of regulatory responsibilities have received less attention in this thesis, although the authorities are partly given attention in Paper V.

Policies will be studied as a final product with related consequences, rather than the process that led to the formulation of policy. Furthermore, institutions and policies will mainly be studied from a Swedish context and in some cases from an EU perspective. It is primarily up to the reader to judge how the main findings of this thesis relates to his or her specific context, although I will do my best to discuss generality to aid such interpretation.

1.6. The structure of the cover thesis

Chapter 2 provides an outline of the key theme in this PhD thesis (landfill mining) and a literature review of previous research in the field related to the subject of the thesis. The theoretical framework of the thesis is presented in Chapter 3, where my approaches to industrial ecology, landfills and institutions are discussed. In Chapter 4, the methodology is presented by unfolding my research process during my PhD studies and discuss the research quality. Chapter 5 consists of a summary of the appended papers, while Chapters 6, 7 and 8 answer the research questions of the thesis through synthesizing the results of the appended papers. Chapter 9 presents my reflection on how my study of landfill mining can inform wider discussions of resource policy. My work is concluded in Chapter 10 by highlighting the major contributions and suggestions for future areas of research.

2.

BACKGROUND

The background describes first the concept of "landfills" and its relation to policy. Then "landfill mining" is discussed through a literature review of its resource, environmental and economic potential and its relationship to policies.

2.1. Landfills

Landfills represents a "waste collective" of accumulated waste in a more or less delimited space. In Europe there are more than 500,000 landfills, and in Sweden around 6000 (EURELCO, 2016). Ninety percent of those landfills are non-sanitary, lacking environmental protection technologies, predating the Landfill Directive (European Commission, 1999). Some of these landfills adjacent to megacities such as London or Moscow have been considered the "largest human-engineered formation in the world" (Melosi, 2016). At the same time, there are numerous small landfills, for example, adjacent to a farm or a village. Common to all landfills is that they have provided an opportunity for people everywhere to get rid of obsolete things. The simplicity and effectiveness of this method means that landfilling is probably the oldest form of organized waste management, dating at least to ancient Athens (Mumford, 1961). Since then, landfilling has globally been the dominant mode of waste management (Kollikkathara et al., 2009; UN-HABITAT, 2010).

In recent decades other waste management methods such as incineration and recycling have challenged landfilling as the principal method. Hence, the amount of household and industrial waste sent to deposition has decreased in many regions. Less than 1% of all municipal solid waste was deposited in Sweden in 2015 (ASWA, 2016). In total, however, deposition is still the dominant method for waste management in Sweden, despite its up-to-date waste management system. Household waste is typically sent to incineration, which reduces the amount of waste but is still deposited in the form of ash. Furthermore, the largest waste stream in Sweden (mining waste) has also increased, due to a large Swedish mining sector in steady increase. Hence, the total amount of disposed waste has increased from around 60 million tonnes in 2004 (EPA, 2007) to 75 million tonnes in 2012 (EPA, 2015a). This is in a country with "virtually zero landfilling" (European Commission, 2012).

There is a variety of landfill types. Material flow analyses (e.g. the STAF project of Yale University) in the field of industrial ecology have traditionally divided landfills into three different types, depending on where in the material flow chart waste is excluded: landfills, tailing ponds, and slag heaps (cf. Kapur & Graedel, 2006), Figure 1. While tailings are "leftovers" after the mill process and extraction of metals from ore, slag is a residue product from the refining of ore by pyrometallurgical processes such as smelting, converting, and refining. The waste in these industrial landfills is thus stuck in a pre-commodity phase and has failed to reach the market. Waste in landfills, on the other hand, have usually once been commodities on the market, but then eventually lost their value, and were buried in the landfill. Landfills are thus a material end station for consumption, a post-commodity phase, a terminus for things once in use; a place of "things you ardently wanted and then did not" (Hawkins, 2006). Furthermore, landfills are usually divided into industrial landfills and municipal landfills. Industrial landfills contain waste chiefly from the manufacturing industry, while municipal landfills contain household waste. Around 80% of all landfills in Europe are municipal landfills, while 20% are industrial (EURELCO, 2016).

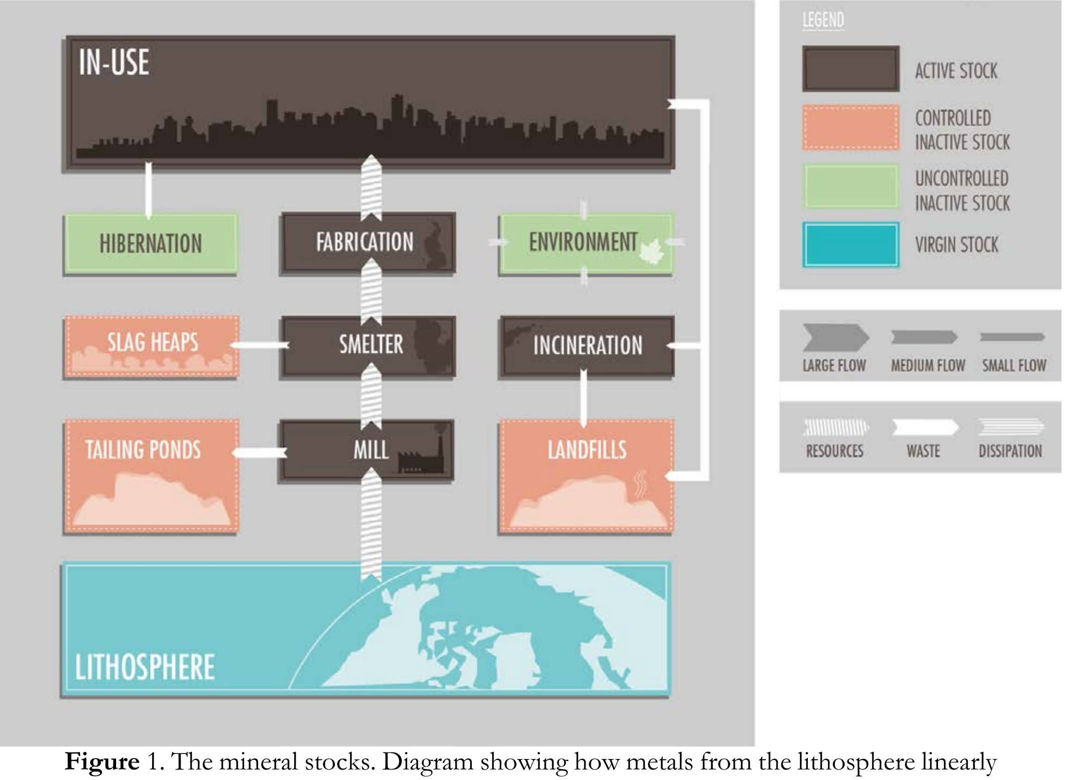

Figure 1. The mineral stocks. Diagram showing how metals from the lithosphere linearly accumulate in different stocks situated in the technosphere. From all stocks, secondary metals dissipate into the surrounding environment (land, sea, air or even space). Hibernation refers to metals neither in-use nor collected by waste management, and could for example be stored in attics. The figure is taken from Paper 1.

The boundaries between the different types of landfills are not always clear. In many cases, industrial waste has been deposited mixed with household waste in municipal landfills. Furthermore, landfills can vary significantly in capacity, content, and design (Krook et al., 2012; Frändegård et al., 2013; Laner et al., 2016). In Sweden, modern active landfills are bottom sealed with drainage and gas collection system, while old inactive landfills are often just covered with soil and unlined, some of which have become ski slopes while others are just grassy hills. All types of waste such as soil, wood, food, sludge, e-waste, pesticides, and appliances such as refrigerators have traditionally been landfilled. Local variations still exist depending on the local industries and their specific waste, but also due to aspects such as moisture content, presence of enzymes, pH, temperature, density, and compressibility of the landfill (Elagroudy et al., 2008). This aspect influences, for example, the biodegradation rate of organic materials and oxidation of iron, thus generally the disposed material and its quality.

2.2. Landfilling, policies and the waste market

At least since the beginning of the twentieth century, Swedish municipalities have been responsible for the collection and management of domestic waste, while the industries have been responsible for their waste. Consequently, all municipalities own at least one landfill, which often also includes industrial waste since the industry had the option to hand over the responsibility to municipalities. However, since the transfer of responsibility costs money, industries that created large amounts of waste normally had their own landfills next to their facilities. Until 1972 it was possible for businesses and households to manage their own waste in Sweden without official interference, as long as it was conducted in line with praxis (Sjöstrand, 2014). At the same time, the municipalities often had poor control over their landfills, which means that the knowledge about the content in municipal landfills is limited, in particular those landfills with older waste.

The inclusion of Sweden in the European Union in the year 1995 changed the Swedish waste market. Municipalities still have a monopoly on domestic waste, but some waste streams are under the producer responsibility (SCS, 1994; 1998), while industries are responsible for their waste. The collection of municipal waste is financed by households and a waste tariff, while industries pay for their own waste, although their costs are in the end put on the consumers (cf. Lepawsky, 2012). Hence, it costs money to get rid of waste. Industries as well as municipalities typically discharge their waste responsibility to different contractors or municipally owned companies (Corvellec & Bramryd, 2012). These actors collect waste and sort it within the organization as far as possible and then sell the few valuable secondary materials such as metals to other private recycling operators who have specialized in specific waste streams. The remains will typically be incinerated and then deposited in the form of ashes or deposited directly.

Landfilling and landfills are strictly regulated today. Firstly, waste stored longer than three years is legally defined as a landfill (European Commission, 1999). Such an activity, according to the Swedish Environmental Code (SCS, 1998), is an environmentally hazardous activity that requires a permit. Landfills are divided into three classes, depending on the type of waste they are allowed to accept: hazardous waste, non-hazardous waste, and inert waste (European Commission, 1999). Waste must, therefore, be characterized and classified according to the abovementioned categories before it enters a landfill.

A landfill in operation needs to fulfill the precautionary measures mentioned in the permit, the landfill ordinance (SCS, 2001) and the Landfill Directive (European Commission, 1999). For example, leachate from water penetration needs to be handled, tested, and treated before being discharged into the environment. Methane gas formed in the anaerobic conditions inside the landfills should be flared or collected for utilization. An active landfill must also be sealed with a drainage layer to collect leachate, and capped upon closure. As a result of the increased regulatory demands, most municipal landfills are closed today, and it is primarily the large central landfills with incineration plants in their proximity that remain open, given the need to deposit ashes.

In general, the regulatory framework of landfills (SCS, 2001; European Commission, 1999) pushes waste away from landfilling through prohibitions and taxes. Since 2002, it is forbidden to deposit combustible waste in Sweden, a ban that has been of great benefit to the municipal incineration plants. Furthermore, disposal of organic waste has been prohibited since 2005. This ban was introduced to reduce methane emissions from the anaerobic environments in landfills and avoid subsidence. In 2000, a tax on disposition of waste was introduced, which in 2016 was around € 50/tonne.

2.3. Landfill mining

Landfill mining is the term most commonly used to describe the extraction of resources from landfills (Krook et al., 2012; Jones et al., 2013). Other concepts have also been used, such as *landfill reclamation* (e.g. US EPA, 1997) or *landfill recovery* (Herman et al., 2014) to emphasize that recycling of disposed waste also opens up opportunities to manage hazardous materials and secure landfills. The other way around could also be the case, where remediation opens up opportunities for recycling. In this thesis, however, the term *landfill mining* will be used, since by excluding the term "mining" from the concept, the resources, which in many ways are the new "thing" with the research field become linguistically hidden.

Landfill mining is here understood as a combined activity of resource extraction and environmental measures, where deposited resources such as metals, plastics, combustibles, and construction materials are recovered while leachate and other environmental problems associated with landfills are addressed (cf. Krook et al., 2012; Frändegård et al., 2013). When the disposed waste is recycled and the landfill is opened up, it seems practical at the same time to address the hazardous waste. It is questionable, however, whether it is in line with the legislation to open up a landfill without handling the hazardous and upgrading the landfill according to the applicable legal standard of protection (cf. SCS, 1998). Although landfill mining should here be understood as an integrated action, focus is primarily on the resource perspective, since, for example, remediation is a well-documented activity (see for example Sharma & Reddy, 2004).

A feature of landfill mining is the potential of fulfilling multiple purposes. By recycling disposed waste not only could primary production be avoided, but the site could be remediated and the landfill infrastructure upgraded. After the operation, more space becomes available in the landfill due to the recycling process, which could avoid the need for new landfills. If the landfill is secured and closed after the operation, the site can be used for construction or as a recreation area. This is a principal difference from traditional resource extraction, i.e., mining, with one sole purpose: to extract one or a few mineral resources from the bedrock.

The concept of landfill mining is based on the perception that deposited material would do greater good elsewhere. Extracting deposited resources means that the material flow turns and changes direction. Landfills as the final destination in the material flow chart instead become a starting point. Such a perspective on landfills proposes a radical reinterpretation of the conceptual position of landfills: politically present instead of hidden away, absent and forgotten, a source of resource instead of a source of pollution, potentially valuable rather than useless. By extracting resources from landfills, waste once abandoned is given a new chance to actually climb up the waste hierarchy, from a state of deposition at the bottom of the waste hierarchy advancing upward towards energy recovery, recycling or reuse. Landfill mining is a way of undoing the earlier practices of landfilling. Hence, landfill mining aims to internalize the material previously externalized by the market. Exhuming and recycling waste from landfills naturally reduces the amount of disposed waste, which could be interpreted as a measure of waste minimization, although the concept is primarily meant to hinder material in-use becoming waste.

The term "landfill mining" is a rather unusual metaphor to use in the field of industrial ecology. If the concept is stripped into its two components, *landfill* and *mining*, these terms communicate a dirty and anthropogenic activity with harmful environmental consequences. Landfills as already said are at the bottom of the waste hierarchy, and associated with a variety of environmental, economic and social problems (Baun & Christensen, 2004). The same goes for mining, which is associated with severe environmental, economic, and social impacts (UNEP, 2013). In industrial ecology, metaphors such as "industrial symbiosis" are otherwise used to signal that the technical solution is natural, green, safe, and uncontroversial. However, put together into one concept, "landfill mining" is believed to potentially limit the problems of traditional mining as well as the problem with landfills. This is by offering an alternative resource reservoir to primary resources as well as addressing the very source of the problem to landfills, the deposited waste.

2.4. Historical recovery of disposed material

Humans have probably recovered disposed material ever since materials have been buried, intentionally or unintentionally (Rathje & Murphy, 1992; O'Brien, 2008; Medina, 2007). One of the first known examples of recovery of buried material is when looters in ancient times exhumed the giant statue of Rhodes, which had fallen several hundred years earlier when it was buried by an earthquake, to sell the bronze to weapons manufacturers (Medina, 2007). Similarly, valuables buried in tombs have in some cases been exhumed at a later time for selling (Medina, 2007). Today, people far down in the societal hierarchy live on landfills to extract resources (cf. Wilson et al., 2006). In these cases, however, waste pickers usually sort and recover the waste that is daily transported and deposited on landfill sites.

The first reported case of an industrial excavation of a landfill, including larger machines such as excavators and sorting equipment, was according to Savage et al. (1993) executed in Israel in 1953 to yield fertilizers for orchards. After that, according to Krook et al. (2012), no cases were reported until the 1990s, when the introduction of stricter landfill legislation made permits for new landfills hard to obtain, which pushed a few landfill owners to think innovatively. As a result, some landfill owners in the United States started to exhume landfills and utilize materials to increase the lifetime of their landfill, obtain valuable landfill space, and postpone the expensive final cover (Spencer, 1990; Richard et al., 1996; Dickinson, 1995; Reeves & Murray, 1997; Cha et al., 1997).

In Europe and Asia a similar trend could be observed, but in these regions the drivers for landfill mining were primarily the increased need for remediation of contaminated landfills and removal of landfills in the way of urban development (Cossu et al., 1996; Hogland et al., 1995; Hylands, 1998). For example, in the city of Helsingborg, Sweden, several cases of landfill mining have been carried out to create space for urban development and remediation of leaking landfills (Hogland et al., 1995).

During the 2000s, landfill mining gained a rebirth, this time, however, driven mainly by a resource perspective and the concerns of many policymakers over a long-term supply of minerals. About the same time, material flow researchers (e.g. Baccini & Brunner, 1991; Sörme et al., 2001; Graedel et al., 2004) began to study the flow of materials in a new way, not as before to predict future sources of pollution, but to identify where resources accumulated in the built environment.

For landfill owners, increased commodity prices led to an increased interest in the disposed material that used to be invaluable. Consequently, several recycling actors have shown interest in extracting resources from their landfills. Numerous small-scale excavation projects have been implemented around the world, for example, in Denmark (Rosendahl, 2015), Belgium (Jones et al., 2013), Finland (Kaartinen et al., 2013), Germany (Franke et al., 2010), Italy (Zanetti & Goido, 2006), USA (US EPA, 1997), India (Kurian et al., 2003), and Thailand (Prechthai et al., 2008). Large-scale resource-driven recovery operations are rare, but have occurred occasionally in the US. For example, approx. 200,000 tonnes of waste from Frey Farm Landfill in the state of Pennsylvania were sent to incineration (US EPA, 1997), and around

38,000 tonnes of ferrous and non-ferrous metals were recycled from an ash landfill in southern Maine (Wagner & Raymond, 2015).

In Sweden, waste companies such as Tekniska Verken, Stena Metall, NSR and Ragnsells are currently examining the possibilities to extract resources from their landfills, and thereby address several other concerns such as leachate and lack of vacant landfill. The difference in this new awakening is that resource recovery becomes a starting point rather than a secondary issue. As a result of this new resource focus, some researchers argue for changing the concept to "enhanced landfill mining" (Jones et al., 2013). This is to differentiate the concept from the old approach with other primary objectives, towards a resource perspective with advanced technology for material process to reach higher quality outputs.

The increased interest in landfill mining from the domestic recycling industry and academia has led to the formulation of a European consortium for landfill mining (EURELCO, to support innovation and diffusion of the subject. Policymakers have also started to engage in this emerging field. In Sweden alone, governmental agencies have conducted three different commissions[1] on the theme of landfill mining, to analyze its environmental impacts (EPA, 2013b), examine the resource potential (SGU, 2014) and consider how resource extraction from landfills can be supported (EPA, 2015b). A major focus of these commissions, at least those performed by the Swedish Environmental Protection Agency (EPA), has been whether the residues from landfill mining shall be exempt from the landfill tax, i.e., a tax for landfilling waste. In addition, a seminar in the EU Parliament organized by EURELCO was held in 2015 to discuss landfill mining as a strategy to manage the many problematic landfills across the EU.

[1] Government commission generally have a decisive influence on Swedish policy and aim to prepare, examine, and formulate new policies on specific policy issues (Hysing & Lundberg, 2015). Government commissions normally include experts, business, and NGOs.

2.5. The resource potential of landfills

Landfills have a great resource potential, but that can be difficult to utilize. For example, Kapur (2006) has estimated that about half of all the copper that had once been in use is now found in various waste deposits or lost to the environment. This estimate can be confirmed by comparing how much copper has been extracted through history (PGL, 1936; BGS, 1920-2016) with how much is in use (UNEP, 2010), Table 1. Such a comparison shows that approximately 602 Mt of copper have been exhumed from below ground since the year 1650 while about 315 Mt is in use. This means that about 287 Mt, or about 50% of all copper is landfilled in tailings, landfills, slag heaps or lost to the environment. Earlier material flow analyzes have demonstrated that only 1-5% of the excavated copper has dissipated into the environment (Bergbäck et al., 2001; Bertram et al., 2002; Kapur, 2006; Kapur & Graedel, 2006). Therefore the clear majority of copper not in-use is to be found in some kind of waste deposit.

The proportion of the excavated metals that ends up in waste deposits varies. For example, about 80% of all excavated lead and about 25% of all the zinc could be found in landfills, Table 1. The variation depends, for example, on the consumption pattern, durability in-use, recycling rate and extraction efficiency at the mine of the specific metal (cf. UNEP, 2010; Reck & Graedel, 2012). Even if the potential to increase recycling by targeting landfills varies it is nevertheless significant in theory.

Table 1. An overview of the global stocks of metals in the technosphere divided between in-use and waste deposits (or lost to the environment), and the Earth's crust, presented as resources and reserves. Please note that the comparison is not symmetrical, since the metals in the technosphere are in total amount while in the Earth's crust only includes those with economic potential (see SGU, 2014 for a similar comparison). However, the minerals in the technosphere have once been classified as reserves. All numbers are presented in megatonnes.

Metal	Minerals in the technosphere[1]	Minerals in-use[2]	Minerals in waste desposits[3]	Resources in the Earth crust[4]	Reserves in the Earth crust[4]
Aluminum	1,000 Mt	550 Mt	450 Mt	>10,000 Mt[5]	5,600 Mt[5]
Copper	600 Mt	300 Mt	300 Mt	>3,000 Mt	700 Mt
Iron	35,200 Mt	15,400 Mt	19,800 Mt	>230,000 Mt	80,000 Mt
Lead	250 Mt	50 Mt	200 Mt	>2,000 Mt	100 Mt
Zinc	450 Mt	350 Mt	100 Mt	>1,900 Mt	250 Mt

[1] The amount of metals in the technosphere has been estimated by using figures for annual global metal production since 1650. References: PGL, 1936, BGS, 1920-2016.
[2] Reference: UNEP, 2010. The years of the determinations vary, but are primarily from the period 2000-2006. Estimates are presented per capita in the reference and have therefore been multiplied by 7 billion capita.
[3] The amount of metals in waste deposits or lost to the environment has been estimated by the difference between the total amount of minerals in the technosphere and in-use.
[4] Reference: USGS, 2013.
[5] Aluminum is calculated by dividing the resource/reserves of Bauxite by 5 (based on how much primary aluminum was produced from Bauxite in the year 2011 (BGS, 2013).

How much of the metals in different waste deposits are likely to be found in industrial or municipal landfills, rather than tailings or slag heaps, is uncertain and differs between different metals. For example, Muller et al. (2006) estimated that 15% of total US iron stocks in the technosphere are in landfills, 12% in tailings and 5% in slag heaps. At the same time, metals cover only a limited share of all the material in a landfill. Sampling and material characterization of municipal European landfills have demonstrated large variations between landfills, with 70-25% of soil material, 25-2% plastics, 15-10% stones and inert material, 12-2% paper, 7-3% wood, 5-2% textiles, 2% organic matter, 5-2% ferrous metals, 1.5-0.5% non-ferrous metals and 0.2% hazardous material (e.g. Cossu et al., 1995; Godio et al., 1999; Bernstone et al., 2000; Kurian et al., 2007; Krook et al., 2012; Frändegård et al., 2013; Laner et al., 2016).

The few percentages of metals are primarily those that had a high use rate such as iron, copper, zinc, aluminum, but also critical metals according to Gutierrez-Gutierrez et al. (2015) with comparable concentrations of mines in the bedrock. Hence, in theory, not only disposed metals but also plastics and renewable waste fuels could become a significant net addition to the recycling flows (Frändegård et al., 2013).

An increased inflow of secondary resources from e.g. landfills to the recycling sector could potentially provide a springboard for the recycling sector to build necessary capacity for the future, as mines are becoming increasingly inaccessible for various reasons (cf. Sverdrup et al., 2015). Recovering waste from a landfill instead of materials in-use becoming waste brings some advantages. The minerals are in theory directly accessible, unlike those in use, because they generally do not fulfill any function or purpose. This makes them more accessible on demand for the recycling sector.

At the same time, landfill mining does not requires the same scattered collection scheme as traditional recycling, since the material is accumulated in one or a few places, which can allow for economies of scale. The concentration of minerals in some waste deposits, such as 2% copper in a shredder landfill in southern Sweden (Alm et al., 2006) may be far higher than in active mines, where copper is mined at an average concentration of 0.8% (Crawson, 2012). However, compared with traditional mines, the total amount of minerals in individual dumps is relatively small and in that sense also more scattered.

Landfills are finite mineral stocks just like in the Earth's crust, and can therefore not become a long-term commitment. However, as long as overconsumption and narrow economic calculations make deposition the preferred option, which is the case for most regions in the world, landfills will potentially be filled with more material. Exactly how much of the total amount of waste in landfills is recyclable and thus constitutes reserves is uncertain (e.g. Winterstetter et al., 2015). The multiple objectives and drivers for landfill mining in terms of, for example, remediation, land reclamation, and the value of the landfill void, can make the resources in landfills available for reasons other than its intrinsic value. This complicates the categorization of deposited material under the existing resource classification system (cf. UNECE, 2004), chiefly based on the economic value of the deposit, which is the central driver of conventional mining. For landfills, it is not necessarily the deposits with the highest concentrations that will be extracted in the first place, instead it could be the deposits with the greatest risks for humans and the environment.

Generally, the quality of deposited waste is lower than fresh waste, due to oxidization and biodegradation (Savage et al., 1993; US EPA, 1997; Kaartinen et al., 2013), while humidity levels and heterogeneity are high, making it difficult to develop functional sorting schemes. According to Frändegård et al. (2013) and Laner et al. (2016), about 50-80% of the minerals found in municipal landfills are possible to recover, depending on site-specific conditions such as sorting technology, the type and quality of the material. However, these calculations are based on the use of sorting technology developed for traditional fresh waste rather than deposited waste. Other technical solutions are also missing, for example, to prospect exactly where the valuable minerals are located in landfills (US EPA, 1997). For example, sampling rarely provides a complete picture of the content, because the content of a landfill does not always follow a logical regularity, due to random deposition. Even if waste flows into the landfill have been logged and documented, there is always a risk that waste has been dumped uncontrolled.

Research on the resource potential of landfills has slowly evolved from being potential-oriented to touching upon obstacles to extract the identified potential, however, mainly in the form of technical barriers such as separation efficiency. There are several national and international projects working on technology improvements involving the chain from prospecting to upgrading the materials[2]. Technology is, however, only one of many factors that determines the possibilities to exploit the potential. The institutions, society, and the market must also be interested, willing, and able to handle the deposited resources for landfill mining to become realized, but have received less attention.

2.6. Landfill mining and the environment

Just like traditional recycling, landfill mining involves environmental impacts in terms of resource use and various emissions, but also avoided emissions since this type of resource extraction is assumed to avoid extracting the same material from the Earth's crust, including its consequences (cf. Frändegård

[2] see: http://www.eurelco.org/projects

et al., 2013; Jones et al., 2013; Laner et al., 2016). Energy recovery of combustibles from landfills may also replace conventional energy generation, which in many parts of the world is fossil based. For this reason, the extraction of disposed resources can generate environmental benefits from a life cycle perspective (Frändegård et al., 2013; Van Passel et al., 2014; Jones et al., 2013; Jain et al., 2014; Danthurebandara et al., 2015). After all, compared to traditional mines, deposited minerals in a landfill are more refined and significantly closer to the market with its location on the outskirts of cities. However, some studies demonstrate moderate climate savings from recycling deposited waste and sometimes even negative impact (Winterstetter et al., 2015; Laner et al., 2016).

The climate impacts seem to depend on site-specific conditions such as the landfill material content in relation to regional aspects such as the background system for energy generation (heat and electricity). For example, a high content of aluminum in the landfill is generally favorable while a high proportion of plastic or rubber intended for energy recovery in a region with renewable energy might result in net contribution to global warming (Laner et al., 2016). In cases when there is no gas collection system at the landfill, which is the case for the vast majority of Europe's landfills, landfill mining virtually always seems to result in avoided climate impact (Laner et al., 2016), if the excavation manages to mitigate the leaching of methane gas. Landfill mining is, however, not only relevant from a climate perspective. For example, toxins inside the landfill can become a potential risk as well as potentially incapacitated.

Due to the lack of full-scale recovery operations, local environmental problems have been less investigated. Most of the risks associated with the disposal of waste seem to revive when the material flow turns and disposed waste is exhumed to the surface, such as transportation, noise, landslides, collapse, smell, risk of infection, dust, fire, health and safety risks, and leakage of metals and other impurities (Cossu et al., 1995; US EPA, 1997). There is a general risk when the landfill is opened up that the emissions that normally seep out slowly instead overflow during an intense period. The opening of the landfill also increases the exposure of the disposed waste, for example, to water.

However, landfill mining also opens up an opportunity to remove the hazardous material and thereby avoid future leaching. After all, the current legislation (SCS, 1998) in Sweden probably forces landfill mining operators to handle encountered hazardous material. Remediation of landfills, which is a quite frequent activity in many parts of the world, has demonstrated that it is possible to exhume garbage from landfills without a significant risk for the local environment (e.g. Möller, 1999; Tyrens, 2010). At the same time, remediation of landfills has also shown that excavations of landfills can create local protests and concerns (cf. Craps et al., 2010). Some landfills hold such a high proportion of toxic materials that they should principally be treated with caution and probably encapsulated. Since there is no sufficient method to prospect the inside of the landfill, there is a risk that unexpected hazards surface when disposed waste is exhumed. This is primarily a safety issue for workers, but if hazardous materials are sent away uncontrolled they may pose a risk where they end up.

In sum, if landfill mining is conducted in a responsible way, according to the safety regulations, resources could be recycled and impacts from traditional mining could partly be avoided. Furthermore, many of the environmental problems associated with landfills could be addressed, since an opportunity is opened up to deal with the very source of the risk, the deposited waste, by remediation measures and installing bottom seal and gas drainage collection systems (Spencer, 1990; Flosdorf & Alexieffs, 1993; Kornberg et al., 1993; Cossu et al., 1996; Cha et al., 1997). But on the other hand, if landfill mining is performed without caution, there is a significant risk for workers, local residents and the environment. Hence, an institutional challenge is to steer towards mitigating the problems of landfill mining, while encouraging the benefits of such operations.

2.7. Institutional conditions, policies and regulations for landfill mining.

There are several policy objectives closely related to landfill mining. For example, increased recycling and resource conservation, as primary resources can be kept under the ground if recycling instead provides the minerals. These policy objectives are stated in the Environmental Quality Objectives (EPA, 2015c) and Sweden's Mineral Strategy (Swedish Government, 2013). Both these objectives are also mentioned in the Raw Materials Strategy (European Commission, 2008) as well as the circular economy package (European Commission, 2015). Moreover, the security of materials and energy supply is a priority of European policies (European Commission, 2012).

Given that landfill mining can potentially reduce the risk of long-term leachate from deposited hazardous material, other societal goals such as the treatment of contaminated sites as mentioned in Sweden's Environmental Quality Objectives (EPA, 2015c) are relevant. In addition, increased recycling can lead to reduced emissions of carbon dioxide, which are stated objectives on the national (EPA, 2015c), regional (European Commission, 2008), and international (UN, 2016) level. However, in cases where landfill mining fails or is performed without environmental considerations these goals can become relevant from a negative perspective, where the operators contribute to the problems rather than mitigation.

Although there are several policy goals with relevance for landfill mining, explicitly formulated goals for landfill mining are lacking. For this reason, there are also no explicit policy instruments designed to realize landfill mining. Since the phenomenon is so limited, at least in Sweden, there are no formulated laws or regulations for landfill mining at all. However, many of the above stated regulations for landfilling (chapter 2.2) are nevertheless also relevant for operations digging up waste for recycling. For example, residues after a landfill mining operation in need of re-deposition can be subject to the landfill tax (Frändegård et al., 2015).

Most economic assessments of landfill mining case studies and pilot projects demonstrate that the costs of excavation, sorting, treatment, and recycling of waste will probably exceed the anticipated revenues for extracted materials (Dickinson, 1995; Fisher & Findlay, 1995; Van Passel et al., 2013; Frändegård et al. 2015). The negative financial results may derive from a focus on municipal landfills with heterogeneous low-grade materials sorted through inefficient sorting equipment (Krook et al., 2012). But it may also depend on the institutional conditions for landfill mining. For example, the current tax system favors primary mineral production and is negative for secondary production through low energy taxes and high taxes on labor, respectively (Ayres, 1997). This institutional phenomenon is probably also relevant for landfill mining, since it will be difficult to build automated processes due to the heterogeneous waste. This calls for the involvement of workers to sort and control the waste in order to produce saleable commodities (Krook et al., 2015). Frändegård et al. (2015) have demonstrated direct impacts of the current institutional conditions, as the cost of re-depositing material through the politically induced landfill tax could represent 30-50% of the total costs for a landfill mining project.

For landfill mining to become profitable the institutional conditions probably need to be adapted to this novel type of recycling. But even if the regulatory framework is adapted to landfill mining, profitability is far from given. In fact, even in an optimistic case, with efficient separation and exemption from the landfill tax, the economic result could be negative (Van Passel et al., 2013). However, if additional revenues such as green certificates could be obtained for the conversion of disposed waste into energy, landfill mining would in this case become profitable according to Van Passel et al. (2013). Previous case studies have demonstrated that profitability of landfill mining operations is possible in cases when further revenues other than from recycling of the material can be included in the form of, for example, the value of land made available, increased landfill space or the alternative costs of leaving the landfill as it is[3] (e.g. Wagner & Raymond, 2015; Frändegård et al., 2015).

In sum, there are unique landfill mining cases, for example an homogenous landfill with high metal concentrations situated in an area with high land prices (Wagner & Raymond, 2015; Frändegård et al., 2015), that can become profitable under current institutional conditions. But for landfill mining to become something more than sporadic attempts there are several studies (e.g. Van Passel et al., 2013; Jones et al., 2013) that call for different institutional configurations. Landfill mining today has thus increasingly become an issue of policy. However, policy-related analysis of landfill mining is scattered, and only specific policy instruments such as the landfill tax, green energy certificates, investment support, and tax breaks are occasionally mentioned in relation to economic assessments, with less reflection on the disadvantages of such institutional changes. A broader investigation of how policies, rules, and laws relate to and cause implications for landfill mining is missing.

[3] Alternative costs are also the driver that has made conventional recycling the rational choice for waste owners, since other alternatives such as landfilling are a more expensive alternative. Recycling is thus allowed to be costly, since it involves lower costs than the alternatives.

3.

THEORECTICAL FRAMEWORK

This chapter provides a starting point for the analysis by presenting the theoretical perspectives that will be used to analyze the empirical findings. First the theoretical basis of this thesis is presented: industrial ecology. But since this theory lacks theoretical approaches for studying institutions, other theories are used for analysis.

3.1. Industrial ecology

Landfill mining is an area of research with close ties to the larger research field of *industrial ecology*, with the overarching normative goal of a sustainable society (Allenby & Graedel, 1993). In this field, the sustainable society is to be reached by bending the linear material and energy flows in society into circularity, similar to the closed loops in nature. Landfill mining in practice and as a topic of research is also typically environmentally driven (cf. Krook et al., 2012; Jones et al., 2013), contributing to increased recycling of secondary resources, although its consequences do not always serve this purpose (cf. Laner et al., 2016).

This thesis focuses on the institutional conditions from the perspective of the practitioner, which usually characterizes research in industrial ecology with close relationship between industry and research (cf. Allenby & Graedel, 1993; Chertow, 2000). This close relationship commonly brings a technical focus or quantitative approach to evaluate the performance of technology in different settings. In line with this focus, the dominant landfill mining research has also been technical and quantitative in its nature. This means, however, that the topic of this thesis, the society surrounding landfills in the form of policies and governmental structures, is not a common perspective in the field of industrial ecology.

The focus of industrial ecology research on the environment and flows means that the methods, approaches, and tools within the field are developed to analyze these aspects, in the form of, for example, Materials Flow Analysis or Life Cycle Analysis. In order to study how disposed materials are shaped by the social, or more specifically for this dissertation; how the "social context enable or constrain envisioned transformations in production and (...) what role do business, governmental, and other organizations play in developing industrial ecology approaches? "(Boon & Howard-Grenville, 2009: 3), additional theories and approaches needs to be applied from other areas of research.

3.2. A socio-material approach to landfills

A perspective that is often used to study how technology, in this case landfill mining, is embedded and influenced by the outside world in terms of institution, economics, cultural norms, and people, is the *socio-technical* (cf. Hughes, 1983) approach. Considering the multiple uncertainties and challenges that landfill mining faces in terms, for example, of technology but also economic, market and regulatory aspects, an approach bringing them all together in interaction seems suitable. Studying the interaction of technology and its social surrounding comes from organizational studies of the British coal mining industry (Trist, 1981), for example in Trist and Bamforth's (1951) study of the interactions between machines and humans in the coal mines.

In studies of the relationship between technology and the social aspect, the material in the form of substances and their properties, the constitution of things may become passive, in the background of the analysis. For example, in Trist and Bamforth's (1951) analysis of the interaction between humans and machines in the coal mine, the material, coal, was overlooked. In the case of socio-technical studies of infrastructure, Wallsten (2015) has demonstrated that these studies, while claiming their explicit interest in material objects, have typically missed the materiality of the pipes and cables in terms of, for example, aluminum, copper and steel. Instead the focus has been on the materiality of flows inside of the systems' built structures. The consequences of neglecting a solid material perspective in socio-technical studies is one of several reasons why such studies tend to overlook environmental issues such as resource efficiency. So to avoid missing the material in the landfills, this dissertation will primary adopt a *socio-material* perspective, where the focus is the relationship between the social processes and the materials. However, the social processes affecting the materials in the landfills and the possibility to recycle them, rather than vice versa, will be in focus.

The sociologist Zuzan Gille (2010) has brought a socio-material perspective to waste studies, and demonstrated how social, technical, and material processes have changed the perception of waste in Hungary over time, and enlisted policies, cultures, economics, and technologies into various "waste regimes": the *metallic regime*, the *efficiency regime* and the *chemical regime*. Gille is mainly interested in different social institutions, following Young's (1982) understanding of resource regimes, such as the structure of rights, rules, and policies to regulate and govern the production and distribution of waste:

"Waste regimes consist of social institutions and conventions that not only determine what wastes are considered valuable but also regulates their production and distribution" (Gille, 2013: 29).

Gille describes how the perceptions of waste came to influence and be influenced by the formulation of policy in Hungary after World War II. As a result of the large amount of resources needed and difficulties in transporting resources in wartime, the waste policies in postwar Hungary were at first based on a view of all waste as metal resources, i.e., indefinitely recyclable. The Hungarian state thus invested in infrastructure for recycling and placed a ban on landfilling, "pushing enterprises to find useful purposes for their waste" (Gille, 2010; 1057).

In the mid-1970s the approach to waste changed and was regarded as a cost of production, an internal matter for each industry. Waste should be reduced through various waste policies such as credits, subsidies, and price manipulation. In the 1980s, scientists and engineers often linked to the chemical industry became influential in the Hungarian waste policy. Together with increased protests against waste management practices, waste was turned into a useless and harmful substance, which led to the encouragement of end-of-pipe solutions through policy. The valuing of waste has thus in many ways been connected to policies (see also O'Brien, 2008).

In this thesis, like Gille I pay attention to how policies are linked to a particular view of, in this case, disposed waste. However, there are fundamental differences between Gille's approach and this thesis. The focus of this thesis is policies with relevance for landfill mining operators. To explain why the policies for landfill mining look the way they do, Gille's (2010) approach is used where the formulation of the policies is connected to the perception of the material to be governed. However, Gille's starting point is different, as she has a broader approach analyzing Hungarian waste policy and institutions after World War II from a historical perspective where she finds a dynamic interrelatedness between the perception of waste and policies, which she categories according to different regimes. Here, the starting point is instead the related waste policies to landfill mining, their built-in perception of the material and how they relate to and influence a landfill mining operation from the perspective of operators.

3.3. The role of institutions

Institutions are studied in a number of different research fields such as philosophy, law, and economics. Therefore many different understandings of how this concept should be used exist. Nevertheless, most seem to agree that institutions are robust, stable, and define the space for maneuvering for actors (cf. Giddens, 1984; Hood & Jackson, 1991; Aoki, 2000). North (1990:3) has popularly defined institutions as the "rules of the game" that guide and coordinate the behavior of actors. Rules, according to North (1990:4), shall include all form of constraints affecting humans, both informal and formal. Informal institutions are socially shared rules, habits, and norms, usually unwritten, while formal institutions are shared regulations and laws formulated by the state.

It is likely that both informal and formal institutions affect the possibilities for mining landfills, for example people's perception of landfills and attitude to the mining activity. But for actors who intend to recycle deposited garbage, the formal institutions such as governmental policy and requirements are probably most relevant. The mapping of the regulatory framework is an important aspect of conventional prospecting. Policies together with market and legal factors are most important in the process of making indicated resources into proven resources (Payne, 1973). Hence, the Fraser Institute (2015) annually explores the policy climate for mining operations and ranks countries accordingly. Therefore, to understand how institutions affect landfill mining, the formal institutions will be particularly highlighted.

A focus on formal institutions means that governmental agencies, policies and how the government uses different economic, informational, and legal instruments to meet policy objectives will come into focus (cf. Linder & Peters, 1990; Howlett et al., 1995; Vedung, 1997; George & Prabhu, 2003; Wolff Schönherr, 2011). Institutions do not however only constrain actors' freedom, but can also open opportunities (North, 1990; Hodgson, 2006). Formal institutions and policies should in this thesis therefore be understood both as potential facilitators and obstacles.

Policies are normally formulated by the authorities with a normative purpose. Commonly policies are implemented to promote political priorities, for example, lower prices, equality, employment, growth or lower emissions (Lin, 1996; Schwartz & Clements, 1999). Favorable institutional conditions have been fundamental for the emergence of all kinds of industries (Wrigley, 1962). However, political interference can be considered particularly important for environmentally driven business. This is because environmentally driven business rarely has explicit market advantages, nor any advantages for the user in terms of lower price and higher performance (Geels, 2011). The company may suffer from lack of profitability and lower returns. Biogas for vehicle fuel brings, for example, both high development costs and lower energy content compared to gasoline, but leads at the same time to lower carbon emissions, and keeping the oil in its place, the underworld. Biogas can also contribute to increased resource efficiency by valorizing resources such as waste that otherwise would not be used. These multiple purposes seem to be a common feature of emerging alternatives, since landfill mining can also as mentioned before serve several purposes, for example, resource extraction and remediation. In contrast, the conventional ways of oil drilling and mining usually have only one purpose: to extract resources as efficiently as possible at lowest possible economic cost.

However, as the multiple benefits are collective rather than private there are often few reasons for private actors to invest in environmentally driven innovations, which Hirschman (1958) has called the "ego-group problem." Landfill mining fits well into the ego-group problem since the potential benefits of this approach in terms of, for example, increased recycling and reduced primary production mainly will materialize at the societal level for the common good or other actors while the cost of excavation, sorting, and treatment of waste are borne by individual actors (EPA, 1997; Krook et al., 2012).

To deal with the lack of engagement Hirschman (1958:24) suggests "inducement mechanisms" and "worthwhile engagement"[4] (1970:38), which in this thesis should be understood as the possibilities of public institutions to translate the collective good into individual benefits, for example, policies that internalize negative or positive externalities and change economic frame conditions (Elzen et al., 2011). Taking biofuels as an example, economic

[4] Hirschman's (1958, 1970) proposal to increase the actors' motivation for solving public problems is increased "public awareness" and "dissonant loyalty," where it becomes costly to disregard the problem or creating a sense of collective membership and care for the collective, respectively.

instruments have been "the major inducement mechanism" (Jacobsson & Bergek, 2004). The introduction of premiums, e.g. exemption from car tax, parking fees and tolls had a major impact on the sales of renewable cars. Simultaneously, policy goals such as "a fossil free society" (Swedish government, 2016), signals that regardless of what is profitable today, it could be wise to make long-term investments in renewable energy rather than fossil fuels.

However, studies of the consequences from policies have also demonstrated negative and sometimes adverse side effects such as impeding trade (Anderson & Martin, 2005), degrading the environment (Kleijn et al., 2001), reducing economic efficiency (Tullock, 1975), disrupting markets, and increasing poverty and inequality (WRI, 2007). Policies in terms of subsidies can also create market advantages that lead to dependencies and lock-ins (Unruh, 2000). Furthermore, the formulation of policy is typically a result of inclusion and exclusion mechanisms (Goffman, 1974), in which the perspective of some actors are highlighted, while other perspectives are denied space, which leads to a specific conclusion. For example, biofuels are often only framed as a vehicle fuel (cf. Wright & Reid, 2011), but might just as well be understood as an issue of energy supply or solving waste management issues.

Studies in political economy have demonstrated close relationships and mutual dependencies between policymakers and industry. Few countries would introduce policies that threaten the dominant industry, at least driven by environmental concerns. The industry is dependent on the state, since the authorities shapes the sector by establishing rules, legal and illegal corporate behavior, tariff protection, grants, government purchases, patents, taxes, and much more (Fligstein, 1996; Lindblom, 2001). On the other hand, at least in a market economy with demands for ever-increasing economic growth, the state depends on industry to create jobs, tax revenues, and value added (Newell & Paterson, 1998). In the energy field, this has been noted empirically, where the fossil fuel sector is the main target for political support (Fine & Rustomjee, 1996; Unruh, 2000; Urry, 2013).

The interdependence between government and industry can establish a certain *institutional culture* (Peterson & Spencer, 1990), i.e., arrangements of beliefs, norms, and practices in a system. In sum, this can lead to institutional *path dependencies*, *inertia* or even *lock-ins* in the prevailing modes (Arthur, 1990;

Unruh, 2000). In practice, the adaptation of regulations and market conditions according to the dominant industry in a region, could make it difficult for alternative innovations, based on other characteristics, to enter an already established market.

An important question of this thesis beyond policy is therefore which structures of governance influence the formulation of policy and how the institutional culture plays in. According to some researchers such as Meadowcroft (2009), the institutions are the main obstacle in transitions, embedded as "frozen residues" (Streeck & Thelen, 2005). This can be to such an extent that necessary policy changes can only happen with fundamental *structural change* (Hannan & Freeman, 1984) with completely new institutions, rather than changed institutions (Hannan & Freeman, 1977; McKelvey, 1982; Freeman & Hannan, 1983). This is a process of change that Schumpeter would have called *creative destruction* (cf. Kivimaa & Kern, 2016).

To investigate whether institutions can deal with major challenges and changes the term *institutional capacity* is sometimes used. The concept was initially used to highlight that technology transfer must be accompanied by capacity building to manage it in the long run (Willems & Baumert, 2003). The solution to environmental problems has sometimes been presented as an institutional challenge. Therefore, environmentally oriented research has increasingly studied the institutional capacity to manage, solve problems, and achieve goals in relation, for example, to climate change (O'Brien, 2006), renewable energy (Wolsink, 2000) or fishing (Blomquist & Ostrom, 1985) and how this capacity could increase (Ostrom, 1990). In this particular thesis *institutional capacity* should be understood as the ability of institutions to manage, solve problems, and achieve the goal of increased secondary resource extraction from landfills.

4.

METHODOLOGY

In this chapter an overview of my PhD studies is provided by describing my research journey. Then the selection of studied institutions and cases are described as well as the methods of data collection. The chapter concludes by presenting the analytical framework of the thesis and a discussion about the quality of my research.

This chapter presents and reflects on the process of preparing this thesis and my methodological choices. The five papers, included in this dissertation, have focused on a wide spectrum of themes and cases. In two of the papers several mineral stocks are studied, while in three papers a specific mineral stock (landfills) are studied in depth. These mineral stocks have been studied from a variety of approaches by comparing the mineral concentrations, how the extraction of these stocks are conceptualized and relate to policies, authorities and markets. To be able to write a synthesis, a common denominator for all the articles was identified. All the articles address the issue of increased recycling in general and landfill mining in particular, and they relate in different ways to the concept of formal institutions such as policies, regulation, and governmental structures.

Dimensions studied during my PhD period that do not fit under the umbrella of institutions are less emphasized. This means that my research covers more than what is presented in this thesis. Dimensions given less attention in this thesis but nevertheless studied during my Ph.D. period, for example, geological aspects such as mineral concentrations, amounts and heterogeneity, are discussed in detail in my licentiate thesis (Johansson, 2013). The written papers are based on a mix of quantitative and qualitative methods. The methodological approach of this thesis, however, is qualitative since the research questions strive to understand how formal institutions influence the possibilities to recycle disposed resources. In this chapter, first I present the research journey during my PhD period to understand how the limitations of my cover thesis have emerged, then the method used to address the research questions, and finally a discussion about the quality of my methodological choices.

4.1. The research process

My research at Linköping University in the Division for Environmental Technology and Management began in 2010. In the beginning, my research was funded by two different projects: "Urban mining: laying the foundation for a new line of business" and "Landfill mining: integrated remediation and resource recovery: Economic and environmental potentials" funded by the Swedish Innovation Agency (VINNOVA) and the Swedish Research Council FORMAS, respectively. Since my research initially was shared between two different projects focusing on two different mineral stocks, *hibernating urban stocks* and *landfills*, the first study had the intention to understand and navigate in the post-mining research, which envisages forgotten and hidden resources that have already been extracted once. This was done by identifying societal mineral stocks that could be of interest for resource extraction, its geological preconditions, and cases where resources have been extracted from these stocks, and for what reasons. Early on, it became clear that it was not only the potential of increased recycling that was unclear, but also the conceptualization of extracting these stocks. The wide use of terms such as urban mining in a context of traditional waste management makes it difficult to distinguish these concepts from already established concepts such as recycling, but also conventional mining. In an attempt to create order and position our research, a literature review of previous studies was conducted, with a focus on the emergence, conceptualization and extraction of mineral stocks in the built environment. This resulted in the first article: Paper I - "An Integrated Review of Concepts and Initiatives for Mining the Technosphere: Towards a New Taxonomy."

Paper I made an effort to lay the foundation for a new research field of mining aboveground, a humble target for the first scientific paper. One of the recommendations in this paper was that every stock in the technosphere should be studied separately, due to varied socio-geological conditions (Johansson, 2013) between the stocks. As a result, the subsequent research came to focus on one of these stocks: landfills as future mines. My involvement in the VINNOVA-funded project on urban mining ended after the first paper. Another conclusion from the literature review of Paper I was that the recovery of resources from waste deposits was not common practice. This aroused my interest in why landfills were not extracted. Consequently, I identified five Swedish cases where resources from municipal and industrial landfills have been extracted. These cases were investigated from a broad approach. The analyses included material conditions, driving forces, technology, markets, culture, local reactions, and legal aspects, and was based on interviews with the manager of each case and analysis of relevant documents such as project reports, official decisions, and consultant reports. Paper II - "Transforming Dumps into Gold Mines. Experiences from Swedish Case Studies" presents this case-based analysis.

The analyzed cases descended from different time periods, and were situated in different contexts. Through interviews and document analysis, it became clear that our perception of landfills, not least manifested in the institutional conditions, were obstacles to landfill mining. In sharp contrast, exemptions and other advantageous conditions targeting traditional mining and primary metal production were found. For this reason, the idea emerged to compare conditions for primary metal production and secondary metal production. In addition, the way the state organized the support to the primary mining sector was assumed to potentially inform how the support to the secondary mining sector could be formulated.

Institutional conditions were primarily considered in the form of subsidies, i.e., direct or indirect economic support to a specific sector, since this type of support is well studied with a developed methodology and could serve as an indicator for political priorities. This limited focus made the broad concept graspable and comparison possible. Subsidies for each sector were identified through interviewing representatives from the associations of secondary and primary metal production, i.e., *Återvinningsindustrierna* ["The Recycling Industries"] and *Swemin*, as well as governmental agencies such as *Statistics Sweden* (SCB) and the *Swedish IRS* (Skatteverket). The interviews were supplemented with analysis of official documents presenting the levels of subsidies. Paper III - "Subsidies to Swedish Metal Production: A Comparison of the Institutional Conditions for Metal Recycling and Metal Mining" - thus contrasted subsidies to secondary and primary production of metals.

These three papers formed the basis of my licentiate thesis: *Why don't we mine the landfills?* (Johansson, 2013). The licentiate thesis aimed to identify socio-geological barriers to landfill mining in the form of material aspects such as concentrations as well as social aspects such as institutional barriers. The conclusions of this licentiate thesis, however, were on a theoretical level, where the institutional conditions for landfill mining proved unfavorable. This was because they were based on landfills as hazardous pollution sources, while the mineral policy primarily focused on facilitating conventional mining. Practical knowledge was lacking, for example about how these institutional conditions influenced real mining operations and if there is any market for deposited material. Inspired by this lack of practical knowledge a new research project was set up, funded by VINNOVA: "Landfills as Mines 2.0 - development of concepts, strategies and measures for increased profitability and environmental performance." This research was carried out in close cooperation with three landfill owners, who intended to extract parts of their landfills.

The close cooperation with waste management companies made it possible to follow a landfill mining project in real time and observe real operations. One of the pilot tests was planned just after my licentiate thesis. It was thus possible to be present at the planning and implementation of the excavation and processing of waste from a shredder landfill. To investigate the marketability, the excavated, previously deposited garbage was analyzed by manual picking in different material fractions and by chemical lab analysis. The results were then compared with the input criteria of different waste treatment methods such as landfilling, construction materials, incineration, and recycling. Input criteria for the various waste management methods were collected through interviews with waste receivers and analyses of governmental documents. By comparing the lab results of the exhumed waste with the reception requirements, the marketability of deposited waste was assessed, in a fourth study, Paper IV - "A new dawn for buried garbage? An Investigation of the Marketability of Previously Disposed Shredder Waste." This article demonstrated how the regulatory framework close to the market in the form of limits and prohibitions could prevent landfill mining operations.

Overall, the studies conducted during my PhD period indicate that institutional conditions seem to be a decisive factor for landfill mining to be realized. This notion is also reflected in the Swedish governmental commissions on landfill mining (EPA, 2013b; EPA, 2015b; SGU, 2014). For example, one of the reports states that "the potential of secondary resources will not materialize by itself [...] therefore, new or changed instruments are needed" (SGU, 2014:4). Furthermore, the reports of the governmental commission open up an opportunity to study how the state understands landfill mining and if it is willing to change and adapt the institutional conditions for the emergence of landfill mining. The commission reports from different agencies also open up an opportunity to see how attitudes have changed over a relatively short time and how they differ between authorities.

By analyzing these reports to see how they frame landfill mining, the capacity of the authorities to deal with issues related to landfill mining was assessed. This study resulted in the last article of this thesis, Paper V: "Is There Institutional Capacity for a Resource Transition? A Critical Review of the Swedish Governmental Commissions on Landfill Mining."

Table 2. An overview of the appended papers and how they relate to the research questions of this thesis. For each paper, the analytical approach, relevant methods for data collection, type of landfills and institutional conditions are also specified.

Paper	Research questions	Methods	Analysis	Relation to institutions	Landfill types
1. Mining the technosphere	3	Literature	Conceptual analysis	The role of support, terminology and learning	All stocks
2. Transforming dumps into gold mines	1,2	Interviews Documents	Multilevel analysis	Institutional lock-in, regimes and learning processes	Industrial and municipal landfills
3. A comparison of subsidies	1,2,3	Interviews Documents	Subsidy analysis	Political support	All stocks
4. Marketability of disposed waste	1,3	Interviews Documents Lab	Market analysis	The regulatory framework and market conditions	A Industrial landfill
5. Institutional capacity for a resource transition	1,2,3	Documents	Frame analysis	Agencies position and capacity	Municipal and industrial landfills

4.2. Selection of study objects

The study of institutional conditions for landfill mining in this dissertation is based on the study of a particular set of landfill mining cases and a certain type of institutional conditions, derived from the appended papers, Table 2. The choice of landfill mining cases and institutional conditions in focus is presented below.

Cases

To identify and understand the institutional conditions for landfill mining, the research has partly been based on empirical data collection from landfill mining cases where deposited material has been extracted. The advantage of studying real cases is that policies are not just studied as passive documents, but in terms of their implementation and consequences (cf. Ritchie & Spencer, 2002). The study of actual cases can be used to identify barriers to landfill mining in the existing regulatory framework and thus point towards changes for landfill mining to be realized. The case of landfill mining was generally not contemplated when the policy was formulated. This means that unintended consequences of the policies are found.

Two types of landfill mining cases have been studied: finalized historical cases and ongoing excavations. In Paper II, five previous cases of Swedish landfill mining were identified through contact with authorities, experts, and researchers. Cases were searched until the same cases kept recurring. The cases were analyzed influenced by a "multiple case study" (Stake,

2013) approach. These five Swedish landfill mining cases were undertaken from 1988-2010 and included different drivers, owners, ambitions, choice of technology, and legal framework. As many cases were studied in parallel, different approaches to landfill mining could be compared and thus evaluated. In Paper IV, an ongoing small-scale landfill mining operation was studied in action, in which the regulatory framework could be studied in detail and how it affected the operators' possibility to recycle material. This case was chosen since it was one of the few operations conducted during this time period. At the same time, the company had a close relationship with our division, in the form of ongoing and previous projects, which opened up opportunities to closely follow the project. Hence, this case was studied in detail.

Formal Institutions

Since the emphasis of policy was not in focus from the outset of my PhD studies, Paper I has a weak focus on formal institutions, while Paper V has a clear focus. Formal institutions have been a way to synthesize the outcome of my papers in this dissertation. Since institutions and policies were not an initial focus, a structured plan for how institutions should be studied was lacking from the outset. My selection of formal institutions to study evolved gradually as described below.

Due to my division and the research projects' close relation to recycling operators, the identification of institutions has generally been based on the practitioners' perspective and the policy problems they have encountered. As landfill mining is not a common practice and therefore is not institutionalized, many interested recycling actors experienced an uncertain regulatory situation as to what laws were applicable. For example, the applicability of the landfill tax to landfill mining operations has been uncertain. This regulatory uncertainty was the reason why the analysis of landfill mining cases in Paper II was largely focused on policies. In the analysis of the cases, different regulatory frameworks came into focus depending on the definition of the activity as a recycling or a remediation activity. The differences between regulatory frameworks were further studied in Paper III between conventional recycling and conventional mining activities, where two different types of metal production were contrasted. State intervention to secure the accessibility to the material was the main regulatory feature that united these activities.

The access to the material was therefore also assumed to be of importance for the realization of resource recovery from landfills.

My identification of relevant institutional conditions has not only been based on the problems formulated by the practitioners. Problems found in the review of landfill mining literature have also been used as an inspiration for identifying relevant institutions. The review indicated that landfill mining studies have been oriented towards demonstrating the potential of landfills as mines. The latter part of a landfill mining operation, i.e., the materials' fate, the outflow from the excavation, official requirements, possible outlets, and market acceptance of the excavated material has received less attention in the literature. For this reason, the marketability of deposited waste and associated institutional conditions in the form of requirements for the use of waste as a resource was analyzed in Paper IV. This focus on institutions, i.e., how institutions influence the marketability, was also of interest for the practitioners, since the marketability of the material will be vital for a landfill mining operation.

Since the institutional conditions for landfill mining were largely uncertain, for example if the landfill tax was applicable or not, the final study, Paper V, approached the authorities and their understanding of landfill mining. This study showed that two different authorities, EPA and Swedish Geological Survey (SGU), were involved in evaluating landfill mining and framed landfill mining either as a remediation or a mining activity. In sum, policies with relevance to landfill mining were identified through close cooperation with practitioners and literature review of previous research. This approach led to a focus on different regulatory frameworks with relevance for landfill mining emphasizing the marketability and accessibility of the disposed waste for practitioners.

4.3. The analytical framework of the thesis

To answer the research questions of this PhD thesis, theories and results have been extracted from the five appended papers, Table 2. The first research question aimed at identifying the institutional conditions for landfill mining and its consequences. The answers to this question are mainly based on the finding from Paper IV and how policies affect the marketability of waste and its implications for practitioners. To understand the current institutional conditions for landfill mining, discoveries from Paper III were also used and the need of state intervention for the actors to access the material. This was put in a landfill mining context by analyzing the accessibility to the material in the cases from Paper II, and how this situation influenced learning processes in the field. The first research question also seeks to identify alternative frameworks for landfill mining, based on different *framings* (Goffman, 1974) of a landfill mining operation. The alternative framings of landfill mining activities have been proposed by the authorities in Paper V as well as in landfill mining literature. Inspiration for the description of the regulatory framework for recycling were mainly taken from Paper IV, the regulatory framework for mining from Paper III and the regulatory framework for remediation from Paper II.

The second research question sought an understanding as to why the institutional conditions for landfill mining look like they do, which depends on the framing of the activity. To understand the differences in the regulatory frameworks, Gille's (2010) approach was used where the formulation of policies is related to the perception of the material. The reason for the many regulatory obstacles of landfill mining can be found in a specific perception of disposed material in Paper II, while the other regulatory frameworks derive from a different view of the material (Paper III).

Furthermore I will also show how the relationship between policies and the ontological perception of waste *locks* (Arthur, 1990; Unruh, 2000) actor's actions into specific trajectories, Papers II and III. This will be done by looking closely at the details in the regulations (e.g. SCS, 1999) with relevance for landfill mining and paying attention to the governmental attitude to the regulatory framing of landfill mining as a remediation or a mining activity (Paper V). But to understand why the institutional conditions look as they do, it will also be necessary to understand the authorities behind the formulation of policy as emphasized in Paper V. This will be analyzed by linking the institutional conditions to specific government agencies and paying attention to its institutional structure and *culture* (Peterson & Spencer, 1990).

Finally, the lessons learned by identifying the institutional conditions for landfill mining and its underlying causes will be used to formulate institutional challenges for landfill mining, according to the third research question. This research question differs from the first and second since it represents a synthesis of what has been emphasized in the previous research questions, rather than extracted directly from my papers. These institutional challenges will also be used as a basis for proposing how the *institutional capacity* (Willems & Baumert, 2003) to manage the challenges of landfill mining may increase (cf. Hirschman, 1958). Discussion on how the institutional capacity can increase were taken from the suggestion of a new mode for assessing landfill mining operations in Paper IV and the remark in Paper V of a new institutional order including a governmental reorganization. The recommendations will partly also be inspired by how similar challenges have been addressed earlier in related areas (Jacobsson & Bergek, 2004; Meadowcroft, 2009; Kivimaa & Kern, 2016). Paper I comes foremost into play in the reflection chapter where I propose a new approach in the discussion about alternative modes of resource production.

4.4. Overview of methods

The papers forming the basis of this cover thesis applied a variety of methods, Table 2. Methods such as time-consuming manual picking of the excavated material, macro-economic studies of political support, and frame analysis of the authorities' perspective on landfill mining were conducted. This means that both quantitative methods, estimating mineral concentrations in waste or subsidy levels for mineral sectors, as well as qualitative methods to investigate underlying reasons or motivations for policies have been implemented during the PhD period. Hence, the PhD period not only entails several different studies to gradually approach and understand how institutional conditions relate to landfills as mines but also an interdisciplinary approach. The interdisciplinary approach of the papers means that they rely on both qualitative and quantitative methods, and that they reflect on multiple realities. Paper IV, for example, is based on the material that is found in landfills, while Paper V seeks to visualize how governments make sense of landfill mining. These are approaches to landfills that do not always coincide. For further detail on the methods of each study, see the papers (Johansson et al., 2012, 2013, 2014, 2016, manuscript) and licentiate thesis (Johansson, 2013).

The qualitative methods in the papers will mainly be used to provide answers to the research questions of this dissertation. A qualitative approach, according to Denzin and Lincoln (2005), is suitable in studies where a phenomenon shall be interpreted and made sense of. A quantitative approach could possibly have been used to evaluate if instruments have realized the intended objectives, if quantitatively formulated (cf. Berg, 2009), or evaluate the policies with the greatest economic impact on a landfill mining case (cf. Frändegård et al., 2015). However, a quantitative approach would not be useful to map and understand policies for landfill mining. Qualitative methods may, as Padgett (2004) puts it, "go where quantitative methods cannot". Below the methods of the papers with relevance to the research question of this dissertation are presented.

Document studies

A fundamental part of studying policies for landfill mining is obviously the actual policy documents in the form of laws, regulations, and commissions. The advantage of studying documents rather than conducting interviews in the mapping of policies is that documents have undergone careful review before publication. Also in the mapping of historical events, including projects performed over 30 years ago, documents are usually written close to the event and are thereby more reliable for details. Another advantage of document studies is that this type of source is not influenced by the researcher's presence in the same way as in an interview situation (Merriam, 1994).

Texts as a source of information have consistently been used in all studies. The study of Paper I examined scientific literature in the field. In Paper II the focus was on technical reports as well as policy documents relevant to remediation and resource recovery of landfills. In Paper III, policies and in particular deviations from policies, laws, and regulations in the form of subsidies were mapped for the recycling sector and the traditional mining sector. In the two subsequent studies, Papers IV and V, policy documents relevant for landfill mining were in focus. In Paper IV, the regulatory framework close to the market in the form of rules and requirements for waste to be recovered was studied. Governmental commission reports on landfill mining were the focus of Paper V.

Interviews

The study of document brings several limitations. For example, documents are normally written based on a specific purpose and context (May, 2001) in the form of, for example, a technical report of pros and cons in a pilot study. Interviews can be used to examine issues that go beyond the contents of the documents (Rowley, 2012). It may also be difficult to know which policy documents are relevant, in particular when a phenomenon such as landfill mining has neither a clear regulatory adaptation nor origin. For this reason, several of the studies have been supplemented with interviews.

In Paper II, with the multiple cases of landfill mining, interviews were conducted with the manager of each project to reach a deeper understanding of the case than what was presented in the technical reports. For example, the technical reports did not contain information about the permission statutes and under which regulatory framework permission was applied for. In the study on subsidy levels, Paper III, the different types of subsidies were identified through contact with various governmental authorities in charge of the recycling sector, the Environmental Protection Agency (Naturvårdsverket) and the mining sector, the Geological Survey of Sweden (SGU) as well as the agencies responsible for collecting information on subsidies, Statistics Sweden and the Swedish IRS. Interviews were also used in Paper IV to identify laws and rules relevant for the recovery of waste. The interviews in the above cases were semi-structured, based on an interview guide with specific themes relevant for the study.

4.5. The quality of the research

As an alternative to judge the soundness of research conducted during my PhD studies from the traditional scientific point of view of validity, generalizability, reliability, and objectivity, below I use four similar criteria, better adapted to qualitative research; *credibility*, *transferability, dependability*, and *confirmability,* which have been proposed by Guba and Lincoln (1989).

Credibility

One important criterion for sound research has traditionally been that the study should test what is intended, i.e., internal validity, or as Merriam (1998) puts it: "How congruent are the findings with reality?" The "reality" is, however, a tricky starting point for qualitative research, because this type of research is often interested in capturing different perspectives on reality, rather than to capture and describe the true nature of reality. One way to get around this, however, is to ensure that the result is credible from the perspective of the only one with legitimacy to make such a judgement: the participants in the research. For this reason, all respondents in the interview studies for Papers II, III and IV have been given the opportunity to refuse to participate and withdraw. In all cases, the questions were sent to the respondents in advance. This was especially important in the Paper II study where certain events of interest took place 20 years ago and therefore the respondents needed particular time for preparing answers. In many cases, transcripts were also returned for review and confirmation. The manuscript of Paper IV, focused on a factual landfill mining case, was sent to the involved operators to see if my interpretation of the policy situation was consistent with how they experienced it.

Shenton (2004) mentions that using methods that have been successfully used in previous studies may increase the credibility of research (see also Yin, 2004). The methods used in the five appended papers are all recognized. For example, the assessment of subsidy levels to examine the institutional conditions (Paper III) is a method commonly used for visualizing political support (see: Bruce, 1990; Steenblik, 2002; IEA et al., 2010; Davidson, 2012). The authorities' attitude to landfill mining (Paper V) were analyzed by frame analysis, which is an established method in policy research (see Creed et al., 2002; Verloo, 2007; Fletcher, 2009).

Triangulation, which means that different methods, sources, and theories complement one another, is a common strategy to enhance the credibility of qualitative research (Denzin, 1978). Brewer and Hunter (1989) argue that the diversity and use of several methods can compensate for individual shortcomings. Overall, a thesis can in itself be seen as a form of triangulation of several methods, theories, and sources to illuminate precisely the same question: to assess the institutional conditions of landfill mining. In each paper there are traces of triangulation. Papers II, III and IV use different sources for information, collected through interviews and document studies. Another form of triangulation is to involve further informants. In Paper II, the same phenomenon was studied in several different cases, by a "multiple case study" (Stake, 2013), which enhances the trustworthiness of the result compared to a single case study. In Paper III, many different authorities and business associations were asked the same principal question: how are recycling and mining subsidized?

Transferability

Transferability, or the equivalent term used in positivistic research, generalizability or external validity, focuses according to Merriam (1998) on "the extent to which the findings of one study can be applied to other situations." Given that institutions and their conditions differ between countries and change over time, this is a very relevant question for this study. Generalizability, however, is a phenomenon that many researchers reject, even in science (cf. Erlandson et al., 1993), while others argue that although each case is unique, it is an example within a broader group (Stake, 1994; Denscombe, 1998).

The institutional conditions studied in this thesis are explicitly Swedish, but at the same time waste laws are largely based on European directives, which makes many of the elements brought into attention in this study relevant in a broader context. As a result of the difficulty in generalizing qualitative studies, many scholars (e.g. Bassey, 1981; Firestone, 1993) argue that the author (the sender) must explicitly describe the context and limits of the study to allow the reader to decide whether it is possible to make a transfer of the findings to other situations. Consequently, this thesis focuses on institutional conditions for landfill mining in Sweden, while each paper describes contextual details of the number of participants involved, methods for data collection and the time period for data collection, and geographical limits.

Dependability

For a study to be credible from a positivistic perspective, it should be replicable; by using the same methods, another study should achieve the same result. But since many central research subjects such as institutions are under change (cf. Fidel, 1993; Marshall & Rossman, 1999), it is uncertain if another study would end up with the same result even if it used the same approach as this thesis. One way to handle this is the use of multiple sources/methods, i.e., triangulation, which can validate the same result through different studies (Lincoln & Guba, 1985). At the same time the research method should be described in detail, not primarily to open up the possibility of a similar study, but rather to enable the reader to assess the quality of the approach. Hence, all documents used as research material, such as the various commissions critically analyzed in Paper V, have been carefully referenced and can thus be studied for those who wish. However, given the specific institutional context of this study, documents in the form of reports, regulations, guidelines, and laws are written in Swedish and therefore difficult to study without a good command of this language. Respondents have in most cases not been mentioned by name, as requested, which of course makes it difficult to conduct the same interview again. However, the positions of the respondents are clearly stated in each study, to enable the reader to judge the quality.

One of the studies in this thesis, Paper I, may prove difficult to repeat based on lack of information given in the published article. In Paper I, the literature review of studies on the topic of post-mining was based on snowball sampling. By using articles important to the field such as Krook et al. (2012), UNEP (2010), Kapur & Graedel (2006) and Gordon et al. (2006), additional articles and literature were searched in the references. The disadvantage of such an unstructured review, based on non-probability sampling, is that replication becomes difficult. However, all articles included in the review may be found in the reference section of Paper I. Hence, the validity of the empirical data is easy to examine, although the shortfall (excluded literature) remains hidden. A further disadvantage of using older articles as a starting point for rolling the snowball is that newer articles may be difficult to find. One way to get around this was to include articles referencing the key articles.

Confirmability

Objectivity is considered important in research in that the subject under investigation, often in laboratories where this approach emerged, should not be affected by the executor. Real objectivity, however, as Patton (1990) observes, is difficult to achieve because researchers always inevitably affect the choice of, for example, the research design. Confirmability is a concept that is more suited to qualitative research and refers to the degree to which the results could be confirmed by others. It is therefore important that the results are clearly based on empirical data and the experience of informants, rather than based on the preferences of the researcher. In the papers I have tried to explicitly foreground the empirical data by carefully citing and translating those parts of the analyzed governmental publications that are used as a basis for conclusions. This gives the reader an opportunity to assess my interpretation. However, it should be noted that the reader is only provided with brief extracts from the original source material, which means that parts may have been taken from a specific context.

Miles and Huberman (1994) also emphasize that researchers should highlight their own position and attitude when relevant. Overall, my view on landfill mining is presented in the background Chapter 2 in terms of the resource potential of landfills and economic and ecological consequences of recovery operations. Additionally, in Paper V on the authorities' position towards landfill mining I have participated in the reports that form the basis of the analysis, which means I may have partly influenced the authorities' attitude which I later study. However, my involvement concerns only the writing of requested background reports, which represented only a small part of the authorities' areas of interest. For example, in connection with the latest governmental commission on landfill mining (EPA, 2015b), I wrote a background report of available instruments in other countries for landfill mining. This information was not used or referred to in the EPA's (2015b) formulation of the report of the government commission.

Finally, the underlying perspective of this thesis should briefly be discussed. The perspective of this thesis on how institutions relate to landfill mining is based on the problems encountered by the operators with the desire to recycle disposed waste. In the formulation of institutional changes the operator is just one of many actors that should be taken into account, and other interest groups that may be affected by landfill mining operations should be recognized. During my PhD studies, local authorities have been approached, but they were reluctant to participate before an application for a large-scale operation was submitted, from which they could pass a judgment. The study of the opinions of local residents about landfills has been started in the form of a master's thesis, but is still in the writing process. An institutional study of landfill mining based on the perspectives of local residents or authorities instead of the operators would likely lead to other identified challenges and conclusions.

5.

SUMMARY OF PAPERS

This chapter presents the appended papers included in the dissertation: its aim, main result, and the contributions of each paper.

5.1. PAPER I – An Integrated Review of Concepts for Mining the Technosphere: Towards a New Taxonomy

The aim of this article was to review the emerging research field of mining the human built environment, the technosphere. Through a literature review of metal stocks in the technosphere, the article began by examining and contrasting the size, concentration, localization, and dispersal of these stocks. Various concepts as well as initiatives to excavate and extract metals from these stocks were then described and analyzed.

The literature review showed that six different stocks of minerals could be identified in the technosphere: in-use, dissipated, in hibernation, and in landfills, tailings, and slag heaps. Besides extracting in-use metals as they successively turn into waste, mining initiatives in the technosphere were generally scattered. When it did happen, in the form of landfill mining or reprocessing of tailings, it seemed to be driven by two interrelated forces. The extraction of metal resources was driven by economic profitability, as in traditional mining, or as part of an innovative remediation project to reduce the costs of remediation and need for re-deposition.

There were a variety of concepts used to frame this research in the form of, for example, *urban mining, landfill mining, mining above the ground* and *secondary mining*. The prevailing concepts, however, were inadequate guides to the complexity of the technosphere, as these concepts were inconsistently defined and disorganized. For example, urban mining has been used to conceptualize mining activities from the whole technosphere, including stocks located in rural areas. These concepts have also been applied to traditional recycling as well as incineration of non-mineral materials. The wide application of the concepts made it difficult to separate this research from traditional challenges of improved waste collection and conventional recycling. To capture the specific challenges of extracting minerals from stocks such as landfills in contrast to recycling of waste flows, a new conceptual definition and taxonomy were proposed. This taxonomy separated the different stocks and its conditions for mining accordingly, thereby suggesting a new way of thinking and studying the technosphere as a mine.

5.2. PAPER II – Transforming Dumps into Gold Mines. Experiences from Swedish Case Studies

The paper analyzes why dumps do not become mines, and identifies challenges for how to trigger such a transformation. In a sense, we were approaching a classical alchemical experiment, to understand how valueless material can be transformed into valuable commodities. Data was collected from five different cases of landfill mining by interviewing actors responsible for the operations and analyzing documents such as project proposals and project evaluations. The empirical data was then analyzed inspired by a transition perspective including notions of lock-ins and regimes.

The main result of the paper was that all cases that were based on remediation, i.e., simply moving the waste to a more appropriate location, or final capping of landfills were successfully implemented. On the other hand, the cases which aimed to recycle, reuse, and recover the masses from the landfill were never completed, although such operations are difficult to separate from remediation operations. The theoretical contribution of this paper was the notion of the "dump regime"; landfills are stuck in being perceived as a dump, a material end station, a problem, useless, literally nothing, and if they have any value it is primarily negative. This regime is made up of a variety of dimensions such as technology, markets, knowledge, practices, learning processes, terminology, culture, laws, science, and policies that emerged and developed over time in tandem with the landfills being ideologically rooted as dumps.

5.3. PAPER III – Institutional Conditions for Swedish Metal Production: A Comparison of Subsidies to Metal Mining and Metal Recycling

The paper analyzes the institutional conditions of primary and secondary metal production in Sweden, by identifying, quantifying, and contrasting the governmental subsidies to the metal recycling sector and the metal mining sector. The purpose of the paper was to indicate and uncover the level of governmental commitment towards these sectors.

The result of the paper shows that the access to metals for both the metal mining and recycling sectors was ensured by state intervention through legislation. But the similarities stop when the government has secured the access to metals. After that, the metal mining sector was subsidized in many ways, for example through research grants, infrastructure investments, reductions and exemptions from landfill tax, carbon tax, and energy tax as well as services to prospectors. The metal recycling sector was only subsidized through research grants. In 2010, the metal mining sector was subsidized by € 40 million and the metal recycling sector € 0.6 million. If the exemption from landfill tax is considered a subsidy, the level of subsidization to the metal mining sector changes drastically to approximately € 4,000 million.

That non-renewable alternatives generally receive more support than renewable alternatives has been mapped out before. In this case, the metal sector was in focus and it is shown that in contrast to the energy transition, the support to the conventional dominant method was not only larger in total but also per tonne produced unit. Considering the formulation of Sweden's mineral strategy, this imbalance will increase since support for the metal mining sector takes multiple forms such as large investments in mining-related infrastructure, while there is no direct support to the recycling sector.

5.4. PAPER IV - A New Dawn for Buried Garbage? An Investigation of the Marketability of Previously Disposed Shredder Waste

The paper examines the marketability of disposed shredder waste; is the market ready to take back the material it once abandoned? A framework with gate requirements of various waste outlets was developed and contrasted with a pilot project focusing on excavated waste from a shredder landfill, sorted in an advanced recycling facility. The framework was constructed by first identifying different outlets for waste such as disposal, construction material, energy recovery, and material recycling. Next the gate requirement of the different waste management practices for accepting waste, i.e., the minimum quality of waste to be, for example, landfilled or recycled was identified. The quality of the waste was investigated by laboratory analysis and manual sorting.

After comparing the quality of the waste with the requirements of the receiver criterion, the result was that only the smallest fraction by percentage proved to have an outlet, the metals (8%), which were sold according to a lower quality class. The other fractions (92%) were not accepted for incineration, recycling, as construction materials or even for re-deposition. This means on a more general level that even if one fraction can be recovered, the outlet for the other material could be unpredictable. Landfill mining may thus result in a waste disposal problem, which easily prevents such a project altogether. This calls for marketability and usability of deposited waste to become a central issue for landfill mining research. The paper concludes by discussing how concerned actors can enhance the marketability, for example by pre-treating the disposed waste to acclimatize it to existing sorting methods. However, the marketability was largely determined by the regulatory framework through its restriction on disposal and use of waste as construction material. Hence, technical improvements must go hand in hand with institutional changes.

5.5. PAPER V - Is There Institutional Capacity for a Resource Transition? A Critical Review of Swedish Governmental Commissions on Landfill Mining

In this paper, we analyzed how the Swedish authorities understand the motives for landfill mining and their attitude for supporting this type of resource extraction. The authorities' attitude was investigated by analyzing three different governmental commissions by the Swedish EPA and the Swedish Geological Survey (SGU); *Review of the landfill tax* (EPA, 2013b); *Analysis of the recovery potential* (SGU, 2014); and *Recycling of waste facilities* (EPA, 2015b).

The result showed that the Swedish agencies seem to hold an ambivalent attitude to landfill mining. When landfill mining was framed as a remediation activity the authorities were positive and supportive, but when it was framed as a mining activity with a strong emphasis on resource extraction the authorities were negative. In essence, the authorities seemed to have difficulties embracing the multiple objectives of landfill mining, which can be an integrated activity of resource extraction, remediation, and land reclamation. The evaluation of landfill mining was based on how conventional practices work, often with only one prime purpose, e.g. either to extract resources or to remediate a polluted site. That traditional mining was a starting point in the evaluation became particularly obvious when the resource potential was to be evaluated. The resource potential of landfills was assessed based on metals with a high occurrence in the bedrock. If the potential instead had been based on metals with low incidence in the Swedish bedrock, the potential would be found in the human built environment. The potential of waste deposits would also have looked considerably bigger if it had been compared with traditional recycling and annual waste flows rather than the mining potential.

Secondary resources in landfills seem to lack an institutional affiliation, since the institutional arrangements that are responsible for landfills primary perceive them as a form of pollution, while the institutions responsible for resources, on the other hand, assume those resources to be found in the bedrock. Finally, we discussed how the institutional capacity for a resource transition can increase by the introduction of new evaluation tools and a new institutional order.

6.

THE INSTITUTIONAL CONDITIONS FOR LANDFILL MINING

In this chapter the empirical and theoretical findings and contributions from the dissertation and its papers are discussed in relation to the first research question. This chapter aims to identify policies relevant for the implementation and emergence of landfill mining.

One policy barrier to landfill mining that has received attention in the Swedish debate (see Schelin, 2013) and governmental commissions (EPA, 2013b; 2015b) is the landfill tax. The reason for the attention is that most landfills contain a high proportion of fines (30-70%) that can be difficult to find an outlet for other than re-deposition. If re-deposition of this material will be subject to the tax it can create considerable cost for landfill mining projects, up to 30-50% of the total costs (Frändegård et al., 2015). The tax may thus discourage actors to even consider landfill mining as an option for managing their deposits.

Supporters of landfill mining (e.g. Schelin, 2013) argue that the recovery operations will ultimately decrease the amount of deposited material according to the intention of the tax and should therefore be exempt from the tax. On the other hand, there is a risk that an exemption will remove the incentive for operators to process and maximize recovery of the waste (Paper III), which is the purpose of landfill mining (cf. Krook et al., 2012; Jones et al., 2013), and instead simply re-deposit it. Tax exemption can thus lead to a situation where only the most valuable resources in the form of metals are recovered, while the residues are re-deposited. Such an approach of cherry-picking the material in a landfill is probably lucrative for business. According to the latest statement from the Environmental Protection Agency (2015), the landfill tax should be paid for residues from landfill mining operations (Paper V). This is because landfill mining operations are equated by the EPA with traditional recycling operations where disposed residues are targeted with the landfill tax.

6.1. Policies influencing the marketability of disposed material

Extraction of a shredder landfill, highlighted in Paper IV, demonstrated difficulties in finding outlets for the exhumed, previously deposited waste. After the waste had been excavated it was sorted in an advanced recycling plant into five main types of material fractions: metals, fines, light waste, heavy waste, and shredder light fraction (SLF), Figure 2. Although advanced separation methods were applied, the metal fraction, which represented only 8% of the sorted masses, was the only fraction with a possible direct outlet. The metals were sold in a lower quality class comparable to metals in ash from waste incinerators. Consequently, the other fractions, i.e., 92% of the material, had no resort because the content was too heterogeneous and contaminated. The lack of marketability for each fraction is presented in Figure 2.

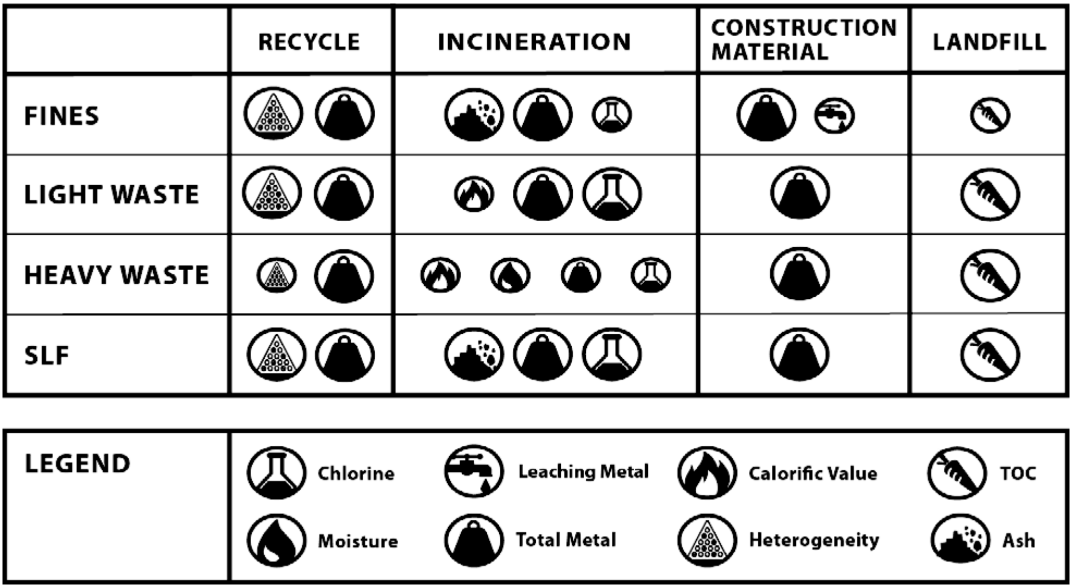

Figure 2. Overview of the separated fractions and the reasons for lacking marketability. The legend represents unacceptable levels of specified substances or compositions. A small symbol indicates a level close to the input criteria. SLF means Shredder Light Fraction. The figure is taken from Paper IV.

The high concentration of plastic and rubber in the landfill was naturally also reflected in the residue fractions (fines, light waste, heavy waste, and SLF), but they did not become homogeneous enough to be acceptable for plastic recycling or pyrolysis. The high concentrations of rubber and plastic meant nonetheless that the calorific value of the fractions was high. However, the calorific value proved too high to be interesting for the incineration plants, which are adapted to municipal solid waste with a lower calorific value. Overall, the biggest obstacle for finding an outlet for the waste fractions was its high levels of heavy metals. For example, the copper content was on average 14 times higher than the limits for incineration and 350 times higher than the suggested limits for the use of waste as construction material, Table 3.

Furthermore, due to the high share of rubber and plastic, the average concentration of organics in the sorted fractions was around 50%, Table 3. The high levels of organics and calorific value meant that the masses were prohibited to be re-deposited, because of landfill ban on waste containing more than 5-6% TOC or 10% combustibles (EPA, 2004). Hence, the exhumed waste was not even allowed to put back in the landfill.

Table 3. The input criteria for waste incineration, construction material and disposal as well as the average quality of residues from a shredder landfill (Paper IV) and a municipal landfill (Karlsson & Åslund, 2014).

Waste requirements/ Fractions	Calorific Value (MJ/kg)	Ash (%)	Moisture (%)	TOC (%)	Cl (%)	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)
Waste incineration[1]	8-16	20	25		1.5	12	700	500
Construction material						0.2	40	20
Disposal[2]				5				
Industrial residues[3]	21	36	21	46	2.5	35	13900	1800
Municipal Residues[4]	8	41	42	7	0.6	2.58	375	112

[1] Grate furnace
[2] Non-hazardous landfill
[3] Average values for four different residual fractions: fines, light, hard, and SLF waste *(*Paper IV)
[4] Average values for three different fractions sorted by size: 0-2 mm; 2-4 mm; and >4 mm (Karlsson & Åslund, 2014)

So although one fraction (commonly metals) is likely to find a market, it is highly uncertain if the lion's share of the waste can be used at all. Therefore, landfill mining projects could easily result in a waste disposal problem due to technical difficulties to meet the current regulatory and market requirements. The problem of finding an outlet for the excavated waste has also been noted in earlier studies. Pilot studies (e.g. Kornberg et al., 1993; Hogland, et al., 2004; Prechthai et al. 2008; Kaartinen et al., 2013; Karlsson & Åslund, 2014) targeting municipal landfills typically demonstrate lower concentrations of TOC, moisture, chlorine, ashes, and heavy metals than the shredder landfill analyzed in Paper IV. However, the municipal landfills normally hold waste with slightly too high levels to be re-disposed, used as construction material or considered for incineration, Table 3.

In practice, the current governmental and market requirements have steered the few operators that have tried to recover disposed waste in large-scale projects to mix the exhumed material with cleaner waste to make it marketable and meet the market requirements (Hull et al., 2005; Wagner & Raymond, 2015). Such a method, however, hardly affects the total amount of organic waste or heavy metals (Paper IV). Dilution implies that the source of the problem is not addressed. For example, dilution does not affect in absolute terms the amount of organic material that is re-deposited, or the amount of heavy metals sent to energy recovery. Hence, the total amount is not reduced, only adulterated to fall within the limits.

It is probably technically possible to valorize the residues through methods such as drying (Kaartinen et al., 2013) and sorting techniques optimized for fine-grained material (Allegrini et al., 2014) to acceptable quality and purity limits of the market (Paper IV). But such reprocessing of waste would bring costs for processing and gate fees. Technical reprocessing adds costs for testing, maintenance, energy, and labor. These added costs will hit an operation that is already economically uncertain, such as the landfill mining case analyzed in Paper IV (cf. Frändegård et al., 2015). Furthermore, the refined fractions are charged gate fees by the waste receivers. Waste is today costly to discard, and basically only metals generate an income. The gate fees alone for deposition cost around € 100-50 per tonne (Frändegård et al., 2015) and for incineration € 40-80 per tonne (ASWA, 2013).

The gate fees are determined by the waste receivers, but are highly influenced by policy. The high gate fees for landfilling are a direct consequence of the landfill tax of € 50. The landfill tax, the bans, and the high cost of landfilling have also created a situation where incinerators can charge significant gate fees (Krook et al., 2015), since waste owners in general do not have other outlets for waste. But even if the previously deposited waste were valorized to levels below the input requirements, the recipients' acceptance cannot be assured, and as long as the waste receivers have a secure supply of the conventional resources the activities are adapted accordingly (Paper IV). Considering that many European countries lack treatment capacity for their waste, many waste owners are willing to pay high gate fees. Hence, due to this lucrative situation, Swedish incinerators have no incentive to feed their overcapacity with deposited garbage with lower quality from a nearby landfill.

6.2. Policies influencing the accessibility of disposed material

Mineral stocks in the bedrock as well as in-use are made accessible through state intervention to the mining sector and the recycling sector, respectively (as visualized in Paper III). The mining sector does not need to buy land or ask for permission from the landowner to access the minerals. Instead a mining permit needs to be reviewed in court, which usually grants permission since mining activity is a stated national interest. Metals from the annual waste flow are made accessible as citizens by law are pushed to sort and bring scrap metal to assigned containers.

Indeed, the material in a landfill has no function (Paper I). But at the same time deposited material as well as the actual landfill are in the legal ownership of the operator or owner[5]. Consequently, the material in landfills is not directly available to external actors. The landfill mining cases studied in Papers II and IV shows similar to previous pilot studies (Spencer, 1990; Dickinson, 1995; Cossu et al., 1996; Cha et al., 1997) that all operations have been performed by the owners of the landfill or in close cooperation. Since it is the owner, commonly municipalities, which has implemented the projects, it means that landfill mining has been initiated by actors with a reverse core activity: to dump waste rather than extract waste. Therefore, the objectives of the projects have most often been to solve unique landfill problems in the form of leaching, lack of space, or bottom sealing (Paper II, Spencer, 1990; Dickinson, 1995; Cossu et al., 1996; Krook et al., 2012) rather than primarily to extract resources. The case in Paper IV is, however, a rare exemption since it was performed by a recycling operator with a focus on extracting resources.

The lack of accessibility to landfills has turned landfill mining activities into a once-in-a-lifetime experience. When the objective of the operation to address a landfill problem has been fulfilled, the actors involved have been satisfied. There has thus been no reason to commit to long-term investments, technological development, efficiency or knowledge-building in landfill mining. These are all aspects that in many ways have proven crucial for industrial development (cf. Wrigley, 1962). However, since metals in the Earth's crust as well as in the waste streams are made accessible by state intervention (Paper III) actors in the mining as well as the recycling sector are not restricted to isolated opportunities. This has been a prerequisite for specialized actors to emerge in these sectors with an interest to invest time and resources into specialization, technology development, and long-term

[5] For a detailed overview of ownership see EBH (2016).

learning processes on how to best plan and execute resource extraction from "their" specific metal stock.

6.3. Alternative regulatory framings of landfill mining

The regulatory categorization of landfill mining is not stable and certain, as landfill mining is not common practice and therefore not yet institutionalized. Given the multiple nature of landfill mining in which several objects can be met, landfill mining has been interpreted as a recycling operation (Paper IV; EPA, 2015; Jones et al., 2013; Masi et al., 2014), a remediation activity (cf. Paper II; EPA, 2013; Kurian et al., 2003; Hogland et al., 2004; Frändegård et al., 2013) or a mining activity (cf. Paper V; Van der Zee, 2004; EPA, 2015; Winterstetter et al., 2015). Such alternative regulatory framings could imply significant differences when it comes to the accessibility of deposited materials, marketability of the exhumed and processed materials, and the overall support of such an operation. Thus, the implementation of landfill mining.

The most common way to frame landfill mining is as a recycling activity, part of a circular economy. Landfill mining, like traditional recycling, is all about transforming waste into resources (Krook et al., 2012; Jones et al., 2013). If landfill mining is framed as a recycling activity as in the case analyzed in Paper IV, the abovementioned policies, taxes, bans, and ownership will most likely be applicable. The disposed waste has already been discarded once and is therefore in the ownership of the landfill operator or landowner with restricted accessibility for outsiders. However, when the waste is exhumed and processed, it seems to become "new" waste and thus applicable to the current market frameworks for waste. Considering the current regulatory and market requirements for waste, it will be difficult to find an outlet for disposed waste (Paper IV). The suggested limits for the use of waste as construction materials are low while waste cannot be re-deposited if the organic concentrations are above 5-6% (Paper IV). Moreover, even if the waste is reprocessed to meet the market requirements, gate fees such as the landfill tax have to be paid, Table 4. Recycling processes are not supported by the government (Paper III).

Table 4. A comparison of different regulatory frameworks for landfill mining based on the landfill tax, marketability, the accessibility to deposited materials and support schemes. (+) means a beneficial aspect and (-) means a negative aspect from an operational point of view.

	Recycling	Remediation	Mining
Landfill tax	- landfill tax	+ the landfill tax is deductible	+ the landfill tax is exempted
Marketability	- landfill bans - high requirements	+ less strict landfill bans - high requirements	+ low requirements
Accessibility	- no access by law	+ if identified as contaminated land	+ if containing valuable material
Political support	- no support	+ governmental grants	+ reduced taxes on energy and CO_2

In many contexts, landfill mining is interpreted as a remediation activity. After all, remediation and recycling of disposed waste share many similarities (Paper II). In both cases, waste is exhumed with related risks. Differences consist in how the excavated waste is handled, to be deposited or valorized. Hence, the EPA suggests that "waste from landfill mining shall in legislation be handled the same way as contaminated soil from after-treatment" [my translation] (EPA, 2013: 9). Framing landfill mining as a remediation operation brings a legal framework, adapted for the benefit of remediation, as noted in Paper II. For example, the landfill tax is deductible (SCS, 1999). The masses in need of deposition are also allowed higher levels of TOC (SCS, 2004), Table 4. In general, however, the masses from remediation projects are subject to the same market requirements as masses from a recycling operation, including, for example, high requirements for using it as construction material. If a landfill is classified as contaminated land, measures should be taken according to the Swedish EPA (2016c), which usually means that disposed masses are exhumed and re-deposited in a sanitary landfill. Hence, if landfills are identified as a significant risk for humans and the environment, disposed waste can become accessible for recycling. In cases when the owner of the landfill cannot be identified, governmental grants are available.

Another way to interpret landfill mining would be to define it as a conventional mining operation (e.g. EPA, 2015b; Paper V). After all, the activity of recovering disposed resources is conceptualized as "mining." The minerals are also extracted from a delimited place, taken from deposits in the underground similar to traditional mining, although it is humans rather than nature that has accumulated the resources. In this case too a legal framework exists, which in many ways is more favorable than for remediation. Whether the ban on landfilling organics applies to mining operations is unclear. However, using residues from mining production, i.e., ballast as construction material is not controlled by governmentally imposed limits. Instead, industries' own standards and the more general rules in the Environmental Code (SCS, 1998) govern the use of ballast as construction material.

Furthermore, for mining activities, the masses that are deposited are exempt from the landfill tax. The energy and carbon taxes are also reduced (Paper III). According to the Environmental Code (SCS, 1998), "Land and water areas that contain valuable substances or materials should as far as possible be protected against measures that could significantly complicate the extraction of these" [my translation] and is to be defined as a national interest. This means that the landowner's tenure may be excluded (Paper III). If landfills are understood as mines, there may thus be an openness for actors other than landfill owners to prospect and eventually extract resources from landfills. This could open up opportunities for specialized actors for landfill mining to emerge just like in traditional mining (Paper III).

7.

UNDERSTANDING THE INSTITUTIONAL CONDITIONS FOR LANDFILL MINING

In this chapter the empirical and theoretical findings and contributions from the dissertation and its papers are discussed in relation to the second research question. This chapters looks into why the different policies for landfill mining look like they do.

7.1. The perception of landfills as dumps

The regulatory regime surrounding waste management and especially landfills is, as noted in Paper II, based on a specific perception of landfills as a problem, as a source of contamination, a material end station for mass consumption, invaluable and useless. This perception is mirrored in the regulatory body surrounding landfills. In the Landfill Directive (EU Council, 1999) as well as the Swedish waste law (SCS, 2001), landfills are classified based on pollution levels: inert, hazardous or non-hazardous. Furthermore, landfill policies strongly advocate the closure and covering of landfills, to be controlled, isolated, and hidden from the outside world. The institutional arrangement in which these laws and regulations have been formulated should also be recognized. Since landfills as well as waste have traditionally been regarded as a problem, they have become an environmental issue under a specific regulatory structure consisting of the *Ministry of the Environment and Energy* and the *Environmental Protection Agency* (Paper V). These authorities evolved during a time when environmental issues focused on nature conservation and protection (Simmons, 1994).

At the same time, this perception of landfills as a source of pollution have not only been manifested by policymakers, but depend on several different circumstances (cf. Gille, 2010). For example, researchers have in their quest to understand landfills strongly contributed to consolidating the image of landfills as something negative (Paper II). The most frequently referenced articles on landfills investigate leachate (e.g. Baun & Chrsitensen, 2004). The negative perception of landfills is close to becoming a universally recognized scientific fact, a *paradigm* using Kuhn's (1962) terminology. The same can be said about the operating practices at a landfill where wheel loaders bring and hide the incoming waste in appropriate cells and then cover the waste with soil in order to reduce the risk of odor, fire, insects, and rodents. Landfills in their material selves have of course also influenced the perception of them as a problem, with frequent leaks and collapses, which over time has raised people's concerns and protests (cf. Bullard, 2000; Walker, 2016).

The perception of landfills as a source of pollution is thus an important ontological constitution of the entire socio-technical system that surrounds landfills, including for example actors, facts, policies, governmental structures, practices, attitudes, and knowledge, but also investments, networks, and technologies, establishing the *dump regime* (Paper II). At the same time, however, this means that a contrasting ontological perspective, promoted by landfill mining operations, in which landfills are a resource base instead of a pollution source, valuable rather than useless, a starting point rather than an end station, is a mismatch. Therefore such operations, where the waste is turned into resources in a recycling effort, will face obstacles, *lock-in* mechanisms (Unruh, 2000), not least in the form of various laws and regulations.

The obstacles that a recycling operation of landfills meet in terms of the landfill tax and bans are such examples. These policy tools were designed to reduce the rate of deposition and the problems of landfills, rather than to become an obstacle to recycling operations from landfills. Although ownership complicates resource extraction from landfills, it is reasonable from a pollution perspective since responsibility could be assigned to externalities such as leachate of hazardous substances from landfills. The strict limits on the use of waste, for example, as construction materials, Paper IV, which is relatively close to the natural background levels, can also be understood as a consequence of the perception of waste as a problem, a pollutant. The effort to reduce emissions and the spread of unwanted substances is a generally stated ambition to protect health and the environment, consequently the fulfillment of the Swedish policy goal of *non-toxic environment* (EPA, 2015c).

Remediation as a strategy for landfills fits relatively well into the dump regime as these operations are of an incremental nature and never question the perception of landfills as a problem (Paper II). In fact, all cases in Paper II that were framed as a remediation activity were successfully implemented, while the cases that to a larger extent emphasized resource recovery were never completed. The reasons were obviously multiple, as noted in Paper II. For example, the technical equipment was better suited for remediation activities than for resource extraction. In addition to technical and market differences, policy also played a role. When the material in the landfill is defined as a pollutant, there seems to be an institutional acceptance to pay as much as necessary to get rid of it (Paper V). Hence, many of the remediation cases in Paper II were financed entirely by the state or municipality and were in principle realized for the sake of the common good. The favorable institutional conditions of remediation, including tax and prohibition anomalies as well as potential grants can thus be understood from the potential benefit of remediation: to reduce the risks of landfills and the fulfillment of the goal of a non-toxic environment. On the other hand, when the managers in one of the resource recovery cases applied for grants from the EU LIFE program the application was denied (Paper II). This is since resource extraction was considered to be contrary to EU principles of how landfills should be managed: landfills should be enclosed and secured.

7.2. The other side of the mineral coin

The understanding of landfills as a problem is not wrong in itself, landfills can unquestionably pose a risk to humans and the environment (cf. Elliott et al., 2001). It involves nevertheless a specific way to understand landfills, which obscures other parts of the same phenomena (cf. Latour et al., 2012; Johansson & Metzger, 2016). The mineral stocks at the end of the material flow chart are manifested by for example policy makers, landfill owners, and researchers as a negativity, to be avoided. The mineral stock in the starting station of the material flow, on the other hand, is emphasized typically as something positive, desirable. For example, researchers, especially geologists and economists, have been successful in highlighting the national economic value of mines (Ejdemo & Söderholm, 2011) and the investment potential on the stock market for households (e.g. Affärsvärlden, 2012). But above all, this perception is mirrored in the Swedish regulatory body of mines (Paper III), which aims to promote the mining sector for the nation's best interest (Swedish Government, 2013). Landfills and mines have thus become each other's conceptual antithesis, although they both are mineral deposits with decent concentrations of potentially valuable materials (Paper I).

Hence, while landfills in Sweden are gradually capped, more and more mines are opened up partly because of favorable institutional arrangements (Paper III), which is one of the most beneficial in the world according to the Fraser Institute (2015). The favorable institutional conditions for mining activities in the form of tax subsidies, governmental investments, research grants, less strict market requirements, and other types of political support can be understood from the perspective that mining in its conventional form, to extract minerals from the Earth's crust, has been the backbone of the economy (Swedish Government, 2013). Hence, mines are legally a national interest (SCS, 1998). For this reason, the minerals in the bedrock are made accessible for the prospecting and mining sector through state intervention exempting the ownership (Paper III). This has created a business opportunity for specialized actors to emerge in the mining sector and ultimately made mining a dominant industrial activity in Sweden.

Since mines have been considered to be a matter of economic growth, the mining sector and primary resources have been handled as a business issue (Paper V). Hence, a regulatory structure of the Geological Survey of Sweden and the Mining Inspectorate, both operating under the Ministry of Enterprise and Innovation, are responsible for formulating and executing policies for mines. SGU also has a clear industrial policy mission: to support the mining sector (SCS, 2008).

7.3. Framing, policy and government's attitude

Landfill mining can be framed in different ways: as an operation for recycling, remediation, or mining. However, the way the regulatory frameworks are formulated and how the governmental agencies make sense of the different regulatory framings of landfill mining may cause problematic consequences for the realization of landfill mining. This is especially the case if landfill mining is framed as a remediation activity (EPA, 2013) or a mining activity (EPA, 2015).

Since it is the minerals in the Earth's crust that have been considered the backbone of the Swedish economy, the regulatory framework of mining activities steers towards recovering minerals from this specific mineral stock (Paper III). For example, energy subsidies for resource extraction apply only in "close proximity to extraction of solid rock" (IRS, 2008) [my translation]. Furthermore, the exemptions from the landfill tax concerns only "waste rock" and "tailing sand from industrial mining activities." (SCS, 1999) [my translation]. In other words, recovering minerals situated in other surroundings such as the human built environment, including landfills with other types of materials in the form of plastic and paper may not be applicable. Since these subsidies do not apply to the built environment[6], for an actor it is more institutionally advantageous to aim for minerals from the bedrock rather than from landfills, especially since there is a mineral information office to assist in prospecting the bedrock (Paper III). Furthermore, conventional recycling is more institutionally favorable than

[6] Besides from tailings, if they contain "tailing sand from industrial mining activities." (SCS, 1999).

landfill mining, since the minerals in use are made available through state intervention, which is not the case for the minerals in landfills.

It is uncertain whether landfills can be interpreted to contain valuable materials (cf. Winterstetter et al., 2015) and become classified as national interests, as the authorities are negative to the resource potential in landfills (Paper V). According to the EPA (2015b), the biggest iron mine in Sweden has much higher concentrations than an average municipal landfill. Annually 5-6 times more iron (25-30 million tonnes) is produced in the world biggest underground mine in Kiruna, northern Sweden than the estimated amount of iron in all Swedish municipal landfills (5 million tons). Since the resource potential in landfills is deemed negligible, the EPA argues that the recovery of minerals from landfills has an insignificant potential to substitute the extraction of virgin resources and thus also the emissions from such operations. This leads EPA (2015b) to the conclusion that landfills are not interesting as mines. Therefore, the EPA finds no reason to support the recovery of minerals from landfills, see Table 5, row 3, by, for example, exempt the landfill tax.

Table 5. An overview of three Swedish governmental reports on landfill mining. The table demonstrates the authorities' attitude toward supporting landfill mining based on how they frame the resource, environmental and economic potential of landfill mining. The table is from Paper V.

REPORT		RESOURCE	ENVIRONMENT	ECONOMY	SUPPORT
1	Review of the landfill tax	+ Great potential	+ Avoids CO2 + Remediation + After treatment	+ Reduces costs for remediation	Reasons for incentives
2	Analysis of the recovery potential	- Limited compared to mines	n.a.	n.a.	New instruments are necessary
3	Recycling from waste facilities	- Limited compared to mines	- Risk of leakage - Uncertain impact	- Costs higher than revenues	Not enough reasons for support

n.a.= not available

However, it should be mentioned that the authorities comes to their conclusions based on including certain aspects of landfill mining while other aspects are excluded (Goffman, 1974). For example, the comparison of the landfill and the mine is based on metals (such as iron) with a high presence and concentration in the Swedish bedrock (Paper V). If the comparison instead had been based on another metal, such as aluminum, the result of the comparison would reverse since Sweden has no bauxite-rich bedrock according to SGU (2014). In addition, the EPA could have framed landfill mining as a recycling activity and accordingly compare the resource potential of landfills with the potential of traditional recycling. Thereby the potential in landfills would appear significantly higher and thus contain valuable resources. On the other hand, if the authorities had framed landfill mining as a remediation activity, the potential would have been low. This is because landfills with high risks, the target for remediation measures, are not necessarily the same landfills with a large resource potential. It should also be mentioned that the EPA is inconsistent in their evaluation of landfill mining. For example, the EPA (2015) comes to the conclusion that landfill mining should be subject to the landfill tax, by paralleling the situation of landfill mining with traditional recycling, as mentioned in chapter 6.1, which is subject to the tax. If the EPA (2015) instead would have continued their comparison of landfill mining with conventional mining, an exemption would have been reasonable since conventional mining is as previously mentioned exempt from the tax.

The EPA (2013b), however, is more open to landfill mining when it is framed as a remediation activity (Paper V), which is more in line with the dump regime (Paper II). When landfill mining is compared to remediation, recycling of deposited material is considered to be environmentally and economic advantageous in front of re-deposition, Table 5, row 1. In this case, the EPA (2013b) primarily emphasizes the environmental benefits of recycling disposed waste. The risks and consequences of landfill mining do not get much attention, which however are accentuated when landfill mining is framed as a mining activity (EPA, 2015). Furthermore, when the EPA (2013) frames landfill mining as remediation activity, resource recovery is regarded as economically favorable. By recovering resources, revenues for a remediation operation could be generated, which in the normal case only involves costs. In a remediation context, landfill mining is thus enacted as environmentally and economically favorable, which was deemed negative in the mining context.

In sum, considering the way landfill mining is presented in the remediation frame, the EPA (2013b) concludes that landfill mining activities should be supported, for example, by interpreting the residues from a recovery operation the same way as in remediation activities. Exemption from the landfill tax for remediation, however, only concerns special types of waste in the form of "contaminated soil" and "dredging soil from remediation" (SCS, 1999) [my translation]. The clear definition of waste as soil in remediation operations makes it uncertain whether other types of waste, especially if it is processed, in the form of plastics, rubber, and paper found in landfills can be tax-exempt. In addition, the EPA has together with the regional county boards mapped each landfill from a pollution perspective, including information on hazardous materials and risks, rather than from a resource perspective with information on valuable resources. Overall, the formulation of the institutional conditions makes it favorable to manage problematic landfills through measures other than recycling, for example through final cover or possibly remediation.

8.

INSTITUTIONAL CHALLENGES FOR LANDFILL MINING

In this chapter the findings from the dissertation and its papers are discussed in relation to the third research question and the identification of Institutional challenges for landfill mining. Suggestion for how the institutional capacity to better address the challenges is also made.

Before identifying challenges, the lessons from the earlier chapters need to be summarized. Considering that landfill mining is not common practice, the concept has not yet been institutionalized. With its multiple purposes, landfill mining becomes difficult for the authorities to interpret according to the existing regulatory frameworks, which are adapted to conventional activities and the realization of one sole purpose at a time. The current regulatory framework also makes landfill mining unattractive. The institutional conditions to extract resources from other mineral stocks are more favorable. This is especially the case for conventional mining from the bedrock, but partly also conventional recycling of minerals in use that gradually become waste. Furthermore, it is more institutionally advantageous to deal with problematic landfills in ways other than recycling the waste, e.g. through capping or possibly remediation.

It needs to be said that the realization of landfill mining not only depends on unfavorable policies. For example, the deposited waste is often heterogeneous and could be contaminated. Thus, specialization, technological development, and learning processes will be necessary for the realization of landfill mining. But even if technical solutions are developed to process deposited waste and concentrate pollution, the metals will still be the only material that can generate any revenue, while all other waste types in most waste markets entail costs. Based on these findings, two fundamental institutional challenges for landfill mining to emerge into a feasible and conventional practice have been identified: conflicts between policy objectives and lack of institutional capacity.

8.1. Conflicts between policy objectives

One institutional challenge for landfill mining is the conflict between increased recycling (EPA, 2015c) and a non-toxic environment (EPA, 2015c). The production of secondary minerals is generally regarded as more environmentally friendly than primary production, for example, less energy is required (UNEP, 2013). Landfill mining in most cases seems to be no exception to this general rule (Frändegård et al., 2013; Laner et al., 2016). At the same time, however, the production outcome, the very resource, from recycling rarely holds as low levels of heavy metals as primary resources (Reck & Graedel, 2012), which in particular applies to old waste in landfills (Paper IV). Similarly, sludge with high phosphorus level from biogas or water treatment plants is rarely as pure as commercial fertilizer from phosphoric mines (McBride, 1995). Hence, increased recycling and a non-toxic environment might be hard to reach at the same time, which becomes particularly clear in the case of landfill mining.

The study of policies for secondary and primary resources has shown that the conditions differ depending on where the material is found: in the built environment as landfills or in the underground as mines. For example, there are no suggested levels for the use of primary resources such as gravel or ballast as a construction material apart from the industries' own standards and the more general rules in the Environmental Code (SCS, 1998). The suggested limits for using waste as construction material, on the other hand, are close to the naturally occurring background levels in soil (Paper IV). The stricter regulatory requirements on secondary resources compared with virgin material not only assigns a higher threshold to the market, but also brings additional costs from sampling and monitoring. In addition, just like fossil fuels (IEA, 2011), primary resources are subsidized (Paper III) as exemplified by the exemption of landfill tax for primary production, while secondary production is subject to the tax. In sum, although there are policy objectives for increased recycling as well as mining (European Commission, 2008; the Swedish Government, 2013), secondary resources are partly penalized with strict market requirements and targeted full taxes, while primary resources are supported through subsidies.

8.2. Lack of institutional affiliation and capacity

Secondary resources available in the built environment, especially landfills, seem to lack an institutional affiliation. Two different authorities have shown interest in landfill mining (Paper V), the EPA (2013b; 2015b) and the SGU (2014). However, on the basis of their institutional culture, the EPA emphasizes material in landfills as a traditional environmental issue in the form of pollution, risks, and uncertainties. SGU on the other hand, on the basis of their institutional culture, seems to have a business-oriented perspective on minerals, but mainly reserved for those found in the bedrock targeting the traditional mining sector. This means that the formal institution, the EPA, responsible for landfills typically governs these sites with the aim to retain everything in the landfill as far as possible to protect the environment. If problematic landfills need to be addressed, remediation is the preferred alternative: "The EPA believes that the important remediation work shall not be jeopardized by uncertain possibilities of recycling disposed resources" (Strauss & Farelius, 2016) [my translation]. The formal institution responsible for mineral extraction, the SGU, tends to overlook landfills as resource reservoirs in their focus on the bedrock (see for example SGU, 2015). If resources are needed, conventional mining is the preferred alternative: "the greatest potential of minerals are found in the Swedish bedrock" (SGU, 2014:4) [my translation].

This institutional separation of secondary and primary resources means that the authorities lack capacity to deal with resource recovery from unconventional stocks such as landfills. When landfill mining has been evaluated it was understood primarily as a remediation activity or a resource activity (Paper V) with environmental gains or risks, respectively. This suggests that the authorities fail to capture the complexity of landfill mining and manage the multiple purposes that are often found in emerging alternatives. Landfill mining could, for example, potentially lead to an integration of remediation, land reclamation, and resource extraction activities. It is only when all the objectives of landfill mining are evaluated in parallel that the full potential and consequences of this emerging concept can be understood. Similarly, biogas is commonly evaluated based on its resource potential as a vehicle fuel (cf. Mol, 2007; Reid & Wright, 2011), which compared to oil is limited. However, when including the additional purposes of biogas such as circulating waste and the closure of nutrient flows, the full potential and benefits of biogas can be evaluated and understood (Feiz, 2016).

8.3. Enhancing the institutional capacity for landfill mining

The governmental promotion of dominant sectors such as traditional mining is in many ways an expected outcome in a Keynesian market economy, with its interdependence between government and industry (Newell & Paterson, 1998). Policies may, however, in rare occasions do the opposite, acting as a "guerilla" (Monk & Abrahamsson, 2012), shifting the focus from the dominant sector towards promoting challenging alternatives, thereby clearing the way for establishing something new. For example, to promote renewable fuels in a world where policy has been adapted to fossil energy, some researchers (e.g. Meadowcroft, 2009) argue for "level playing fields" where old and new technologies can compete without all the lock-in mechanisms. For renewable energy and biofuels, the introduction of subsidies as well as policies destabilizing the fossil sector have been the major inducement mechanism (Jacobsson & Bergek, 2004; Kivimaa & Kern, 2016).

However, to reach level playing fields by transferring the subsidies of the conventional practices, in this case the mining sector (Paper III) directly to the recycling sector is probably not a good idea. For example, many of the subsidies to the mining sector are adapted to their energy intensiveness, demonstrated by the reductions in the energy and carbon tax highlighted in Paper III, while the recycling sector is generally considered to be labor-intensive (Ayres, 1997). This is probably also the case for landfill mining. The heterogeneous material will make it difficult to build a constant process, along with the need for workers to continually monitor pollution levels (Krook et al., 2015).

A better choice is probably instruments that, for example, put a price on the avoided emission of carbon dioxide and heavy metals. Such an instrument could perhaps be funded by a green tax system. Here money is redistributed from the mining sector, which must pay for the external effects of their activities, while secondary production can get paid for avoided impacts through their activities. Thus, a progressive tax that increases with environmental degradation in the mining sector, with environmental savings in the recycling sector. To ensure effectiveness of such a system, some kind of return is required, where the recipient of support must measure and demonstrate the environmental savings as an effect of their actions. After all, recycling activities such as landfill mining create both positive and negative externalities, which need to be balanced and contrasted to primary production in such an evaluation. However, the implementation of policies that challenge current power relationships requires huge political endeavors and is possible only in exceptional cases (Jänicke & Jacob, 2005).

Creating an openness to landfills according to the cowboy model of the minerals in the bedrock is an uncertain way forward. This is since such a policy would exclude the owner, who probably has the greatest knowledge about the landfill content in the form of valuable as well as hazardous materials. Removing the many policy instruments identified in chapter 6 as obstacles for operators may also not be desirable, as many of these instruments hold important functions. After all, landfills are a potential problem and a threat to the environment and health. The ban on landfilling organic waste can avoid future emission of methane. To lower the requirements for using waste as a resource may potentially lead to higher levels of toxins in the human environment. Another way to harmonize the policy objectives of increased recycling with the current market and policy requirements is to allow radical solutions such as landfill mining to adopt a greater flexibility in the governmental assessment of recycling projects (Paper IV).

Experiences of such regulatory approaches can be taken from continental European countries where primary resources tend to be scarce in contrast to Sweden. In these countries, the pressure to use waste as a resource has encouraged greater flexibility, demonstrated in the trade-offs between the importance of resource circularity on the one hand and the risk of pollution on the other. For example, in Sweden there are only suggested values for heavy metals for the use of waste for landfill cover of construction works (EPA, 2010). In Denmark, on the other hand, specific values have been formulated for different types of construction works with different risks of leaching and exposure (Miljøministeriet, 2012). The use of waste as construction material, for example in road construction, is thus common in Denmark (Paper IV).

If the levels for using waste as construction material were specified in Sweden, a larger share of the residues from landfill mining operations could potentially find an outlet. Other examples of regulatory flexibility could, for example, be to allow re-deposition of residues, although containing a few percent to much organics. Or the authorities could allow higher emissions from the incinerator than permitted. But this would only be if the environmental benefits of the projects outweigh the disadvantages, for example, through combining the recycling practices with handling of hazardous material, remediation, and after care.

In such cases, the responsibility should be on the operator to prove the benefits. But to make a decision, the authorities needs to be able to grasp the whole complexity of landfill mining (Paper V). Pollution risks, for example, of increased leaching, transport, and odor as a result of landfill mining operations need to be contrasted with its potential in terms for example of avoided primary production and remediation. For the authorities to assess initiatives towards an increase production of secondary resources, enhanced tools and methods are needed, a challenge that should attract the research community's attention. These enhanced evaluation methods need to adopt a broader approach than the current methods and embrace many perspectives in parallel. Evaluations, such as those highlighted in this thesis, are typically detailed so as to avoid over-simplification. However, the detailed evaluations bring a narrow perspective that misses other necessary elements for policymakers to take a balanced decision.

In the current institutional arrangement where the EPA seems to perceive unconventional resource deposits, for example landfills, as problems, while SGU focuses on minerals in the Earth's crust, it is difficult to see any openness for such institutional change. Therefore, if landfill mining is to be realized, new institutional arrangements are needed (Paper V) where the whole complexity of unconventional resource extraction operations such as landfill mining can be understood and evaluated both as business and as a pollution issue. New business models, changed market conditions, and ultimately new governmental structures will then be needed. Only with deep institutional changes can radical policies change to become something more than just an idea in a PhD thesis.

9.

REFLECTION

This chapter is a reflection on how the findings from the dissertation can inform the current resource debate.

9.1. Towards a resource transition

Many scholars and officials have suggested a new approach to waste, a profound change in the resource system, often with the support of policy changes. The European Commission (2015) calls for a systemic change in how resources are recovered in the economy: a "transition to a resource-efficient and ultimately regenerative circular economy." To realize the circular economy, the European Commission (2015) has proposed ambitious policy objectives and regulatory and economic instruments to achieve these goals. Others have talked about a much-needed *Resource Revolution* (Heck et al., 2014) and a changed use of existing resources towards higher efficiency. Their recommendations for policymakers are to remove subsidies and correct market failures.

These proposals of higher efficiency mainly concern the resources in use, the ones that are active and already part of the market. The review of the various secondary mineral stocks in Paper I showed that minerals in-use are only one of several available stocks of secondary resources. The amount of mineral resources in inactive stocks, i.e., waste deposits, are comparable for many metals. Therefore, it would be motivated to include all secondary stocks in the discussions of a changed resource system. After all, many of these inactive minerals were once considered valuable and originally a reserve in the Earth's crust. By paying attention to all stocks, the production of secondary mineral resources can potentially increase.

The recovery of inactive minerals, however, brings fundamental changes. Since the material in waste deposits has already been excluded from the market, abandoned for some time, the extraction of such resources often brings other challenges than traditional recycling. From an institutional perspective, many of these challenges also seem to derive from an adaption of rules, culture, and support to traditional resource extraction. I propose the concept the *resource transition*, since I believe this concept can capture the full potential of secondary resources in the technosphere and the socio-ecological drivers to leave the current system of resource extraction.

The resource transition is a long-term structural change in the resource system toward dominant use of secondary mineral resources. In contrast to concepts with a focus on circulation, the resource transition looks broader and targets, for example, not only those minerals already within the economy, but also the secondary resources currently excluded from the economy and no longer part of the anthropogenic cycles. So while the concept "circular economy" focuses on avoiding material being excluded from anthropogenic flows, the resource transition focuses on avoiding substantive exclusion of material, but also on including resources previously excluded.

As an alternative to the persistent use of virgin resources, the resource transition proposes that waste, i.e., secondary resources, shall be increasingly used and become a more important source of resources in the economy. This transition questions "primary resources as the basis for the production of manufactured goods" (Gregson et al., 2013: 7). Characteristic for the concept *resource transition* is thus that it also emphasizes the need for a transition, i.e., a time-consuming and industrious process of system change from unsustainable use of resources towards a more sustainable use. In this way, the resource transition is similar to the ongoing energy transition toward dominant use of renewable energy.

10.

CONCLUSIONS AND FURTHER RESEARCH

This chapter presents the conclusions of the aim of this thesis: to assess the institutional conditions for landfill mining. Suggestions for a new mineral policy and future research are presented.

This thesis recognizes a transition in the resource system. In the context of circular economy with a focus on the material already in the market, this thesis calls for a focus on the material once excluded from the market. These abandoned stocks of resources are mainly found in waste deposits and require unconventional forms of resource extraction, which in this thesis has been referred to as landfill mining.

In contrast to previous studies of landfill mining, this thesis does not end with the conclusion that there is a resource, economic or environmental potential in secondary stocks. Instead, it tries to look beyond the potential and investigate whether there is a market for the deposited material and how the current laws relate to such an unconventional activity. It has been demonstrated what a social perspective, emphasizing the role of institutions, can contribute to the understanding of landfill mining and its challenges. Landfill mining is a multi-dimensional activity involving several aspects such as markets, technology, policies, laws, and culture. Many of these dimensions, however, have been developed to handle forms of activities other than landfill mining, in terms for example of dumping waste rather than extracting waste from landfills. This mismatch makes the implementation of landfill mining difficult.

10.1. The institutional conditions for landfill mining

There is a clearly defined perception of landfills and deposited waste as a problem, a hazardous activity, at the end of the material flow. This is manifested in the regulatory regime surrounding landfills. The policies for landfills strongly advocate avoidance, isolation, final closure, and post-monitoring of landfills. To do the opposite, to liberate the disposed waste through a landfill mining operation, will thus meet obstacles, for example, direct regulatory barriers that impede the accessibility and marketability of the material and the resistance from the involved stakeholders.

There are also several other regulatory regimes that may indirectly affect the implementation and emergence of landfill mining. The institutional conditions for extracting minerals from stocks other than landfills are more advantageous. Even if a landfill would have the same material conditions as an adjacent mine in terms of mineral concentrations and amounts, extracting minerals from the mine would be a better business prospect because of the favorable institutional conditions. Furthermore, problematic landfills are to be managed by measures other than recycling. If the deposited material is defined as a pollutant, the process of remediation is allowed to cost money and governmental grants are available. Resource extraction, on the other hand, should according to the government be profitable on its own.

Considering the prevailing institutional conditions for landfill mining, recycling operators, landfill owners, and remediation actors are not very likely to engage in the activity of recovering disposed resources. To adapt the institutional conditions according to landfill mining is risky because many of the identified barriers fulfill other important functions such as reducing emissions from landfills. At the same time, it is not certain that landfill mining is desirable. Recycling can contribute to avoidance of primary production, but there are risks involved with opening up a landfill and exhuming the buried material in terms of pollution affecting humans and the environment. On the other hand, to abandon the deposited material means that chemicals could leak into the environment for a long time.

10.2. Towards a new mineral policy

The production of secondary resources will probably need to increase in the future. Over time, protests, expensive energy, lower concentrations, and increased regulatory requirements will make primary resources less accessible and shift the focus towards secondary stocks (cf. Sverdrup et al., 2015). This does not necessarily mean that secondary resources will be recovered from landfills. However, evolutionary economics has demonstrated that it is difficult to tell in advance which options (in this case stocks) will prove most viable. Therefore, policies should be diverse and allow for many options. This can be exemplified in the energy transition, where various forms of biofuels such as biogas, ethanol, and electricity are promoted (Kemp et al., 2005). Due to the uncertainty about how secondary production will emerge in the future, the authorities should show a greater openness to different forms of resource recovery, including landfill mining.

The Swedish mineral policy is adapted towards traditional mining, including major investments and subsidies. Some of these subsidies target policies that were designed to capture externalities from the extractive industries. But by reducing the energy and carbon tax for the mining sector, these policy tools become toothless. At the same time, there are no instruments to trigger environmentally preferable choices such as recycling schemes by materializing the collective benefits from such options into the economy of private actors. Given the current institutional logic, according to which virgin resources are the preferred alternative, there is a risk that the institutional conditions will push towards extreme types of mining from more inaccessible reserves at the bottom of sea or the outer space. The alternative is to instead utilize those minerals in our immediate vicinity, in our hands in the form of a cell phone, or accumulated in landfills, the urban fringe.

This thesis gives some ideas on how a resource policy can be reformulated with secondary resources in the front seat. Such a resource policy needs, however, to consider the total environmental impact, rather than focus on particular elements in the material in terms of, for example, organics. This is the logic of the current regulatory framework for waste. Considering the organizational culture around waste and resources, where secondary resources are an environmental issue under the Environmental Protection Agency and primary resources a business issue under the Swedish Geological Survey, any openness to address this complexity is limited. A resource transition thus requires fundamental changes, such as reorganizing the governance of resources, beyond the introduction of new policy instruments.

10.3. Further research

The resource transition has indirectly been discussed through alternative forms of resource production, via re-use, recycling, urban mining, and circular economy. However, as far as I am aware it has never been explicitly articulated before. Due to the lack of a clear articulation, researchers devoted to transitions have generally not focused on resources. Instead they focus on the transitions of the energy, transport and food sectors (cf. Geels, 2011). This thesis has shown that many of the key foundations of a transition are present: a traditional production mode with severe socio-ecological consequences, and an alternative in the form of recycling that more or less can potentially replace the old system.

Since resources are a new and not particularly focused phenomenon in a transition context, there are great opportunities for further research and testing of different perspectives such as the multi-level perspective (Kemp et al., 2005). Personally, however, I think that certain aspects are more interesting than others. This thesis has identified a number of changes that are needed to realize landfill mining, but whether these choices are legitimate is another question. So far, this issue has been addressed by assessments of the economic, environmental, and partly social potential of such operations. Lessons from large-scale projects that cover different types of landfills would create a much better basis for decision-making for policymakers to evaluate whether landfill mining is of any interest.

Furthermore, the identified conflicts between a non-toxic environment and recycling as well as recycling and primary production deserve more attention. In part by asking the authorities how they understand the relationship between these objectives, but also to develop tools that can facilitate decisions that require tradeoffs between these objectives. This thesis has also shown that there are many interesting lessons to learn from countries with different preconditions, such as the absence of primary production, and how they handle the abovementioned conflict points. An in-depth study of different countries' institutional conditions for resource extraction would be an interesting next step.

11.

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