The Specter of Scarcity
Experiencing and Coping with Metal Shortages, 1870–2015

Hanna Vikström
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Summary

In the twenty-first century, world demand for metals is reaching previously unprecedented levels. New skyscrapers, smart phones, LED lamps, along with wind turbines, cutlery and batteries, are all crucially dependent on an ever broader range of metallic raw materials. In spite of an ever-growing supply of metals, actors have long feared metals scarcity and its severe consequences.

This thesis – departing from an understanding that metals scarcity is not an objective geological fact, but is better analyzed as an experience, a fear of a shortage – explores through five case studies why business and state actors have experienced metals as scarce and how they coped with scarcity from 1870 to 2015.

The underlying reasons for scarcity experiences comprise factors such as high prices, a lack of substitutes, domestic unavailability, limited infrastructure and increased demand. In the view of businesses and the state, a shortage of metals could hinder successful industrialization. Defining metals as scarce or critical was a first step in their attempts to ensure access through strategies including exploration, recycling, substitution, and trade agreements.

Previous research on critical metals and scarcity has left several gaps which this thesis addresses. Smaller countries, most of the nations in the world, are largely under researched in the literature. Here, I focus mainly on Sweden. I show that Sweden’s experience of metals scarcity was rather similar to that of larger countries. However, Swedish actors sometimes felt more vulnerable because they were much less able to control metal flows than could the great powers. For example, as one of my case studies shows, because Swedish steelworks were deeply concerned about the British Empire’s dominance of chromium supplies in the interwar era, they attempted to secure the supply of this metal by opening mines in Turkey. Interestingly enough, they were presented with this opportunity precisely because they were a small and neutral nation; Turkey did not want to cooperate with the imperial powers. Small countries provide interesting examples in understanding the dynamics of metals scarcity.
Furthermore, earlier research has focused on the period from World War I on. I counter this by devoting two of my case studies to scarcity experiences starting in the Second Industrial Revolution, when manufacturers began to use an increasing number of metals to manufacture their products. From this period until World War I, many new technologies saw the light of day; in one case study I analyze how metals scarcity affected the development of incandescent lighting. Manufacturers struggled to find sufficient supplies of osmium, tantalum and thorium – metals which gave off a pleasant glow – because these had never before been used commercially. Industrial actors during this period experienced scarcity simply because there were no extraction systems in place. Businesses turned to vertical integration, substitution, and also embarked on new paths to cope with scarcity and ensure their products’ success. However, only after the war and in the context of acute resource shortages did state actors begin to classify metals as critical or strategic, becoming more involved in securing access.

Over time, industries manufactured an increasing number of specialized products that required unique metals with specific properties. This sometimes resulted in experiences of scarcity. Works within history of technology have often analyzed the use of metals, but neglected to inquire whether metals scarcity affected how technologies developed, and where metals were sourced from. As I show in this dissertation, the use of new metals in technologies made a significant contribution to actors’ experiences of scarcity. Lamp companies at the turn of the twentieth century as well as steel works in the interwar era and electronics businesses in the 21st century all worried about scarcity due to technological trends.

Sometimes business actors instead embarked on alternative technological paths to alleviate scarcity, or substituted metals. However, to claim that scarcity can always be resolved through technology is a gross oversimplification, as is accepting our ever increasing consumption of metals without question, despite the social and environmental consequences of extraction. Over all, no matter how much efficiency may increase, the increased demand for metals in high-tech industries makes the specter of metals scarcity likely to continue haunting us for years to come.
Key Words: scarcity, metal shortages, critical metals, strategic metals, Sweden, small countries, history of technology, experiences of scarcity, coping with shortages, technological trends, World War I, resource crisis.
Sammanfattning


Den här avhandlingen – som utgår från att metallknapphet inte är ett objektivt, geologiskt faktum, utan bör analyseras som en upplevelse, en rädsla för en kommande brist – undersöker i fem fallstudier varför industriella och statliga aktörer har upplevt metallknapphet och hur de hanterat den, från 1870 till 2015.

De bakomliggande orsakerna till upplevelser av metallknapphet innefattar faktorer såsom höga priser, brist på substitut, ingen inhemsk produktion, begränsad infrastruktur och ökad efterfrågan. Från företagens och statens perspektiv kunde en brist på metaller hindra framgångsrik industrialisering. Att definiera metaller som knappa eller kritiska var ett första steg i deras försök att säkerställa tillgång genom strategier som prospektering, återvinning, substitution och handelsavtal.

Tidigare litteratur om knappa och kritiska metaller har ett antal luckor som jag adresserar i denna avhandling. För det första fokuserar jag på mindre länder, vilka i stor utsträckning är underbeforskade. Framförallt tittar jag här på svenska aktörer, och kommer fram till att de i stort sett upplevde metallbrist av samma orsaker som större länder. Små länder är intressanta exempel, de är mer särbara eftersom de i stor utsträckning saknade kontroll över metallflöden. Svenska stålverk var under mellankrigstiden under mellankrigstiden avgjordt av det brittiska imperiets dominans av krommarknaden. För att försöka försäkra sig om tillgång till krom öppnade de gruvor i Turkiet. Intressant nog fick de denna möjlighet precis för att Sverige betraktades som en liten och neutral nation; Turkiet ville inte samarbeta med stormakter.

För det andra är perioden före första världskriget också underbeforskad – forskare har till stor del fokuserat på tiden från och med första världskriget. I min avhandling kommer jag fram till att första världskriget inte var en brytpunkt för aktörers knapphetsupplevelser, men de har

För det tredje tillverkade industrier med tiden alltmer specialiserade produkter, vilka krävde unika metaller med speciella egenskaper. Detta resulterade ofta i upplevelser av knapphet. Forskare inom teknikhistoria har ofta analyserat användningen av metaller, men har försummat att fråga sig om metallbrist har påverkat teknikutvecklingen. I mina fallstudier visar jag att användningen av ny teknik ofta har resulterat i knapphet. Lampföretag runt sekelskiftet likaväl som elektronikföretag från 1990-talet oroade sig för metallknapphet på grund av de alltmer unika metaller som var helt nödvändiga för att de skulle kunna tillverka sina produkter.

Nyckelord: knapphet, metallbrist, kritiska metaller, strategiska metaller, Sverige, små länder, teknikhistoria, upplevelser av knapphet, strategier för att hantera brist, teknologiska trender, första världskriget, resurskris.
Introduction

On 22 September 2010 shocking news reached the Western world: Chinese customs officials had blocked shipments of rare earth elements to Japan. China accounted for about 95 percent of the world production of rare earths – metals indispensable in the manufacturing of electronics, including batteries, computers, and smart phones. Japanese industry was completely dependent on Chinese supplies. Since 1990 China had dominated production and kept prices low. The low prices, together with environmental concerns, had forced the only alternative mining operation, located in the United States, to close in 2002. Now, eight years later, there was simply no one else to turn to. Only months before, according to the Telegraph, Japan had inquired whether China could increase its exports of rare earth elements. Now, suddenly, Japan was left with nothing. “A disruption of supply,” claimed the Economist, would “paralyze the Japanese economy as much as an oil embargo or food blockade.” Because Japan dominated the technical processing of rare earths, the rest of the world would be affected as well.

The sudden halt of rare earth elements exports was closely linked to another conflict. Before the supply disruption, Japanese authorities had arrested the captain of a Chinese fishing boat in the East China Sea, more specifically, in an area where both China and Japan claimed sovereignty, rich in marine resources and believed to hold natural gas reserves. Just days later, the Japanese authorities released the captain. China then resumed its exports of rare earths, but relations between the countries

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2 “China blocked exports of rare earth metals to Japan, traders claim,” The Telegraph, 24 September 2010.
3 Rare earth elements are a group of 17 elements, occurring together with the radioactive elements uranium and thorium. They have unique properties.
4 Klare 2012, p. 160.
5 “Japan Responds to Rare Action. Corporate Japan adjusts quickly to a shortage of rare earths,” The Economist, 20 January 2011.
remained frosty. Japan was alarmed. Among other things, the nation began to stockpile rare earths and attempted to substitute other metals for rare earth elements, fearing what the future might bring. The government initiated discussions with Vietnam and Mongolia about new production facilities and supplies of these critical metals. Major industrial companies, such as Toyota and Hitachi, for their parts, attempted to eliminate the rare earths contained in their products. The government even began to study the potential for deep water mining of rare earths, seeing it as an unexplored frontier which they could control.

Japan was not the only nation worried; politicians in the United States became extremely anxious as well. The U.S. Department of Energy, according to the Financial Times, set out to create a “strategy to increase United States production, find substitute materials and use rare earths more efficiently,” and the Pentagon initiated a “complete study of the United States military dependency.” “We are certainly putting our country at risk in terms of our national security if we don’t do something to ensure that we have an adequate supply,” stated Kathy Dahlkemper, a democratic member of the U.S. House of Representatives. Rare earth elements suddenly came to the fore of the political agenda. Politicians in numerous countries responded to the threat as if it were a weapon, a political, economic or military weapon that China could wield at any time. They appeared strong and determined in public, but on the inside they were trembling.

Aim

The story above is one of the latest examples of how metals scarcity has caused dread among industries and state actors. Metals are crucial constituents of manufactured objects, but they are also finite resources which are traded across political borders, and which actors over and over

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7 “Bare Anger,” The Economist, 4 November, 2010. Beijing, on the other hand, claimed that they had not banned the exports of the rare earths, and never had prevented shipments to Japanese multinational companies such as Toyota see “China blocked exports of rare earth metals to Japan, traders claim,” The Telegraph, 24 September 2010.
again have feared they would not be able to acquire. They have been frightened by the potential consequences of not being able to access one metal or another, fearing that a shortage would destroy their business, prevent industries from expanding, or even harm the national economy. They have been haunted by a specter of scarcity – and they have applied all means at their disposal to prevent it from materializing.

Taking as its point of departure the simple but important observation that metals scarcity is hardly a new phenomenon, the aim of this thesis is to explore, through a number of case studies, why state and business actors have experienced metals as scarce and how they coped with metals scarcity from 1870 to 2015. Throughout this period, access to raw materials was crucial for industries to keep up their manufacturing processes, and to stay competitive. While metals clearly had been important to human societies long before 1870, the difficulties in ensuring access to them became apparent from the Second Industrial Revolution on, when industries began to use more metals in greater quantities for manufacturing of various products and technologies. From then on demand for various metals increased quickly. Increasingly, businesses, and later on state actors as well, began to fear being left without key metals. As shown by the introductory story, these fears are still with us today.

Resource scarcity is commonly described as a mismatch between supply and demand. While increased demand and limited supply are clearly important dimensions to take into account in the history of metals scarcity, a main argument in this thesis is that this is an oversimplified line of reasoning. Metals are sometimes available or extracted in only a few places worldwide. But no matter how abundant they have been and where they are extracted, business and state actors have frequently expressed concerns about a pending shortage. And they have acted accordingly to avoid future shortages.

Another general conception is that a resource is scarce only when it is nearing depletion. On the contrary: my thesis starts from the understanding that scarcity is by no means an objective, geological fact. Throughout this thesis and the five articles, I analyze and unravel what metals scarcity is by focusing on the metals described by business and state actors as scarce, critical or strategic during different time periods.
over the past 150 years (see figure 1). I argue that it is advantageous to study a long period as it offers a perspective on the slow changes over time, which is crucial when seeking to understand the long-term dynamics of metal shortages.

It is through the shifts in actors’ opinions on whether or not a metal is scarce, and the wider political and historical context in which such arguments are formed, that it is possible to unravel why actors have experienced metals scarcity. This is precisely what this thesis does by looking at the various case studies. I explore actors’ experiences of metals scarcity in different epochs through engineering journals, governmental reports and archival documents. Additionally, I examine the different strategies the actors have applied in order to cope with metals scarcity.

Figure 1. Timeline of articles
Research questions

The more specific research questions in this thesis are based on three major gaps in the literature on metals scarcity, as explained below. Each article relates to one or more research questions (see Table 1).

First, historians have generally studied metals scarcity from the perspective of large nations or imperial powers (and their colonial possessions), and large companies. Great Britain, the United States, France, and Germany figure prominently in this literature. Ian Lesser’s *Resources and Strategy*, for example, mainly concentrates on how nations such as France, Japan, United Kingdom, Germany, and Italy tried to secure their access to mineral, metal and energy resources from 1914 until 1980s, and the problems they faced. He focuses primarily on the two World Wars as well as the economic recession and commodity crisis of the 1970s. He emphasizes the important role that securing access to various resources, through substitution and acquiring mines, plays for the outcome of the wars. In a similar vein, Raymond Dumett’s “Africa’s Strategic Metals” focuses on the Allies’ attempt to secure alloying metals for steel manufacturing from Africa. Edward Barbier’s sweeping *Scarcity and Frontiers* also focuses mainly on the world’s large nations’ exploration of new frontiers to ensure access to resources including minerals.

Other historians have focused more specifically on individual metals, including tungsten, tin, copper, aluminum, and, of course, iron. In *Tungsten in Peace and War*, Ronald Limbaugh highlights the uneven distribution of the world’s known tungsten deposits and the resulting importance of international trade for access to this metal. The U.S. government faced a difficult choice, either to import tungsten or to attempt establishing a domestic industry. Limbaugh focuses mainly on how a specific American mining enterprise, the Nevada-Massachusetts Company, tried to control domestic mines and supply the United States with tungsten, a strategy that would diminish its dependence on foreign suppliers. While the American tungsten was more expensive than China’s, it was an attempt to dispel the threat of having to resort to foreign,

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12 I have largely excluded iron in this thesis given the large literature on the subject, but have of course included it should it be portrayed as scarce.
potentially unreliable supply, ultimately resulting in a glut.\textsuperscript{13} In a similar vein, *Aluminum Ore*, edited by Robin Gendron, Mats Ingulstad and Espen Storli, explores the history of bauxite, the most important aluminum-bearing mineral. The authors bring up various aspects of the global industry by focusing on developments in a range of countries in Europe, North, South and Central America, and Asia. While they discuss the importance of local actors and deposits in numerous countries, they largely focus on the great powers and large companies, along with the transnational flow of the crucial mineral these were trading in.\textsuperscript{14} *Tin and Global Capitalism*, edited by Mats Ingulstad, Andrew Perchard and Espen Storli, provides various perspectives on the importance of another metal, tin, in manufacturing processes, and elaborates how nations such as the United States, Britain and Germany attempted to deal with their demand, while also shedding light on how tin reserves in the Congo and Malaya were exploited and developed from 1850 until 2000. L. J. Butler’s *Copper Empire* explores the British Empire’s development of copper mining in Northern Rhodesia and its importance to the British economy from the colonial era through the decolonization period.\textsuperscript{15}

How the smaller, non-imperial countries\textsuperscript{16} experienced and coped with metals scarcity is less visible in the literature.\textsuperscript{17} Yet these countries are even more likely to be dependent on imports of metals and more likely to be affected by metals scarcity. A large part of this thesis focuses on one arguably small country: Sweden.\textsuperscript{18} Sweden is a smaller player in the global economic and political arena. It is also a large producer of iron and

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\textsuperscript{13} Limbaugh 2010.
\textsuperscript{14} Gendron, Ingulstad and Storli 2013. There are also other historians who have written about aluminum, for instance, Mimi Sheller 2014; Bertilorenzi 2016.
\textsuperscript{15} Butler 2007.
\textsuperscript{16} It is difficult to pinpoint what a small country is, as there are many aspects such as economy, political influence, and size to account for. See e.g. Tõnurist 2010. Thus, using a relative concept is more fruitful.
\textsuperscript{17} There are exceptions, of course, see e.g. Storli 2013, who mentions in passing that a Norwegian company tried to secure bauxite properties in the Guianas in the 1920s and then sold it to a large aluminum company, Alcoa. Also, Thonstad Sandvik 2009, explores how small producers in the inter-war nickel industry managed to stay on the market and had to pursue certain strategies.
\textsuperscript{18} Sweden was neutral through the World Wars and the Cold War, but was nonetheless severely affected by the wars. Focusing on such a country adds to the literature on how nations with limited markets and capital have dealt with scarcity.
also copper, and a large consumer, particularly in its steel and manufacturing industries. Iron and steel are at the heart of Swedish industry, a fact that is also strongly reflected in historical research on the country.\footnote{See e.g. Bergström 2009; De Geer 1960; Jernkontoret 2011, Pettersson 1997; Petterson 1988; Fritz 1997; Fritz 1988. In economic history works, the focus is also on iron and steel, see Schön 2012; Larsson 2014.} There is a large literature on the history of Swedish iron ore mining and on issues like Swedish exports of iron to Germany during World War II.\footnote{Hedberg and Håkansson 2008; Fritz 1973; Fritz 1974; Karlbom 1965.} But there has been almost no research regarding Swedish \textit{imports} of metals.\footnote{However, there are some exceptions. Economic historian Göran Bergström in \textit{Från Svensk Malmexport till Utländsk Etablering} mentions that Grängesbergsbolaget attempted vertical integration in the 1970s to ensure their supplies of, for instance, nickel, Bergström 2009.} And this is the case despite the fact that, although Sweden sits on large iron ore deposits, the country has been crucially dependent on imports of alloying metals, which have thus often been perceived as scarce and critical. Ensuring access to these metals was a prerequisite for success.\footnote{Thomas Misa, in \textit{A Nation of Steel}, mentions in passing that the chromium-molybdenum steel developed in the 1920s was well adapted to American automobiles. One reason behind the success, he mentions in passing, was that the United States possessed rich deposits of molybdenum, Misa 1995, p. 232-233.} This brings us to the first research question: \textbf{How have manufacturers and state actors in small countries experienced metals scarcity and how have they handled it?}

\textbf{Second}, most previous research on metals scarcity has targeted the period from World War I onwards.\footnote{See Eckes 1979; Lesser 1989. Topik and Wells 2012, mentions the increased use of metals, notably copper and iron, before World War I, however, focus more on the period after World War I. Also they neglect other metals which began to be used in earnest. Gendron, Ingulstad and Storli’s edited book \textit{Aluminum Ore}, mainly focuses on the period from World War I on.} The extent to and ways in which metals scarcity was an issue before World War I have received less attention from historians. With some exceptions,\footnote{See e.g. Ingulstad 2015a; Limbaugh 2010, p. 1-17; Burt and Kudo 2015; Wolfe 2015; Bertilorenzi 2016, p. 1-100.} the broader literature uses World War I as a starting point for the debate on how to secure minerals and metals. Espen Storli, for example, mentions that although bauxite was used before 1914, it was only with the outbreak of World War I that it became a strategic resource, essential to warfare.\footnote{Storli, 2013.} Political
scientist David Haglund, in a similar vein, claims that the concepts of critical and strategic metals dates back to the time after World War I, as only from 1919 on was there literature on the topic of how to deal with potential shortages and strategic minerals.\textsuperscript{26} Yet it is a well-established fact that the industrialization process in Europe and North America, and especially the Second Industrial Revolution, with its expansion of infrastructure, especially in shipping, plus mass production, increased consumption and rise of big businesses, resulted in dramatically increased demand for natural resources.\textsuperscript{27} At the same time, advances in metallurgy made many metals with specific properties more available to manufacturers.\textsuperscript{28} Against this background it is plausible to assume that metals scarcity had been recognized as a problem long before World War I, especially from the 1870s on, and especially within industries that were undergoing rapid growth at the time. Articles I and II explore this issue, which can be translated into the second research question addressed in this thesis: \textbf{Was metals scarcity a problem for industries and states before World War I, and if so why? How did the actors cope with it? Additionally, did actors perceive specific metals as scarce from 1870 until World War I?}

\textbf{Third}, metals scarcity is often neglected when discussing designs of technological artifacts and systems. Manufacturing objects and products is clearly intertwined with access – and the lack of access – to metals. Yet historians of technology have largely failed to account for how resource scarcity has affected technological paths and how the development of technology has shaped perceptions of scarcity.\textsuperscript{29} Lewis Mumford, in \textit{Technics and Civilization}, acknowledges that many metals became crucial components in industry starting in the 1930s.\textsuperscript{30} In \textit{Networks of Power}, Thomas P. Hughes notes that the high cost of electricity was an issue in the decades around 1900, especially as the transmission distances grew. In this context, Edison expended great effort to save copper in electrical wires.\textsuperscript{31} Hughes, along with James Utterback in \textit{Mastering the Dynamics of Innovation}, also acknowledged that metals like tantalum

\textsuperscript{26} Haglund 1986; Haglund 1984; Smith 1919; Lesser 1989.
\textsuperscript{27} See e.g. Chandler 1959; Barbier 2011.
\textsuperscript{28} Rosenberg 1982.
\textsuperscript{29} See e.g. Alexander 1978; Temple 1978.
\textsuperscript{30} Mumford 2010, p. 231.
\textsuperscript{31} Hughes 1983, p. 83-84, 166-174; Utterback 1994, p. 61-68
and osmium were needed in light bulbs. In Of Bicycles, Bakelites and Bulbs, Wiebe E. Bijker similarly mentioned briefly that steel supply was an important factor in manufacturing bicycles in the 1870-80s.\textsuperscript{32} Nathan Rosenberg, throughout his book Inside the Black Box, returns to the importance of metallurgy and metals with specific properties for innovators and manufacturers. He claims that “many innovations had to await the development of appropriate metallurgical inputs with highly specific characteristics.”\textsuperscript{33} However, none of these authors follow up their observations by analyzing the metal supply further.\textsuperscript{34} They only briefly mention the increased use of metals; they rarely analyze the extent to which scarcity affected the designs of objects and where the raw materials were sourced from.

There are a few interesting exceptions to this pattern. Hermione Giffard, for example, explores in “A Hard Sell” how Germany, Britain and the United States adopted cemented tungsten carbide cutting tools in the interwar era. One reason why they adopted these tools, she argues, was metal shortages. Using these tools required less iron and tungsten than their predecessors, so to save on these metals they turned to a new technology.\textsuperscript{35} This line of reasoning echoes Nathan Rosenberg’s classical argument that technological change is “the most powerful mechanism of response” to resource scarcities,\textsuperscript{36} and illustrates nicely how technology can be shaped by – and how it can arguably resolve – metals scarcity. Bringing this aspect to the fore enables a more nuanced understanding of the shaping of technology. Taking inspiration from authors such as Rosenberg and Giffard, this thesis further problematizes the relationship between technological change and metals scarcity. This leads us to the third research question: \textbf{How has metals scarcity shaped technological development, and how has technological development shaped actors’ perceptions of metals as scarce?}

\textsuperscript{32} Bijker 1995, p. 35.
\textsuperscript{33} Rosenberg 1982, p. 61.
\textsuperscript{34} Hughes 1983, p. 34-37; Utterback 1994, p. 61-68; Rosenberg 1982.
\textsuperscript{35} Giffard 2015.
\textsuperscript{36} Rosenberg 1976, p. 249.
Table 1. Research questions (RQ) in each article

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Situating the thesis

Metals in world history
This section provides an overview of metals in history based on secondary sources. It offers a background for the case studies by introducing the role of metals for human societies in a historical perspective.

Human societies have made use of metals over a period spanning at least four thousand years. The first metals to be extracted included tin, copper, gold, and silver. They were put to use in weapons, coins and jewelry. The Roman Empire, for its part, used lead in its water system – in piping and aqueducts. Over time an increasing number of metals found their way into society. In the Middle Ages, with the introduction of blast furnaces that could be heated to high temperatures, the large-scale use of iron saw its breakthrough. This became crucial for the manufacturing of tools and weapons. The demand for iron and other metals grew in the period that followed, and mining technologies improved. During the fifteenth and sixteenth centuries it became possible to extract metals buried deep underground. Apart from technical advances, metals also became subject to scientific research. A common line of thinking during the Middle Ages was what we today call alchemy, the belief that metals transformed over time from base metals, iron, to precious ones – gold and silver. This conception gradually faded.

In the early eighteenth century chemists began to view metals as the building blocks of matter. This changed the perception of metals, which began to occupy a central role in the emerging discipline of chemistry, with chemists successfully identifying several new elements. The nineteenth century was a vibrant period in the history of chemistry, with additional discoveries of new elements, and the development of

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1 Sundin 1991, p. 149-151; Lynch 2010, p. 9-17; for more information on early metallurgy see Tylecote 1992.
2 The most well-known work from that time is clearly Agricola’s *De Re Metallica* (On Metals), published in 1556. It was a complete survey over all aspects of mining and metallurgy. See further Coulson 2012, p. 401-7, 48-51; Lynch 2010, p. 40.
4 Fors 2015.
technologies to extract, purify and refine them. Swedish scientists, for instance, were credited with the detection of metals including yttrium, molybdenum, cobalt and scandium. All over the world scientists sought to categorize these elements. In 1869, a periodic table, with the structure to which we are accustomed today, was published by the Russian chemist Dmitri Mendeleev. Mendeleev sorted the elements in rows and columns according to their atomic weights and properties (see figure 2). This system left space for elements which he believed were yet to be found. It was further improved over the years, turning into the periodic table as we know it today.

Figure 2. The periodic table. A metalloid is a chemical element which has properties that are a mixture of metals and nonmetals. In this thesis I treat metalloids as metals if the actors define them as such

Source: Wikimedia 2012

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5 See e.g. Day and Tylecote 1991.
6 Weeks 1968; Aldersey-Williams 2012, p. 81f, 355f; for more on Mendeleev and how the periodic table was received in different countries, see Kaji et al. 2015.
The Second Industrial Revolution in the Western world, the start of which is commonly dated to around 1870, further increased the use of and demand for metals. Raw materials, especially iron, were crucial for industrialization. Manufacturers had long used cast steel to make tools, but it was labor-intensive and the material obtained was brittle. From the mid-nineteenth century the Bessemer and Martin processes revolutionized the steel industry, making it possible to remove impurities from iron by heating it to even higher temperatures. Manufacturers also began to add alloying metals to the iron, such as manganese, tungsten and chromium, seeking to improve the quality of steel. By adding these in different combinations, manufacturers succeeded in creating steel that was tougher, harder, more resistant to wear, and able to withstand higher temperatures. Demand for steel increased now that it was less brittle and more durable. Numerous industries found use for it, from machine builders to railroad companies. Manufacturers began to use non-ferrous metals in their industrial processes as well. One example was aluminum, for which chemists developed an extraction process in the 1880s. In the following period, numerous manufacturers found use for the metal, for example, in buttons for uniforms, and, more importantly, in electrical power lines. Additionally, from 1888 on, manufacturers began to manufacture tin cans, which became a popular product because they were much sturdier than the fragile glass jars they replaced.

This development coincided with the development of shipping over longer distances and the expansion of railway infrastructure, making it easier to transport minerals. Shipping times across the Atlantic Ocean decreased from about 21 days in the 1850s to about five in the 1880s. The Suez Canal was opened in 1869, dramatically shortening shipping routes between Europe and Asia. Decreased fuel prices also enabled cheaper transport, and a series of free trade agreements meant that commodities could cross political borders more easily. All in all, it became easier to transport and import resources across vast distances, and this, together with development of improved extraction and purification methods, enabled countries – especially those with colonies – to take greater

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7 Cf. Mumford 2010, p. 229f; Limbaugh 2010, p. 5-12; Fry and Willis, 2015, p. 102f, Bijker 1995, p. 35.
8 Mumford 2010, p. 229-234.
9 Storli 2013, p. 25; Sheller 2014, p. 45.
10 Wolfe 2015.
advantage of their resources. However, only valuable commodities such as silver, gold, tin and copper from Asia and Africa were profitable to transport to Europe, whereas bulk resources like coal and iron ore became subject to large-scale transoceanic trade only after World War I.\textsuperscript{11}

Natural resources and metals became increasingly important for economic development. Edward B. Barbier called the period from 1870 to 1914 the “golden age of resource based development” as “peripheral economies” supplied Europe and the United States with resources on an unprecedented scale, fueling industrial and economic growth.\textsuperscript{12} The total production and consumption of metals and other resources escalated. Businesses consolidated, pooling more capital, accompanied by the rise of consumer society from the 1870s on. This structural change further paved the way for increased production. In Sweden, steel production increased tenfold between 1870 and 1914.\textsuperscript{13}

Another aspect of the increased use of resources was that engineers and manufacturing companies managed to refine and purify metals on a commercial scale. Germany became the world’s industrial leader in the processing and refining of metals. The Germans financially controlled major tungsten deposits, for example, from which they brought the crude mineral, only to refine and sell it on the international market.\textsuperscript{14}

The increased transnational flows, and the growing use of and dependence on metals made it essential for industries and nation-states to map natural resources. Starting in the mid-nineteenth century, several countries, including Sweden, founded national Geological Surveys to map their domestic mineral deposits. Access to resources began to concern also the state.\textsuperscript{15} Both the U.S. Geological Survey and the German Metallgesellschaft AG began to publish mineral statistics.\textsuperscript{16} Apart from nations’ individual attempts to map their own resources, the Swedish

\textsuperscript{11} Barbier 2011, p. 369-378, 412; Topik and Wells 2012, p. 57. This coincided with the manufacturing of special steel – demanding scarce metals imported from other parts of the world – to build ships for long transatlantic distances, see Schön 2012.

\textsuperscript{12} Barbier 2011, p. 368-462.

\textsuperscript{13} Chandler 1959; Stråth 2012.

\textsuperscript{14} Limbaugh 2010, p. 14-17.

\textsuperscript{15} See e.g. Eriksson 1978; Westermann 2015.

\textsuperscript{16} Westermann 2015, p. 8.
geologist Arvid G. Högbom initiated a collaborative effort to map the iron ore resources of the world, a work which was presented at the 1910 International Geological Congress in Stockholm. The joint effort resulted in a detailed, two-volume description of iron ore resources in countries all over the world.\textsuperscript{17}

After World War I, industries continued to develop new products based on a variety of metals. The rise of consumer society stimulated the development of new technologies, and shipping became cheaper. There was a boom in demand, as Barbier notes, from 1913 until 1950. Businesses began to use tungsten products in automobiles, electronics, household appliances, airplane engines, and farm equipment.\textsuperscript{18} Another element, chromium, was used in large quantities for the production of stainless steels. The mechanical and electric industries also found uses for new metals. Lewis Mumford, in his 1934 book \textit{Technics and Civilization}, concluded that “rare metals now have a special place in the industry.” Companies found use for selenium’s special properties – its electric resistance varied inversely with the intensity of light and it was used to manufacture electric door openers. The lighting industry also experimented with a range of rare metals. Starting in the 1930s, General Electric, for example, set its sights on manufacturing a fluorescent lamp, eventually deciding to base it on mercury.\textsuperscript{19} Demand for aluminum also soared, especially in the growing aircraft industry.\textsuperscript{20} The use of platinum grew as well, especially from the 1930s on, in applications such as catalysts, power switches, thermostats, glass manufacturing and artificial silk.\textsuperscript{21}

Clearly, these trends were dependent on access to metals. Metals, as World War I had made apparent, were also crucial for the production of military technologies including weapons and aircraft. After the war, there was a trend to turn to domestic, or colonial, mineral resources as much as possible. The United States and the Soviet Union were largely self-sufficient in many metals. South Africa began to develop its own steel

\textsuperscript{17} The iron ore resources of the world 1910a, The iron ore resources of the world 1910b; Sundquist and Nordlund 2004.
\textsuperscript{18} Limbaugh 2010, p. 59.
\textsuperscript{19} Mumford 2010, p. 231; Bijker 1995, p. 218-221.
\textsuperscript{20} Sheller 2014, p. 61f; See further Hayao Miyazakis film \textit{The Wind Rises}.
\textsuperscript{21} Davenport 2013, p. 410-430.
industry based on its own rich ores. But due to the need for a growing number of special metals that were only available in certain places, even these larger nations became increasingly dependent on foreign trade. Many European nations without domestic mineral resources became highly dependent on metals sourced from colonies – their own and others’ – in Africa, Asia and Latin America.\textsuperscript{22}

In a material world such as ours the race to create improved materials is a never-ending saga. Manufacturers have continuously improved technologies for the mapping, mining, extraction, purification and transportation of resources, seeking to meet the increased demand for metals. One of the most important trends in the interwar and post-World War II eras has been lighter metals replacing previously used heavier ones. Aluminum began to replace tin in the manufacturing of cans, for instance.\textsuperscript{23} Additionally, in the aftermath of World War II metals like the rare earth elements became crucial in various industrial applications. The breakthrough came when engineers managed to isolate these elements from each other so that they could be used separately. Their unique properties enabled the invention of new materials, and manufacturers succeeded in developing new products.\textsuperscript{24} Meanwhile, titanium and zirconium were prerequisite for constructing nuclear power plants,\textsuperscript{25} while niobium and tantalum found use in alloys for high-temperature applications such as jet engines.\textsuperscript{26} Many of these metals were extracted in only a few places worldwide, which meant that certain places and countries became dominant suppliers. However, it was apparently deemed less problematic to be dependent on trade, as several international trade agreements were established after World War II; at least, critical and strategic metals were not as prominent a topic of discussion among political actors.

Over time, though, demand for metals only continued to rise. One reason for this was the emerging industrializing countries in Asia including Singapore, South Korea and Hong Kong. Another major change was the digital turn, which was crucially dependent on metals with unique

\textsuperscript{22} Barbier 2011, p. 463-551.
\textsuperscript{23} Wolfe 2015, p. 76.
\textsuperscript{24} Vikström 2011.
\textsuperscript{25} SOU 1980:12.
\textsuperscript{26} Keenlyside 1949.
properties, most of which had previously not been used in large quantities. The electronics industry, which saw its breakthrough in the 1970s and took off in earnest from the 1990s on, has generated revolutionary products such as batteries for electric vehicles and cameras, as well as LED screens and magnets in smart phones – all of which have been critically dependent on metals such as rare earth elements, cobalt and tantalum. Another example is platinum, largely extracted in South Africa, which has found increasing application in electronics as well as in jewelry, in the chemical and dental industries, and in catalytic converters.  

Throughout the world, companies eagerly sought new materials to improve and develop technologies. Another industry that became dependent on various metals was renewable energy technology. These products came to require rare earths and platinum along with indium and lithium. These metals were largely imported from countries located in Africa, Asia and Latin America.  

To give a perspective on the metal demand as of 2010, a citizen in 2008, reported the Geological Survey of Sweden, will use around 1700 tons of minerals and metals during his or her lifetime, amounting to an annual demand of 25 tons. To offer just one example, a smartphone is constituted of about 40 elements, most of them metals. While an increasing number of metals are found in the everyday objects that surround us, one of the most important materials is still steel, crucial in diverse products ranging from flat-screen TVs, refrigerators, to cranes, drills, pipes and wine tanks, while also being used massively in the construction industry and a multitude of infrastructure projects. In fact, iron and aluminum accounted for 95 percent of the metals mined from 1950 to 2010. To sum up, metals are one category of resources that have been crucial to human civilizations for centuries and millennia, and the supply only continues to grow (see figure 3). From the 1990s countries such as China, India and Brazil have emerged as new huge consumers of raw materials. A result of the growing demand is that most high-grade deposits have been mined, and mining companies have been forced to

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turn to ores with lower and lower grades. Yet extraction continues at an unprecedented pace.\textsuperscript{31}

![Figure 3. Global production of copper 1900–2014 (million tons)](image.png)


**Metal shortages in the historical perspective**

This section gives an introduction to metals scarcity in the historical perspective from the end of World War I until today. Metal shortages have long been perceived as a threat both to state actors, who worried about the geopolitical dimension of metals scarcity, and industrial actors, who had to make sure that they had access to the metals on a daily basis. The section thus situates my own research and contextualizes the different case studies.

Metals are finite, non-renewable resources that are unevenly distributed in the world. This has often given rise to experiences of shortage. No country is self-sufficient in the production of all the metals it needs, and

\textsuperscript{31} Schaffartzik et al. 2016.
trade is often a requirement for supply. Hence access to metals is a problem that crosses political borders, and becomes a global issue.\textsuperscript{32}

Societies have had to deal with shortages of metals for centuries. Judging from the previous research, however, dependence on imports of specific resources attracted great attention and became particularly visible during World War I. Military equipment, ships, and airplanes were all dependent on metals, sometimes sourced from regions far away. When the trading routes were suddenly disrupted it proved difficult to import metals. The United States as well as Europe and Japan expressed concerns regarding the supply of metals, including platinum, tin, aluminum and tungsten, beginning to label them as “strategic” (for more details, see the section below on strategic and critical metals). They were crucial for industry and warfare.\textsuperscript{33} Even if the metals could be accessed, they were deeply concerned about the soaring metal prices. Hence it was difficult for industries to afford and access many metals.

After the war, prices stabilized and the international metal trade revived. This was certainly welcome, as domestic metals production was far from sufficient in most nations, so that supply from foreign countries was a necessity.\textsuperscript{34} Yet the concerns regarding future shortages for industry lingered after the war.\textsuperscript{35} For example, by the 1920s canned foods – stored in tin cans – made up a growing part of American and Canadian families’ diet. As a consequence, a potential scarcity of tin, according to Joel Wolfe in “Summer’s Food for Winter’s Table”, concerned the U.S. government.\textsuperscript{36} The U.S. Geological Survey mapped available resources, publishing a book of global geological inventories of minerals. They were concerned that it was no longer sufficient to map domestic resources, wanting the whole world to be inventoried in order to understand “world demand and supply.”\textsuperscript{37} This revealed that the quest for access to metals had become visible at a higher political level as well as in corporate boardrooms.

\textsuperscript{32} Keenleyside 1949.
\textsuperscript{33} Ingulstad 2015a; Lael and Killen 1982; Limbaugh 2010, p. 42; Gendron, Ingulstad and Storli 2013; Lesser 1898.
\textsuperscript{34} Lael and Killen 1982.
\textsuperscript{35} See for e.g. Smith 1919.
\textsuperscript{36} Wolfe 2015, p. 82-83.
\textsuperscript{37} U.S. Geological Survey 1921, p. 3.
Throughout the interwar era, nations increasingly began to introduce trade barriers and tariffs that somewhat restricted trade. Generally, the interwar era would be remembered as an era of protectionism. There were also a growing number of cartels, through which leading producers sought to keep prices high. In 1928, for example, the German company Krupp and General Electric of the U.S. fixed the tungsten carbide price at five times the cost of production. Unsuably, manifold countries aspired to supply and control their own growing demand for metals. Japan invaded North China and Manchuria to secure access to iron and magnesium. Metals were a prerequisite for a range of new technological innovations that saw a major breakthrough, for instance, in advanced steels. This innovative product required alloying metals that many countries lacked.

According to Leith’s “Mineral Resources and Peace,” published in 1938, there were enough mineral resources in the world to meet all nations’ demands. But the uneven distribution of metals in the world indicated that no country could be self-sufficient, and they did not trust the market. The British Commonwealth of Nations and the United States controlled about three-quarters of the mineral reserves known at that time. Large imperial powers like Britain and France had an advantage in securing access of sought-after metals; they could turn to their own colonies’ resources. Many businesses, meanwhile, sought to control their entire supply chain during the 1930s and 1940s, attempting to achieve what economists refer to as “vertical integration.”

Findings of resources, particularly those viewed as scarce and crucial for industrial production, motivated imperial powers to invest in overseas mining operations. The British Empire, controlling vast mineral rich regions, turned to Rhodesia for copper, as L. J. Butler explores in Copper Empire. There, they mined, enriched and imported the country’s

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38 However, Storli 2013, p. 25 claims that the history of the bauxite industry on the contrary was an exception to this development.
39 Barbier 2011, p. 518.
40 Limbaugh 2010, p. 120; Larsson 2014, p. 298; Industriens utredningsinstitut 1954, p. 64-65; Eckes 1979, p. 50-53. For more information on the interwar era and Minerals see further Eckes 1979, p. 27-55.
41 Leith 1938.
42 Thonstad Sandvik 2009.
minerals at low cost. New deposits were not necessarily exploited immediately, but saved as security, in case they might need it later. The British Aluminium Company, for example, controlled a deposit in British Guyana, but did not bring it into production. From 1937 to 1945, the U.S. imported one-third of the Indian province Travancore’s monazite — a mineral comprising thorium and rare earths — which sustained two-thirds of their own demand. It should be emphasized that the vast colonial territories in Africa and Asia were of great importance not only for the imperial nations; many smaller, non-imperial countries also depended on the colonial regions of the world in their efforts to cope with metals scarcity.

During World War II the demand for metals increased further, partly due to the large amounts of war equipment manufactured. The United States alone imported minerals from 53 different countries. They had already set up a large stock-piling program to reduce vulnerability and have a secure supply should supply disruptions occur. Still, it was particularly difficult to gain access to alloying metals, including for steel manufacturing, crucial for warfare. The Axis powers Germany, Italy and Japan all found it problematic to import alloying metals to manufacture special steel. Germany imported most of its iron from Sweden, in return for large-scale exports of coal. Raymond Dumett claimed in “Africa's Strategic Minerals During the Second World War” that the Allies won World War II because they turned to Africa’s riches of alloying metals: molybdenum, cobalt, tungsten, and vanadium, metals needed to manufacture various kinds of steel. Still, just before Japan surrendered, President Truman was very concerned about his country’s dependence on the foreign supply of metals.

43 Butler 2007.
44 Storli 2013, p. 33.
46 There were of course also other sources of supply; a small molybdenum mine was located in Norway, see Sanders and Ingulstad 2016.
47 Bateman 1952.
48 See further Ingulstad 2011.
49 Dumett 1985; Leith 1938.
50 Lesser 1989, p. 47f.
51 Dumett 1985.
52 Ingulstad 2015b.
After World War II, some analysts anticipated that the demand for geologically rare metals would increase once the properties of certain metals became known, but there was one problem: they might be more vulnerable to shortages as a result. According to Keenleyside, cobalt and columbium (niobium), used as alloys to make metals withstand the high temperatures of jet engines, were two potentially scarce metals, difficult to find in economically viable concentrations.53

Access to natural resources and the availability of metals became a more general concern in the metal-consuming nations after the war. From the late 1940s and early 1950s on, the large imperial powers began to lose their colonies, becoming highly dependent on imports from these newly independent countries.54 Additionally, a structural change had taken place; by the 1950s most minerals were sourced from developing countries, not industrialized ones.55 This was a cause for concern. In 1951, U.S. President Truman and British Prime Minister Attlee organized the International Materials Conference, as a result of the anxieties regarding the supply of raw materials. At this conference some subgroups with representatives from several countries were formed to investigate the supply, exports, imports and production of metals. Some groups later recommended that governments establish international allocating systems for tungsten, molybdenum, manganese, nickel, cobalt, copper, zinc and lead.56

Even worse, metal prices soared during the Korean War, and several nations experienced resource shortages.57 In the United States, the Truman administration was greatly concerned about access to minerals, and decided to appoint a group led by William Paley to investigate the future long-term supply of raw materials. The commission published a report in 1953: *Resources for Freedom*.58 One issue at hand was the

53 Keenleyside 1949.
54 Nocentini 2004.
55 Barbier 2011.
56 International Materials Conference 1951.
58 United States President’s materials policy commission 1952. See Eckes 1979 for a discussion on how the report was received.
Soviet Union’s influence in mineral-rich countries. In the context of the Cold War, this was seen to change the dynamics of access to resources.\textsuperscript{59}

In 1970s worries became even more pronounced. One important debate concerned the incipient concerns regarding perceptions of depletion, as outlined in the Club of Rome’s report, \textit{Limits to Growth}.\textsuperscript{60} What is more, even before the 1970s metal prices had already begun to increase. Then, in 1973, they skyrocketed in reaction to the oil crisis. State actors worried; the fear of OPEC was echoed in concerns about access to metals. The new geopolitical turbulence was especially problematic because of industrial nations’ growing import dependence. While in 1950, according to Ian Lesser, the United States was dependent on imports of half its supplies of four metals, in 1976, this number had increased to 23.\textsuperscript{61} In addition, Western Europe and the United States continued to fear that their growing supplies of metals from countries in Africa, Asia and South America would be disrupted because of the Soviet Union’s influence in those resource-rich regions.\textsuperscript{62}

State actors sought to assist industry in securing access to minerals, as they were also affected by metal shortages. For instance, in 1979 the European Communities tried to secure access to minerals by updating the Lomé agreement regarding cooperation with the African, Caribbean and Pacific states – former European colonies – on mineral resources. This made it easier to invest in mining in these countries.\textsuperscript{63}

For a time minerals figured less prominently on the global political agenda. However, with new changes in the global economic and political landscape, together with an increased use of minerals in digital technology, new problems arose. As of 2000 China and Australia controlled the majority of the world’s key mineral resources. Moreover, the geography of demand changed when countries such as China, Brazil and India emerged as new large consumers.\textsuperscript{64} Several nations, especially in the West, have become concerned about China’s dominance as a metal

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\textsuperscript{59} Barbier 2011, p. 464f. \\
\textsuperscript{60} Meadows et al. 1972. \\
\textsuperscript{61} Lesser 1989, p. 148-149. \\
\textsuperscript{62} Westad 2007. See p. 208-249 for Soviet and United States interest’s in South Africa. \\
\textsuperscript{63} For more information on the first and second Lomé agreement see Asante 1981. \\
\textsuperscript{64} Humphreys 2010. 
\end{flushleft}
supplier, particularly as metal prices have increased. In 2008, the European Union launched a Raw Materials Initiative to deal with its dependence on the foreign supply of crucial minerals. The debate became more visible on the public agenda, particularly after media reports of China blocking exports of rare earth elements in 2010 (see the Introduction).\(^{65}\)

The public and political concerns have persisted. The debate regarding the limits to growth in resource extraction is ongoing in some arenas, and the question as to whether we are exploiting the earth’s last frontiers has resurfaced, as evinced by provocative books like Michael Klare’s *The Race to What’s Left* of 2012. Klare claims that ore concentrations are declining, so that there is not much left to exploit. In the same spirit, researchers are attempting to project whether we have reached “peak minerals”; in other words, whether mineral production has already peaked.\(^{66}\) However, for the most part, researchers have concluded that there are sufficient mineral resources in spite of growing consumption. In *Scarcity and Frontiers*, Edward Barbier argues that depletion is not a pressing problem, but instead it is environmental and social problems caused by mining that will limit future extraction rates.

Metals mined in only a few places have continuously caused major political concerns, and not only China’s dominance has been problematic. In 2001, according to the *New York Times Magazine*, Sony had difficulties getting the Play Station 2 into American stores due to a temporary shortage of coltan (niobium and tantalum) sourced from the Democratic Republic of Congo. Suddenly, the demand for tantalum powder had increased, and prices soared.\(^{67}\) Independent of such price fluctuations, many metals extracted in the Democratic Republic of Congo – notably tantalum, tin, tungsten and gold – have been identified as “conflict minerals.” The extraction of those metals feeds into ongoing conflicts in the area.\(^{68}\) There are few alternative suppliers; according to the U.S. Geological Survey, almost seventy percent of tantalum

\(^{65}\) British Geological Survey 2015.

\(^{66}\) Mason et al.2011; For a discussion on the rhetoric’s of peak oil see Bridge and Wood 2010.


\(^{68}\) Nicholas Kristof, “Death By Gadget,” The New York Times, 26 June 2010; see further Eichstaedt 2011.
production in 2016 was sourced from the Democratic Republic of Congo and Rwanda, and the metal is essential in smartphones and electronics. There are few substitutes. These issues have obviously caused concern among industrial and business actors. Ultimately, judging from the China and Congo experiences, our increased demand for metals in technologies including smartphones and solar cells will continue to play a part in the shaping of new (geo)political landscapes.

**Categorization of metals**

This section sheds light on the diversity of metal categories which different actors have used. It gives a broader understanding of how actors have classified metals because of their properties and what they have perceived to be the most prominent features over time.

Metals are often categorized into various groups, for example, base, industrial, and precious metals. Scientists, industrial and political actors classify metals according to their various applications and use. They do not always agree on which category the metals belong to. Physicists and chemists have different scientific definitions of these groupings, and historians have used different classes. Moreover, the categorizations have changed over time. These changes are reflections of our society’s use of metals, its needs, demands and perceptions. This section discusses some of the most commonly used categories.

The most important metal historically is clearly iron. It is usually referred to as a base metal, meaning that it is abundant. Other base metals – abundant and relatively cheap – include zinc and lead. These metals are fairly evenly distributed and are mined in large quantities. Lead is used mostly in bullets, gasoline and batteries, and zinc is largely used in brass and galvanization. In a world without zinc, as the popular American TV series *The Simpsons* reminds us – there would be no car batteries, no telephones with rotary mechanisms and no handguns (as the firing pin is made of zinc).  

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69 The metal was also extracted in Brazil, Burundi, Canada, Ethiopia, Mozambique and Nigeria. U.S. Geological Survey 2017.  
70 The Simpsons, Season 3, Episode 16, *Bart the Lover*. 
In contrast to the bulky base metals there are the **noble metals**, which share specific chemical properties. In particular, they do not react easily with other elements – they are resistant against corrosion and oxidation. According to the chemical definition, this category includes ruthenium, rhodium, palladium, silver, osmium, iridium, platinum and gold.\(^{71}\) Physicists have another definition of noble metals that includes only copper, silver and gold.\(^{72}\) Historians, on the other hand, often use the category **precious metals**, which largely overlaps with the noble metals. The most common precious metals are silver and gold, platinum and palladium – shiny metals used in jewelry and coins. They bring with them a notion of privilege and luxury. The classification of metals as precious has varied throughout history. Before the 1880s, aluminum was also seen as a precious metal. It was perceived as rare and valuable, and was also used in jewelry. The same goes for copper; before electrification, it was mainly used in jewelry and coins – and thus categorized as precious.\(^{73}\) Today copper is generally considered to be a base metal.

As if these categories were not enough, there are also **industrial metals**. These can include the alloying metals tungsten and manganese, but also copper, aluminum, zinc, tin, lead and nickel. In the 1952 Van Royen et al. stated that:

> The machine age has wrought one significant change, in that major emphasis has shifted from precious metals and gems to coal, iron ore, petroleum, and certain other critical industrial minerals such as tungsten and manganese.\(^{74}\)

Perceptions of minerals and metals as “industrial” indicates how they have been used. Platinum was initially thought of as a precious or noble metal, but it eventually also came to be seen as an industrial metal – used in electrical equipment and in chemical processes.\(^{75}\) Similarly, as mentioned above, aluminum was perceived as a precious metal throughout most of the nineteenth century, but when it became possible

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\(^{71}\) Britannica 2015.
\(^{72}\) According to physicists metals are noble if the d-bands of the electronic structure are filled and the Fermi level is not crossed. As a result only copper, silver and gold are noble metals, see Hüger and Osuch 2005.
\(^{73}\) Topik and Wells 2012, p. 98.
\(^{74}\) Van Royen et al. 1952, p.1.
\(^{75}\) Aldersey-Williams 2012, p. 29f.
to produce it on a larger scale from the abundant mineral bauxite, aluminum came to be seen as an industrial metal and sometimes even as a base metal.\textsuperscript{76}

In the steel industry, one of the largest industries today, one important division is \textbf{alloying metals}. These are metals that are added to iron and carbon – the basic constituents of steel – to create various steel types with different properties. Examples of alloying metals are chromium, cobalt, manganese, nickel, tungsten and vanadium. Stainless steel usually contains around eleven percent chromium, but other steel alloys contain only about one percent of an alloying metal. An older name for these metals is \textbf{side metals} (\textit{Nebenmetalle} in German).\textsuperscript{77} Alloying metals are mostly considered to be those used with iron, but not exclusively. Brass and bronze are two early examples of the long historical legacy of non-iron alloys. Copper, lead and aluminum all have alloying metals, which are added to improve and alter the properties of the base metal to better fit a specific purpose.

As far as steel is concerned, it is important to distinguish between \textbf{ferrous} and \textbf{non-ferrous} metals. As “ferrous” designates a metal that contains iron, only iron, and sometimes steel, although it is not a metal in its own right, can be referred to as ferrous. Nonferrous metals, according to the Merriam-Webster dictionary, are those “not containing, including, or relating to iron.”\textsuperscript{78} This implies that there is another chemical definition having to do with how the metals are refined, as non-ferrous ones are usually refined through electrolysis rather than smelting.

Further, there is another division of metals into \textbf{light metals} and \textbf{heavy metals}. This chemical and physical distinction between the categories has to do with the density of a metal. Light metals include aluminum, beryllium, lithium and magnesium. While this is a scientific definition, historians have identified lighter metals as the ones which enable a different kind of society to emerge. Lewis Mumford in \textit{Technics and Civilization} draws our attention to “lighter metals”, aluminum in particular, during what he calls the Neotechnic phase, roughly defined as starting around 1870. Rare metals, which Mumford also claims to be an

\textsuperscript{76} Aldersey -Williams 2012, p. 255f; Coulson 2012, p. 307-312.
\textsuperscript{77} Rubinfeld 1928.
\textsuperscript{78} Merriam-Webster 2015.
important part of the Neotechnic phase included tantalum, osmium and tungsten, to name a few, that made it possible to manufacture various compact industrial objects – light bulbs, airplanes and steel. Mimi Sheller makes a similar analysis in *Aluminum Dreams*, pointing to aluminum as the material underpinning a new era of “light modernity.” However, most metals are heavy metals. In environmental history, heavy metals are associated mainly with toxicity, in the context of both the environment and public health. From this perspective, the most important heavy metals are cadmium, mercury, and lead. Yet, according to the scientific definition, this category includes most metals, with the metal exhibiting the highest density being osmium – otherwise considered a noble or rare metal.

**Radioactive** metals are yet another category of metals that has received attention from historians of various disciplines. The concept of radioactivity was introduced when scientists discovered special properties of certain metals. The metals defined as radioactive today, such as uranium and thorium, were not described as such during the late nineteenth and early twentieth centuries. Thorium, for its part, was found to be one of the main sources of lighting. These metals have taken on a whole new political meaning, shaping political relations and landscapes, especially from World War II on, having become transformed into valuable nuclear materials as was explored by historians such as Itty Abraham in “Rare Earths” and Gabrielle Hecht in *The Power of Nuclear Things*. Clearly, in the nuclear age, uranium is thought of less as a metal than as a fuel and as a building block for nuclear weapons.

**Critical and strategic metals**

While metals are sorted into categories depending on their properties or areas of use, some of them have also been classified by actors as **strategic** or **critical**. These concepts, introduced after World War I, originated in a fear of shortage and strong supply dependence. In other

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79 Mumford 2010, p. 229f.
80 Sheller 2014.
81 Nordling and Österman 2006.
82 Bright 1949.
83 Abraham 2011; Hecht 2012.
words, they are based on the actors’ perceptions of the difficulties involved in accessing them.\textsuperscript{84}

Judging from the existing literature, classifying a metal as strategic or critical implies that it is essential to national defense, society and/or economy, and that it is to a large extent imported from potentially unreliable suppliers.\textsuperscript{85} For the most part, the distinction of a metal as strategic rather than critical relates to whether it is vital to the military-industrial complex. Alternative interpretations have stated that a strategic metal is perceived as being subject to higher insecurity regarding imports.\textsuperscript{86} Swedish state actors, for instance, seem to have preferred classifying metals as critical rather than strategic (see Article IV). Interestingly enough, there does not seem to be a consensus as to what exactly each of these different terms implies.\textsuperscript{87}

When resources became classified as critical or strategic, state actors were more likely to make active efforts to secure supply.\textsuperscript{88} As a result, steel companies, for instance, have had an interest in classifying their alloying metals as critical or strategic – and, in so doing, compelling the state to accommodate their needs and assist them in securing access. In any case, strategic minerals have occasionally occupied a prominent place in foreign policy – at times, the perceived need to secure access has actually shaped foreign policy decisions.\textsuperscript{89}

Historically, critical and strategic metals have belonged mainly to the categories of alloying, base, industrial and lighter metals – with some variation over time. Various metals have been classified as strategic over the years; for example, tungsten around World War I, while in the 2010s the most commonly discussed and publically known critical metals are the rare earth elements.\textsuperscript{90} In Article IV, I discuss in greater detail how Swedish actors’ classifications of metals as critical have varied over time.

\textsuperscript{84} See Ingulstad 2011, p. 6f; Haglund 1986.
\textsuperscript{85} Haglund 1984.
\textsuperscript{86} Haglund 1986; Lesser 1989, p. 149.
\textsuperscript{87} See further Chakhmouradian, Smith and Kynicky 2015.
\textsuperscript{88} Storli 2013.
\textsuperscript{89} Eckes 1979; Ingulstad 2011; Haglund 1986.
\textsuperscript{90} See e.g. British Geological Survey 2015; European Commission 2010.
Whether or not a metal becomes strategic or critical varies spatially and temporally, as all nations differ in their mineral endowment. Additionally, it can also depend on where a metal is refined. A metal may be mined in numerous countries, but some of these nations may still be dependent on imports of the refined metal from another country. Thus, domestic geological occurrence is only part of the explanation as to why metals become classified as strategic and critical. Another part of the explanation is the use of the metal. If an imported metal suddenly becomes necessary for a specific application, for instance, military technology, then it could become regarded as strategic. Thorium, for example, became perceived as “strategic” for many countries that felt the urge to develop nuclear weapons after Hiroshima and Nagasaki.⁹¹

The underlying reasons why certain resources are categorized as strategic or critical cannot be understood without a political and historical context. The severe shortages in 1917 and 1918 due to World War I were decisive in determining and shaping actors’ understandings and perceptions of how raw material shortages could affect industrial and military power. Military forces were also affected by technological developments, applying more specialized technologies which made them increasingly dependent on imported metals. Political actors had not yet realized it, but this trend became apparent in the context of World War I. As a result, the concept of strategic metals was introduced in the 1920s. But the concept of “critical metals,” meaning those that were easier to access than strategic metals, came later, in the 1930s, according to Alfred Eckes.⁹²

The Americans compiled lists of those strategic metals of which high amounts were needed for military applications. Their list grew from 17 just after World War I to contain 75 elements by the end of the Korean War.⁹³ Clearly this was reflected in the increased dependence on imports of unique metals within specialized technologies (see metal shortages in historical perspective). In 1952, Van Royen et al. declared that the United States’

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⁹¹ Abraham 2011, p. 110.
⁹² Eckes 1979, p. 43; Haglund 1986.
⁹³ Ingulstad 2011.
domestic resources can no longer meet the ever expanding demand and the resulting dependence on imports has necessitated the addition of these metals to the growing list of strategic materials in which the country is deficient and the adoption of measures to offset the accompanying security hazard.\textsuperscript{94}

Over time, the concept of critical and strategic metals shifted somewhat, from being strongly correlated with defense to being thought of instead as crucial for industry in general. One reason, as noted by Ian Lesser in \textit{Resources and Strategy}, was probably that the military’s demand for metals was gradually outpaced by industrial demand.\textsuperscript{95} From 1973, as David Haglund claims in “The New Geopolitics of Minerals,” the concepts of critical and strategic resources expanded to cover greater fears of scarcity, in the form of politically induced disruptions to the supply of minerals due to uneven distribution.\textsuperscript{96} The late 1970s and early 1980s have been referred to as an era of “resource wars.” The United States and Western Europe, in the context of the Cold War, feared that the Soviet Union’s influence in resource-rich regions of sub-Saharan Africa, Asia and Latin America would cause political instability and disrupt resource flows. In particular they worried that the Soviet Union’s interference in South Africa would block the West’s access to many strategic and critical minerals.\textsuperscript{97} In 1981, Reagan’s U.S. Secretary of State Alexander Haig confessed that he had “long been troubled by what is rapidly becoming a crisis in strategic and critical materials.”\textsuperscript{98} Another U.S. official, James Santini, was concerned that if the Soviet Union were to gain “control over southern Africa,” this would give the Russians “control of at least 15 of the most strategically important minerals in the world.”\textsuperscript{99} Resources, especially strategic and critical ones, became highly visible on the political arena during this time.

The same debates have arisen again in the twenty-first century. The European Union in 2008 encouraged its member states to renew their

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\begin{itemize}
\item \textsuperscript{94} Van Royen et al. 1952, p.2. For more information on the Paley report see Eckes 1979, p. 175-198.
\item \textsuperscript{95} Lesser 1989, p. 148-149.
\item \textsuperscript{96} Haglund 1986, p. 221.
\item \textsuperscript{97} Lesser 1989, p. 147-157.
\item \textsuperscript{98} Ibid., p. 153.
\item \textsuperscript{99} Lesser 1989, p. 154.
\end{itemize}
mineral strategies and list their critical metals. Not long after, in 2011, the British Geological Survey published its first risk list, ranking metals based on supply risk. In 2014, the Geological Survey of Sweden followed, listing Sweden’s critical metals. Similarly, the U.S. Department of Energy compiled a table of metals of importance in “clean energy.” Rare earth elements came out on top of the lists by the British Geological Survey and the U.S. Department of Energy.

The criticality here seems to stem mainly from perceptions of political risk and the fact that resources are unevenly distributed and mined in only a few countries (while physical depletion is much less of an issue) together with an increased demand. Industrial and state actors who were dependent on access to such metals feared relying on imports of rare earth elements from the People’s Republic of China – as China had threatened to halt exports of these metals, as well as Chinese supplies of tungsten and antimony and of conflict minerals from the Democratic Republic of Congo. Such dependencies were usually described in relation to geopolitical turmoil. Evidently, while the conceptualizations discussed here have changed considerably over the years, the fear of looming shortages due to potential supply disruptions, a specter of scarcity, has remained a constant in the debate.

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100 Frøland and Ingulstad forthcoming; European Commission 2010.
101 Sveriges Geologiska Undersökning 2013; British Geological Survey 2015; U.S Department of Energy 2010; European Commission 2010. There was no mention of military applications, only the industries’ demand at large.
The Specter of Scarcity

Theoretical approach
I have been inspired by a range of history of technology approaches as outlined in seminal works such as Wiebe E. Bijker, Trevor Pinch and Thomas P. Hughes’s edited 1987 book *The Social Construction of Technological Systems* and Thomas P. Hughes’ 1983 *Networks of Power*, along with more management-oriented works such as James Utterback’s *Mastering the Dynamics of Innovation*.¹ I am also inspired by Actor Network Theory (ANT), especially Bruno Latour’s *Science in Action: How to follow scientists and engineers through society*.² These broad and well established theoretical frameworks are not used explicitly in the case studies, but they have inspired my overall perspectives and lines of reasoning.³ However, in the history of technology field, the nature of resources and scarcity experiences are often neglected, or analyzed merely on the margin.

When seeking to understand why actors defined metals as resources, felt the need to secure access to metals, why they experienced scarcity and why they decided to cope with scarcity in certain ways, I have sought further theoretical inspiration from other fields. Thus, I have turned to political ecology, geography, environmental humanities and environmental history where resources and scarcity experiences do play an important role.

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³ The above mentioned constructivist theories have been helpful for thinking about how and why technologies have taken the form they have, and how actors from different social groups have been able to influence technologies. But, they also have shortcomings. For instance the SCOT approach tends to be social-deterministic and as such may hide the roles which artifacts and the physical environment can play. Using *Actor-Network Theory* could shed light on these material aspects, but the methodological principle of following the actors in this approach have made it difficult to use it for some of my case studies, simply because of limitations in the source material.
What is a resource?
Why is a mineral defined as a resource? In this thesis I argue that it is essential to understand the social processes that transform a material object into a resource. In my theoretical approach I take inspiration from scholars such as geographer Gavin Bridge, who claims that a resource comes into being only when someone defines it as such. As the geographer Erich Zimmermann put it back in 1951, “resources are not, they become.” A mineral is a resource to someone only when he or she has decides that it is useful for a specific purpose and in a specific social context. In line with Bridge and Zimmermann, my view is that rocks and chemical elements have no intrinsic value in themselves.

Humans give material substances value and decide that they have a demand for, as Zimmermann put it, “neutral stuff.” Thus, resources enter into a normative economic system. “Rare earths became valuable,” concludes Itty Abraham, “when they moved from scientific curiosity to industrial use,” that is, when they became attractive for manufacturers. Ole Sparenberg in “The Deep Sea as a Contested Space” tells a story of how manganese nodules in the deep seabed came to be perceived as a resource, creating a need to regulate access to the sea floor, but later on it was transformed again, this time into insignificance – not worth exploiting. In a similar vein, environmental historian William Cronon in Nature’s Metropolis shows how animals became meat at the turn of the twentieth century. He writes that “mammals began to dwindle as soon as the market economy placed a price on their skins,” showing that traditional relationships to animals changed when they were assigned an economic value. This process of valuing and devaluing is constantly ongoing. Jodi Frawley, in “Prickly Pear Land” for example, discusses how the “prickly pear” changed from being a plant to become a weed in Australia, taking over the environment. In Morocco, however, it is highly

5 Zimmermann 1951, p. 15.
6 Ibid., p. 15.
7 Crist 2013.
8 Abraham 2011, p. 102.
9 Sparenberg 2015.
valuable, used for cosmetics. These shifts are significant, as they mirror cultural values and perspectives on the environment in specific contexts. Anthropologist Anna Tsing observes how a mushroom is sought after in some parts of the world while in other parts it may not even be worth noticing.

The place where the resource is situated eventually receives boundaries through political and economic processes. Such boundaries can be renegotiated. A mineral deposit, for instance, may have a seemingly fixed boundary at a certain moment of time, but such demarcations can change quickly due to, for example, demand, extraction methods, political incentives, environmental laws and price. The area in which it is contained is revalued in social and economic terms, which can also change its relationship to its surroundings. The economic price of the area as a resource tends to have priority over other values the place might have had. Others’ interpretations of the area, as a potential leisure area or as a national park, for example, are often overlooked. Not always, however. Environmental historian Gregg Mitman in “Hay Fever Holiday” describes that the growing health tourism industry – privileged people going to sanitariums in need of fresh air – was economically more important to the White Mountains, Maine, than resource extraction. To conclude, what a resource is, and to whom, and continues to be an ongoing debate. The process in which areas are transformed into resources is highly dependent on the context within which they are situated.

Theorizing scarcity

In this thesis I argue that we are more likely to capture the true nature of scarcity if we view it not as an objective, geological fact, but rather as a perception, an experience, a feeling of uncertainty based on a fear of a current or future shortage. While certain metals undoubtedly occur less frequently than others, I oppose the view that scarcity is merely a property of the physical world. In other words, it is not sufficient to research actors’ future projections and the size of reserves. Such simple

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12 Woman’s cooperative, Agadir, Morocco, Guided Tour, 2nd January 2017.
13 Tsing 2011.
14 Mitman 2003.
calculations cannot explain their experience of the matter. To fully understand scarcity experiences it is necessary to take the analysis further by asking questions such as: Why did they begin to worry? What were the underlying reasons?

To understand such experiences, I mainly take inspiration from political ecologist Lyla Mehta’s edited book *Limits to Scarcity,*\(^\text{15}\) where she suggests that “scarcity rarely takes place due to the natural order of things.”\(^\text{16}\) From the perspective developed in this thesis, the interesting part of such a statement is not the shortage as such, but rather who formulates the statement and why they experience scarcity. Additionally, the field of geography has encouraged me to further understand how the identification of scarcity can affect actors. How a resource is classified, according to the geographer Gavin Bridge, tells us more about the society we exist within than about the thing itself.\(^\text{17}\) It mirrors society’s values and demands and visualizes contexts in which resources are perceived as scarce. Opening up the black box of scarcity can thus contribute to a broader understanding of the role of resources in a more entangled web of politics, power, technology and culture.

Scarcity is commonly perceived to be linked to economics. Economists usually define scarcity as a mismatch between supply and demand.\(^\text{18}\) In other words, if there is a greater need than can be supplied, a resource is scarce. Such simple definitions may seem reasonable, but they do not help us to understand scarcity as it is actually experienced. As Jasveen Jairath claims in “Advocacy of Water Scarcity: Leakages in the Argument,” it takes away the social dimensions of the problem.\(^\text{19}\) Furthermore, it contributes to a view that scarcity is isolated from other events at a certain point in time, neglecting such experiences. Neglecting the underlying reasons behind supply and demand discrepancies also makes it difficult to understand why actors worried, and also why they chose to pursue certain strategies to cope with their fear of scarcity. It is crucial to take experiences seriously.

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\(^{15}\) Mehta 2010a.

\(^{16}\) Mehta 2010b, p. 3.

\(^{17}\) Bridge 2009.

\(^{18}\) See e.g. Barbier 2011.

\(^{19}\) Jairath 2010, p. 218.
Actors can experience scarcity for many reasons. Many resources, including metals, are finite. A common line of thinking about scarcity is related to depletion of resources. Ultimately, a resource is described as depleted when it is not possible to extract more under prevailing conditions. However, there are differences in opinion on the extent to which depletion is actually a problem that hinders the growth of industries. Some argue that increased prices and technological development historically has transformed low-grade ore bodies – previously not deemed exploitable – into attractive deposits, and that there is no reason to believe that such development will cease. Thus, the only obstacles to extraction are environmental and social problems. Following along this line of reasoning, scarcity occurs only as a temporary situation and can always be alleviated. This perspective has been challenged by authors like Michael Klare in *The Race to What’s Left*, who argues that the ore concentration is decreasing, and soon all the viable deposits on the earth will have been exploited. According to him, we will soon be facing a global resource scarcity problem. In my opinion, both of these arguments are flawed, contributing to a simplistic understanding of resources and scarcity, and failing to account for experiences of scarcity which are often not related to geology.

Scarcity experiences and questions regarding possible depletion can also be related to technological trends and technological change. Most obviously, the development of new technologies typically generates new demand for one or the other metal, in a way that fuels scarcity experiences. Recently, for example, there has been a great debate on whether it will be possible to extract enough lithium to supply batteries for a growing number of electric cars. However, technological trends can also ease scarcity experiences, as new innovations may lead to a situation where a given metal is no longer necessary in a particular technology. Historical examples include the switch from tin to aluminum cans (which somewhat eased tin scarcity), or the decision not to manufacture a lead-in wire of platinum but instead use other less scarce...

20 Pierce 1989; Barbier 2011.
21 Klare 2012.
22 See also Sabin 2013 for a discussion on whether technological development will eliminate scarcity.
23 Vikström, Davidsson and Höök 2013.
metals (Article II). Sometimes new artificial substitutes make a resource redundant, eliminating particular scarcity experiences (Article V).

Even though resources are geologically limited, they are not necessarily scarce, as Nicholas Xenos concludes in “Everybody’s Got the Fever”. In other words, the mere perception of scarcity does not necessarily imply that resources are lacking in a geological sense. Different actors can have contradictory views of whether a resource is scarce or abundant. Such contradictory views are interesting to analyze, as they bring to the fore the social context of how actors perceive resources and why. Samer Alatout, in “States’ of Scarcity” explores how water in Israel was transformed from abundant to scarce through a shift of power and the centralization of technologies. There were two competing notions of water, as abundant and as scarce, and eventually the perception of water as scarce came to be the dominant one. This was the case even though there was no geophysical water scarcity in the region. Actors’ perceptions of scarcity (or abundance) yield multiple understandings of the complex relationships between resources and actor’s perceptions of them.

Another crucial component in explaining scarcity is fear of a future (rather than immediate) shortage. In Wood, Joachim Radkau claims that there was no real wood crisis in eighteenth-century Europe. However, people periodically feared a future scarcity of wood. The fear of future shortages often compels actors to take action, or to use rhetoric about shortages to legitimate their actions. Radkau argues that actors often underestimated the amount of resources available, while also showing that the fear of a shortage made them even more interested in actually quantifying the remaining resources. In fact, these actions may well have alleviated future shortages – and so in the end they did not come about.

Access and control are key elements of perceptions of scarcity. Jairath claims that scarcity ultimately is the “exclusion of the majority from a

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24 Xenos 2010, p. 32; Samuel and Robert 2010.
27 See further Bridge and Wood 2010.
28 Radkau 2012, p. 182.
resource."

If a few control most of a resource, others may find it scarce. It is a matter of control, access and power. On a local scale there may be a shortage of one or the other resource, whereas there is none on a global scale — it is a question of allocation. It is crucial, states Mehta, to think about for whom resources are scarce. If regulating a resource is outside one’s control, or if the one who needs it is in a position with limited power, it is more likely to be scarce. Jairath argues that water scarcity is a result of the (mis)management of water, a distribution of water which excludes most people — hence it becomes scarce to them. Another obvious reason why certain groups experience scarcity is that the resource is too expensive for them. One example is food. The wealthy experience an abundance of food, while people who cannot afford to buy food suffer from starvation. Similarly, Radkau claims in Wood that new ways of evaluating the forest, as a market resource, made the locals suffer, as they struggled to afford the free market price.

When something is viewed as scarce it is given a higher value. “Key to scarcity,” notes Mehta, “is the idea of value.” Perceiving something as scarce creates the urge to gain access to it before someone else does. This is a dimension of power: having something that is attractive to others creates a hierarchy. In a book by one of my favorite authors, Tove Jansson’s Comet in Moominland, Hemulen — a character who is easily offended by the slightest of critique — is collecting flowers, and is especially excited about the rare ones. He dreams of them and wants to possess them before anyone else does, desiring to control a rare resource. This logic is not limited to fictional characters. Nicholas Xenos, as well as Sajay Samuel and Jean Robert, argued that it is desire which makes actors claim that resources are scarce. In other words, it is the “wants” more than the “needs” that are the deciding factor in shaping scarcity, and whether companies or people are prepared to make economic sacrifices to get access to a resource perceived as scarce.

30 Mehta 2010b, p. 3.
31 Jairath 2010.
32 Mehta 2010b, p. 4.
33 Radkau 2012, p. 158.
34 Mehta 2010c, p. 69.
36 Xenos 2010, p. 33f; Samuel and Robert 2010, p. 109f.
If a country, a region, or a municipality is dependent on resources that are not available locally, actors often perceive those resources to be scarce. Since long-distance trade flows become crucial for access in such cases, and actors may fear supply disruptions, which can, in turn, reinforce the perception of scarcity. Yet the local or domestic unavailability of a resource cannot in itself explain their experience. The supply of a resource does not necessarily have to be problematic just because it is imported. The nature of the relationship to the supplier and how functional the trade is are far more important. A resource that is traded across political borders can be difficult for certain nations to access, depending on factors like transport modes and logistics, tariffs, and various international agreements, whereas for others access may not be a problem at all.

The perceptions of a resource as scarce can greatly affect policy and politics. “Scarcity emerges as a political strategy,” argues Mehta, and “it is used to justify certain interventions over others.” It functions to serve “powerful actors.” Alatout shows that certain visions of water as scarce affected Israel’s politics. Similarly, Radkau wondered how serious the complaints about wood scarcity actually were, as scarcity claims could just as well be a strategy to claim traditional rights. In the same vein, governments and companies could view scarcity as an opportunity to make others dependent on them and gain influence in a complex, intertwined world.

**Coping with scarcity**

Actors have tirelessly tried to cope with metals scarcity using a number of strategies. This section describes the most common ones, in a historical perspective. The discussion here is partly based on my own research, while I have also taken inspiration from earlier accounts of how actors

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37 Lilliestam and Ellenbeck 2011.
38 Mehta 2010b, p. 4.
39 Ibid., p. 2.
40 Radkau 2012, p. 164.
have dealt with their experiences of resources as (potentially) scarce – including not only metals, but also, for example, energy.41

To begin with, both state and business actors have often attempted to cope with scarcity by increasing **prospecting and exploration activities**, domestically and also in foreign areas (see Articles I, II, III, V). Barbier, in his book *Scarcity and Frontiers*, argues that when a resource is scarce it often results in exploitation of new “frontiers,” areas perceived as empty and remote, previously not subject to extraction activities.42 Historically, this strategy has been strongly linked to the acquisition and exploitation of colonial territories.43 This is a common trait in the literature on global resource extraction in the historical perspective. Alanna O’Malley, for example, discusses how colonial imperial powers controlled and gained access to tin deposits in the Congo during the early twentieth century.44 Petroleum, which took on strategic importance starting in the 1910s, was also sourced mainly from colonial regions, such as the Dutch East Indies and imperial Russia’s Transcaucasian domains.45 Sometimes, companies and nations turned to domestic resources. The German state, when cut off from supplies during World War I, tried to find new deposits within its borders. The Hungarian state similarly turned to its own deposits of bauxite.46 Another frontier is the sea floor, which has occasionally been perceived as a potential source of supply for various resources.47 Klare in *The Race to What’s Left* claims that the Arctic is the last resource frontier on earth to be exploited.48 Such places have been possible to map through advances in technology, with prospecting methods having taken leaps over time. The possibility to use remote sensing, air planes and satellites, enabled actors to prospect rugged and remote terrain.49 The use of such technologies can be regarded as responses to perceived resource scarcity.

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41 Actors have used similar strategies in coping with energy shortages as well as metal shortages.
42 Barbier 2011.
43 See for e.g. Dumett 1985.
44 O’Malley 2015.
45 Black 2012.
46 Storli 2013.
48 Klare 2012.
49 Sabins 1999.
Another classical strategy has been to strive for diversification (Article III). If the resource needs of a particular company or state are supplied from several sources, it decreases actors’ vulnerability to disruptions and price variations while strengthening security. Resources from different sources are not always compatible, however.\(^{50}\) While in theory it seems unproblematic to use ores from various sources, using resources interchangeably can create unforeseen problems because the composition of the resource can vary. Light bulb manufacturers, for instance, preferred Brazilian monazite to American ore, as the latter contained impurities that had to be removed before use (Article II). Thus, when attempting to switch from one supply source to another, manufacturers could suddenly face difficult challenges.\(^ {51}\) Yet it was often possible to solve such problems by developing new chemical and technical processes, thus allowing for a more diverse supply.

A closely related strategy for companies and state actors is to open or buy new mines – domestically or in foreign countries. By controlling the deposits on which they depend, actors become less vulnerable – or so they have often felt.\(^ {52}\) In this context, actors have commonly attempted vertical integration as a strategy to cope with scarcity (Articles II, III). If a company controls the entire supply chain (yet a step further than controlling mines or deposits), then it is even less vulnerable to disruptions of various kinds.\(^ {53}\) These strategies were common, particularly during the first half of the twentieth century. Light bulb manufacturers, for instance, attempted to control the whole production chain (Article II). Similarly, in the 1930s Swedish steelworks aimed at controlling the resource flows in order to be less dependent on other suppliers. Espen Storli claims in “The Global Race for Bauxite” that multinational companies often played crucial roles in starting up mining operations, in cooperation with state actors of major powers. State actors began by sending out their own geologists to locate deposits.\(^ {54}\) By establishing control over mineral deposits, refining sites and also transports, a nation or company hoped to ensure future access.

\(^{50}\) See Alexander 1978, p. 444-445; Freese 2006.

\(^{51}\) Cf. Högselius, Åberg and Kaijser 2013, p. 47-49.

\(^{52}\) Storli 2013.

\(^{53}\) See also Bergström 2009.

\(^{54}\) Storli 2013.
Another strategy is substitution, which manufacturers have experimented with continuously. There are different types of substitution: either certain metals with similar properties could substitute each other, or alternatively, a different material could substitute a metal (see further Articles I and IV). While substitution is common, however, the result may not be as good as with the original metal. In the steel industry substitution has been a common strategy. At the beginning of the twentieth century, substitution was largely pursued in Europe, as local resources were no longer sufficient. During the World Wars, substitution was decisive to manage resource shortages (Article I). Wartime Germany was unusually successful and innovative in this regard. When German manufacturers could not access copper during World War I, for example, they attempted substituting it with aluminum. Nathan Rosenberg emphasizes that substitution and technological change can be difficult to distinguish. They are inevitably interlinked, as technological development is often what makes substitution possible. A new composition of a material, based on more common and less expensive metals or an artificial substitute, is an alternative. One example is cryolite; a mineral defined as a resource when it became crucial in aluminum production from the 1880s on. The aluminum industry found a synthetic substitute and eventually the need for natural cryolite decreased (see Article V). Thus, substitution is a strategy used when there is a crisis at hand, sometimes seemingly enforcing technological development.

Manufacturers using substitutes could also be said to switch to a new technological path (Article II). Such path switching may sometimes provide solutions to scarcity of resources. During the 1930s, for example, the Germans, according to W. O. Alexander, anticipated a future shortage of aluminum and developed alloys that used magnesium in place of aluminum. Another example is the tungsten lamp, which was more successful than its predecessors partly because the material used for its filament was less scarce than the other metals the lamp industry had experimented with (see Article II). It should be noted, however, that path switching may stem not only from attempts to cope with resource

56 Storli 2013.
scarcity; sometimes an alternative technological path is pursued to reduce weight, or to increase strength or durability. Hence, alternative technologies, while largely intertwined with substitution, appear to be more about developing technologies further, sometimes because of a shortage, but sometimes out of a desire to change the properties of a material or product.

Another approach is recycling (Articles I, II, and especially IV). This strategy has historically been used to decrease many resource shortages. Metals, being finite resources, have long been reused in a variety of applications. However, manufacturers have often found it challenging to recycle metals. It has typically been expensive, chemically difficult or energy intensive. Historically, it can be seen that recycling is strongly connected with advances in chemistry and technological development. There are also differences in the products that are recycled. Businesses have continuously recycled steel and iron. However, products in the digital era, such as smartphones and computers, are now becoming smaller with increasingly many features. Such objects are much more difficult to recycle because of their complex chemical composition. Particularly in times of crisis, manufacturers have continuously attempted to recycle to a greater extent. Metals can be recycled from used products, from waste and scrap, and also from old infrastructure. Often there are economic reasons for recycling metals. Altogether, recycling is and has been crucial for manufacturing industries. In the debates about sustainability and reuse in the early twenty-first century, the recycling of metals has been a particularly prominent strategy. However, to recycle even more efficiently, it is necessary to technologically and chemically improve the processes (see further Article IV). According to Graedel et al., only a few metals are recycled to any substantial extent, but more could potentially be recycled if policies regarding recycling were to be reformed.

Resource savings constitute a further strategy. Initiated by both state and business actors, it has been pursued mainly during times of crisis and in particular during the World Wars, when the usual flows of resources

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59 Graedel et al. 2011.
60 See e.g. Vikström et al. 2013; Bardi 2014, p.214f
61 Wallsten 2015, p. 11f.
were interrupted. It has also been popular when the resources in question were either geologically scarce or very expensive. Commonly, manufacturers have attempted to use less of the resource or state actors have initiated rationing (see Articles I, II and IV). An extreme type of resource savings has been to ration and gather jewelry in order to use the metals for military applications. The U.S. government, according to Lael and Killen, forbade the use of platinum in jewelry in 1918, and collected the metal during World War I.\(^63\) Jonas Scherner states in “Tin and the German War Economy” that Germany managed its tin supplies during World War II partly due to resource savings, by using tin for war purposes only, and also by reducing exports of goods containing tin.\(^64\)

**Stockpiling** is yet another frequently used strategy to come to terms with scarcity, particularly when there is high dependence on imports; this is common for energy resources and many minerals (Article IV). While businesses may amass a moderate stockpile of metals and minerals, they have often indicated that stockpiling was a task better taken on by the state. State actors in many countries, including the United States and Sweden, introduced stockpiling programs for resources, including metals.\(^65\) The United States originally introduced its program in 1939. The idea was that the stocks, in case of war, should be able to meet essential needs for a period of at least five years.\(^66\) Nazi Germany initially decided against adopting such a strategy; by the time the authorities did consider it, metal prices were found to be so high that such a program was simply too expensive.\(^67\) After the 1973 oil crisis, many countries again became interested in stockpiling various resources; Lesser concluded that in Europe, only France and Sweden had such stocks, while the United States continued its program.\(^68\) A nation with a stockpile, so goes the theory, will be less vulnerable and can avoid both price variations and short-term supply interruptions, while its manufacturing industry can

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\(^{63}\) Lael and Killen 1982.  
\(^{64}\) Scherner 2015.  
\(^{66}\) Ingulstad 2011, p. 4f; Lesser 1989, p. 108f.  
\(^{67}\) Sparenberg 2017.  
continue to operate. This decreases dependence on foreign suppliers, at least in the short term, depending on the size of the stocks.\textsuperscript{69}

Another type of strategy is to commit to \textit{bilateral or multilateral agreements} (Article IV). Such agreements can ensure future supply for years to come, and they can be made by both state and business actors, often jointly. Countries of various sizes have different experiences regarding agreements of this kind. For smaller countries with limited demand and limited capital, the main possibility is multilateral agreements, as Hans-Otto Frøland and Mats Ingulstad conclude in “Europe cannot engage in autarkical policies,” simply because they account for only a small portion of a given exporting country’s total output.\textsuperscript{70} In contrast, countries with greater demand are typically so important for the exporter that they can sign bilateral agreements, since the exporting nations are likely to be interested in ensuring a larger part of their exports through certain arrangements. Bilateral agreements can definitely increase stability on the market, argue Högselius, Åberg and Kajser in their analysis of natural gas in Cold War Europe. This effect is not limited to bilateral agreements; multilateral agreements can also stabilize markets and create potential for long-term relationships.\textsuperscript{71} Thus, such agreements can ensure access and decrease perceptions of scarcity.

A closely related option is to develop \textit{friendly relations with exporting countries, or, alternatively, joint operations to exploit deposits}. Trustful international partnerships, according to Högselius, Åberg and Kajser, do reduce vulnerability.\textsuperscript{72} This kind of strategy decreases the political risk of supply disruptions. Germany, finding itself cut off from supplies of bauxite during World War I, managed to establish such good relations with Hungary that it was able to form joint ventures with domestic companies to operate mines in that country. Similarly, Japan cooperated with other, neighboring states, British Malaya and the Caroline Island, to begin operating bauxite mines

\textsuperscript{69} Cf. Högselius, Åberg and Kajser 2013, p. 49-51.
\textsuperscript{70} Frøland and Ingulstad, forthcoming.
\textsuperscript{71} Högselius, Åberg and Kajser 2013, p. 45-46.
\textsuperscript{72} Ibid., p. 41-43.
during the interwar era. These partnerships allowed the countries that were dependent on imports to ensure a relatively stable supply.

All in all, actors have mobilized a variety of strategies to cope with resource scarcity. Underlying many of them are improvements in technology, enabling manufacturers to identify new mineral deposits, create substitutes, or develop techniques to recycle materials. Several of the strategies discussed here are closely intertwined, such as prospecting and diversification, or substitution and technological path switching. It is evident that business and state actors are closely entangled in trying to cope with scarcity, and it is necessary to account for both when analyzing the strategies they pursue.

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73 Storli 2013.
74 Rosenberg 1976, p. 256.
Method and sources

Overall methodology
Writing this PhD thesis has been a long journey and, as it often happens, the scope and focus of my research have changed considerably over time. I originally set out to write a thesis about why strategic metals were classified as such from 1870 until 2015. The reason for choosing a long time period was to understand the slow changes occurring over time. Per Lundin argues that historians have to address important, current-day problems and put them into a historical perspective, by looking at the processes that transformed the past into the present. Thus historians can challenge the notion that this was the way things always had been, and also question what seems to be inevitable or natural.\(^1\)

To break the subject down and study it, I decided to use the case study method. As Robert Yin puts it in *Case Study Research*, the case study method is relevant when asking “how” and “why” questions, in other words, descriptive and explanatory questions. Case studies usually give in-depth answers to these questions.\(^2\) Only one case study is limiting, according to Yin, as it is difficult to base general observations on it.\(^3\) This dissertation covers a long time period and a broad scope, with five case studies from 1870 until 2015, allowing me to draw more general conclusions. It presents opportunities to explore the same problem from different points of view, in different places, and in different time periods, and thus come to a more universal understanding.

After some time I recognized that what I actually was studying was metals scarcity. Research questions often change during the course of a work, especially when, as Swedish historian Göran B. Nilsson notes, the researcher is confronted with primary sources.\(^4\) I was no exception here. The engineers in the journal I first studied did not discuss strategic metals, which was my hypothesis, but debated scarcity. It is important, John Tosh argues, to not force oneself on the material, but rather to alter one’s questions to accommodate the sources.\(^5\) Simultaneously, while

\(^1\) Lundin 2016.
\(^2\) Yin 2009, p. 9.
\(^3\) Ibid., p. 15.
\(^5\) Tosh 2000, p. 78f.
reading and searching the literature on the subject, I realized that scarcity was a better way to describe what I analyzed, and would thus be a more fruitful frame for my project. So I changed directions slightly. Apart from that, I also recognized that in analyzing how actors responded to metals scarcity, it would be impossible to study industrial actors without including state ones. Throughout the thesis I have used metals scarcity as the key framing concept, as both an analytical and empirical tool.

Overall, my thesis analyzes actors’ experiences of metals scarcity and how they coped with them. Their actions are often indicators of their future expectations; otherwise they would not be concerned about supply. As historians we have to take serious consideration of actor’s visions of the future. If we neglect to do so, it is all too easy to end up writing “backward history,” as Göran B. Nilsson warns. In other words, we might find ourselves trying to explain why what happened actually had to happen. Clearly, this deterministic view would limit other possibilities, pieces of the puzzle which historians can reveal or shed new light on. To minimize this risk, one solution is to actually follow the actors, by trying to see history from their vantage points and telling the story as they experienced it, an approach I have attempted wherever the source material has allowed me to do so.

Additionally, in order to understand the actors’ experiences and remain in the proper temporal context, I have consistently used their conceptualizations of what contemporary analysts referred to as “strategic,” “critical,” or “scarce” metals. There is no consensus on the terms (see the section “Critical and strategic metals”). However, as I am not interested in the exact definitions, but rather in the actors’ experiences and their responses, whenever possible I have used their wording. In my own analysis, though, I have used the concept of metals scarcity.

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Selection of case studies

This dissertation is based on five case studies, which represent my own interests, curiosity, gaps in previous research, and the project’s empirical and theoretical aim.

Historically, new resource frontiers have long been framed as an answer to resource shortages. One of the areas which currently figures prominently in this context is Greenland. I first came across Greenland as a metal frontier while working on my master’s thesis. The media were focused increasingly on the Arctic and especially Greenland, claiming that the island’s minerals were of interest because of global warming and the melting ice. The government of Greenland echoed this narrative. However, every statement belongs to a context, so to understand why this narrative was so prominent, I decided to contextualize it by exploring Greenland’s mining history on the basis of secondary literature and the full set of the mining industry’s most important magazine, the Mining Journal, focusing on why the mining industry actually invested in and explored the island for its mineral deposits from the 1981 until 2014 (see further Article V).

To further understand why actors experienced metals as strategic and critical, I decided to analyze the debate on expanding mining activity, in other words, why engineers perceived which metals as strategic and critical. Such debates shed light on the underlying reasons for scarcity experiences. The time period I selected was 1870 – 1918. There were two reasons behind this choice. First, my funding came largely from a larger research project, Sweden and the Origins of Resource Colonialism, 1870-1930; and second, most previous research used the aftermath of World War I as a starting point for the debate on strategic and critical metals. I decided to challenge the latter notion by designing a study of metals scarcity during the period before 1918 in Sweden. To get a long, uninterrupted historical perspective, I consulted a technical journal targeting the users of metals – engineers and industrialists. There are a few technical journals that could have been of interest, but the most prominent at the time was the well-known Swedish engineering journal

7 It was here that it became evident that they debated scarcity, and I decided to focus on scarcity instead.
Teknisk Tidskrift, which reported in detail on various issues in Sweden during the time (see further Article I).

The study of Teknisk Tidskrift pointed to further interesting questions, which I subsequently integrated into Articles II, III, and IV. On several occasions, writers in the journal reported that metals used in incandescent lighting were scarce. Aside from incidental remarks in the journal, I discovered that previous research had not explored this issue further. As it seemed to be of central importance, I decided to pursue writing an article on this topic. I applied to the Chemical Heritage Foundation in Philadelphia, which awarded me a fellowship to write the article and put at my disposal their resources, books and collections to research the subject (see further Article II). Apart from a large library, the Chemical Heritage Foundation held a collection of objects, including light bulbs, and a museum where some old light bulbs were on display. These objects inspired the article further and gave me a greater understanding of the difficulties raised in the manufacturing process of objects. My initial intention was to write a longer history of metals scarcity in light bulbs, being inspired also by the potential supply problems that twenty-first-century manufacturers of LED lamps had in securing access to gallium, a metal extracted for the most part in China. While this would clearly have been interesting, I decided to focus on the formative period of incandescent lighting, which also coincided with the timeline of the above mentioned research project.

Another outcome of Article I was that numerous metals which the Swedes perceived to be scarce were alloying metals used in steel manufacturing. Sweden, a large steel-producing nation, did not have domestic deposits of these alloying metals. Then how did they access and manage their supply of alloying metals? These questions led me and my project collaborators Per Högselius and Dag Avango to the steelworks’ archives. We decided to approach Sandviken, one of the largest and oldest steel works in Sweden, and a prominent manufacturer of special steel – in which alloying metals are a crucial component. We asked the archivist whether Sandviken’s archives contained any sources on the company’s approach to accessing alloying metals, particularly from foreign countries. The archivist sent us an excerpt from a book published in 1938 in connection with Sandviken’s 75th anniversary. Here we found that the company had invested in a
The Specter of Scarcity

Turkish chromium ore mine. We decided to further investigate this, and it turned out that the archive held several boxes with correspondence regarding the matter. This material also led us to additional archives, namely those of Jernkontoret and of the Ministry of Foreign Affairs, who were also involved in the undertaking. From these sources we began to unravel the story.

Similarly, to some extent Article IV takes its inspiration from Article I, while also drawing on a literature search at the beginning of the project, which I had carried out while exploring which minerals and metals had been perceived as scarce or strategic in Sweden. During my work on Article I, I had found in Teknisk Tidskrift detailed notes on an “Industrial Meeting” held in 1917, that is, at the height of World War I. At this meeting political and industrial actors discussed resource shortages, with access to metals being the subject of lively debate. Moreover, I came across other sources that discussed and listed which metals were critical in Sweden during different periods. While there was a substantial body of research on critical metals in the United States, there was little information on how smaller countries had dealt with these issues over time. Thus, I became curious about how the notion of critical metals changed over time in a small country such as Sweden. In the end, the article came to span a period of nearly a hundred years, allowing me to cover changes over a longer period of time. This approach also allowed me to provide a perspective on today’s issues regarding critical metals. While the sources were inconsistent, they still allowed me to understand the contextual reasons why metals were described as scarce over a long time period.

Some of the case studies could have been dissertations of their own. One could argue that focusing the entire thesis on either the Swedish steel industry (Article III), Sweden’s critical metals (Article IV) or the light bulb industry (Article II) during a specific, shorter period of time would have been a good research strategy. While such an approach would have given greater depth, it would simultaneously have limited my understanding of how actors experienced and coped with metals scarcity

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8 Hedin 1938, p. 98-99.
across time and place. The phenomenon of metals scarcity is not specific to a certain industry, but a common problem for manufacturers and state actors all over the world. The different case studies aim to shed light on this, and the fact that metals scarcity is an ever changing concept. Together, the articles contextualize and show the complexity of metals scarcity. Each study adds a part of the answer to the overall research questions, and allows more general conclusions to be drawn, contributing to the existing body of historical research on scarcity and on metals. In other words, the study has external validity.

Sources
This dissertation is situated within a historical tradition based on primary sources in the form of journals, archival collections and governmental reports. Journals are my main primary source. While scholars often use journals as secondary sources, reporting on events, what companies have done, etc., I used them as primary sources, meaning that I analyzed debates, opinions and phrases as they appear within the journal. In this way I was able to reconstruct how metals scarcity was discussed in society at various points in time. Another reason to choose journals as primary sources is that they comprise an uninterrupted series of documentation. They can also be regarded as a symptom of the discourse in society. Hence, it was possible to follow a specific topic or issue, the development of an industry, a metal or a reoccurring debate over a long period of time. My studies spanned periods of 30 to 50 years and journals are a solid, consistent source in which it is possible to trace these long-term trends. In this thesis I analyzed articles from:

- *Teknisk Tidskrift*, 1870–1918
- *Engineering and Mining Journal*, 1880–1914

*Teknisk Tidskrift* is a Swedish engineering journal published by *Svenska Teknologföreningen* (The Swedish Engineering Association) starting in
1870. Its focus has, however, shifted over the years. From the beginning, the weekly issues covered numerous topics, including chemistry and metallurgy/mining, and electrotechnology, to name a few, plus contemporary debates. From 1893 the journal was divided into one weekly main part, and a series of thematic booklets, which were published eight times a year, devoted to themes such as architecture, civil engineering, chemistry and metallurgy/mining, electrotechnology, mechanics and shipbuilding. The last issue was published in 1977, after which only the 1967 spin-off focusing on technology, *Ny Teknik* (New Technology) was published.

Returning to the early years, *Svenska Teknologföreningen* was an association for engineering students from the Royal Institute of Technology in Stockholm, founded in 1861. Initially only engineers from the Royal Institute were allowed to join, but from 1910 it was open to engineers from other universities and institutes as well. Over time, a majority of the Swedish engineers became members of the association, which represented the engineering profession and the industry’s interests and also focused on technological development, and this was reflected in the journal. Although *Teknisk Tidskrift* was available to only a limited number of engineers to begin with, it was still one of the leading journals at the time, and also began to account for a broader variety of technological developments. In spite of being somewhat limited, the journal brought up highly relevant issues to a growing community of engineers at various positions within Swedish society.\(^{10}\)

The other journals I used were published in English. The U.S.-based *Engineering and Mining Journal (E&MJ)* was first issued as *The American Mining Journal (AMJ)* in 1866, as a competitor to the western-based, U.S.-focused *Mining and Scientific Press (MSP)*. The editors of *American Mining Journal* strived to present a broader perspective on the mining industry. The broader interest was already evident in 1868, when the editor, Rossiter Richmond, changed the journal’s name to *E&MJ*. One of the main contributors and later co-editor, engineer Richard Rothwell, wanted the journal to focus on coal and steel, and he pushed for the journal to develop in this direction. However, it also suffered from some problems in the early years, with its leadership changing several times in

\(^{10}\) Fjaestad 2016; Fjaestad and Kaiserfeld 2015.
the early 1900s. In spite of such problems, the journal survived and was later absorbed by McGraw-Hill, a large publisher, in 1917. *Engineering and Mining Journal* was, according to Michael Coulson in *A History of Mining*, influential in terms of mining opinion in the United States; as it continued to expand with time, the publication came to be the world’s leading journal in its field. Overall, it targeted a larger audience, reporting on the metallurgical and mining industries in numerous countries, on prospecting finds, and on the changing markets for minerals and metals. As the editors were very interested in minerals and metals, from 1893 until 1941 the *Engineering and Mining Journal* was complemented by an annual supplement, *The Mineral Industry: Its Statistics, Technology and Trade* (MI), a publication which specialized on the mining industry and specific minerals in the United States and globally. It had separate chapters devoted to specific metals and minerals which provided detailed information on uses and where the metals were extracted.\(^\text{11}\)

The second English-speaking journal that I have used is the London-based *Mining Journal*, a weekly global newspaper focusing on mining development, commodities, investments and company updates. It was firstly issued in 1835, and is still an important journal for the mining industry. Harry English started the paper, based on the conviction that minerals were crucial for the industrial revolution, and a publication on mining was essential. To begin with the journal focused on reporting about reforms in the British mining industry, but as it became evident over time that Britain was dependent on minerals from numerous foreign countries, the journal then came to focus on the world as a whole. The *Mining Journal* also bought additional journals, adding to its wider knowledge base of mining. The journal has continued to be one of the world’s most influential over the years, expanding and also publishing additional supplements, for instance, targeting countries, commodities and areas of interest. The journal was a platform where not only mining companies, but also investors could learn about new mining activities, geological exploration, mining technology, commodity markets and investment opportunities, as well as understanding how technology is

\(^{11}\) Coulson 2012, p. 405-407.
driving resource exploitation. As such, the *Mining Journal* constitutes an important historical document.

**Archives** are, of course, another crucial primary source. One of the case studies, Article III, partly takes a business history perspective and explores, as mentioned above, how a Swedish steelwork, Sandvikens Jernverk AB, tried to gain access to metals it perceived as scarce or critical from 1925 until 1950s. These questions could be answered only through archival research, starting with the company archive. As Sandviken was not the only actor involved, we also consulted the archives of the other participants. From the Sandviken sources we learned that the Swedish legation in Constantinople was deeply involved in the Turkish project, and another important actor was Jernkontoret, a branch organization for the Swedish steelworks. Thus we decided to include these three different actors. Their archives held valuable correspondence, board meetings, memos and detailed material about imports of raw materials. All in all, we thus made use of the following archives:

- Sandvikens Jernverk’s archive
- the archives of the Swedish legation in Constantinople and Ankara
- Jernkontoret’s archive

Lastly, governmental reports are another important source in this thesis. I focused on reports targeting commodities and strategies to cope with future shortages. The value of governmental reports lies in the insights they give into what state actors view as important for the country at large, and which debates they consider central. I used the Swedish Official Investigations of the State (Statens offentliga utredningar, SOU), reports by the Industries Institute, and reports from the Geological Survey of Sweden and the Ministry of Enterprise and Innovation. These reports were compiled by state actors. Additionally, I also consulted reports from the government of Greenland, the Geological Survey of Denmark and Greenland, and the European Union.

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12 Coulson 2012, p. 400-402; see further *The Mining Journal*.
13 It would have been possible to include the Swedish Foreign Ministry’s archive but this side of the story was already included within the materials, and it did not add as much to our story.
Taken together, these three groups of primary sources provide multiple perspectives on how business and state actors perceived and responded to potential metal shortages. “No accounts can recover the past as it was,” claims Keith Jenkins in *Re-thinking History*, and “we ‘judge’ the accuracy of historian’s accounts.”\(^{14}\) As historians we try our best to get as accurate an understanding of the past as possible, but this is inevitably an outcome which depends on the chosen sources. All sources are, of course, incomplete, inexact, and colored by interests or judgements. To get a more nuanced picture, historians can and should use multiple sources.\(^{15}\)

Other sources complement those I have described here.\(^{16}\) For example, the starting point of Article V was to question why media portrayed the melting ice as the main reason why mining companies became interested in Greenland’s minerals. The media reports can in this case be described as tendentious; however, this impression made it even more interesting for me to analyze them. Additionally, at times I brought in fiction, as it often brings to the fore opinions that are not reflected in other documents and sources. Along with fiction I paid attention to how popular culture, including TV series and films, have portrayed resources, metals, and metals scarcity. This gives an understanding of the public debates and knowledge about metals within society.

Moreover, I consulted material objects, such as light bulbs, which I took an interest in while working on Article II. Historians, I argue, can ask new questions by consulting objects and paying attention to material culture. Gazing at the filament in a bulb, for example (see figure 4), inspired me to ask questions regarding the actual difficulties in creating and manufacturing filaments. This is not explicitly mentioned in Article II,

\(^{15}\) Tosh 2000, p. 89.
\(^{16}\) It is simply impossible to account for the huge amounts of information that are available today with the digitalization and multitude of sources. There are always some shortcomings depending on one’s primary material, as it has limitations. Almost all sources presented here are printed documents and records. Written sources such as reports can be polished and may only tell a certain part of the story, see Myrdal 2012; Hodder 1994. According to John Tosh 2000, 89, we should collect information from all relevant sources. While this of course would be advantageous, in my case there are simply too many possible sources. To strictly follow Tosh’s advice would perhaps make the story richer, and may strengthen the argument, but at some point the value of yet another source does not add to the story.
but nevertheless it was a source of inspiration. Moreover, whenever possible I consulted places. I visited Greenland twice in the context of writing Article V, and this has given me a much greater awareness of the tensions on this island regarding mining, and the strains between Greenland and Denmark. I had the opportunity to visit abandoned mining sites on Disko Island, off Greenland. Traveling there made visible the problems of climate change; the melting sea ice and glaciers actually present challenges in terms of shipping. It also provided insights on how mining operations could function in a colder climate. While this is not made explicit in Article V, it contributed to my background knowledge.

Finally, I used statistics on production data and prices to get a better understanding of how much the production of metals has increased and how their prices have developed globally. Here I relied mainly on data provided by the U.S. Geological Survey.

![Figure 4. Glowing light bulb filament.](attachment:image.jpg)

Source: Photo by Hanna Vikström

In 1973 Göran B. Nilsson pointed to the importance of relevance and representation for a historian when choosing sources.\(^\text{17}\) In other words, does a source answer the question, and is it relevant to use? Additionally,

\(^{17}\) Nilsson 2005.
is it representative for the period and event which we are studying? The journals I studied are representative for engineers and the mining industry, and as such they can answer the questions which my research has posed. All of them are technical mining or engineering journals targeting – and written by – engineers and company representatives. Therefore, they are vital sources for understanding how these actors, who have also been the most important metal users, perceived metals scarcity and how they tried to cope with it. Additionally, the journals gave valuable insights into the broader context of the period, about which topics were up for debate and which issues made it into the news.  

Regarding the other case studies, the archival materials as well as the governmental reports were crucial documents for the industry and state actors, and they clearly accommodate their views. Thus, I argue that the studies in this thesis have internal validity – they do not allow ungrounded conclusions to be drawn.

This thesis covers a long time period, from 1870 to 2015. This in itself is a challenge, but at the same time an opportunity, as it facilitates an understanding of how gradual changes occur and what distinguishes different time periods from each other. Of course, one problem with such a study could be that the sources I used are of different kinds and not always consistent over the entire time period examined. While this is not a problem for the individual case studies, it may be an issue when comparing them. However, it allows for multiple perspectives. Journals have become more specialized over time and may not give the same context in the 1990s as they did in the 1870s. The past stretches all the way into the present. It proved more challenging to write about the most recent period. Article V and part of Article IV cover the period from 1990 to 2015, and this very recent past can be more difficult to understand from a historical point of view, as it is part of ongoing changes.

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18 At times I set out to find more specialized journals. Article II focuses on incandescent lighting, and I searched for journals which were geared towards the lighting industry. It turned out that none of the interesting sources that I could read, published in English, covered the whole period and could thus not be considered a reliable and valid source. When working on Article I, I considered other journals, for instance, Kemisk Tidsskrift, but its scope was too limited compared to Teknisk Tidsskrift, which as it turned out included articles from Kemisk Tidsskrift, hence my decision was not too difficult.

19 Yin, 2009, 40-45.

processes and shifting political relations which are still being reshaped by various actors. In spite of these problems, I argue that historians should try to make sense of the present, as we are well equipped to provide insights and distinguish trends. To conclude, studying metals scarcity from an historical point of view allows for a greater understanding of the present, laying bare the historical processes in which actors define metals as scarce, strategic or critical.

**Delimitations**

The topic of this thesis invites numerous perspectives and research questions. I have chosen an actor-based approach, focusing mainly on the manufacturers of various products (companies) and state actors. In other words: those who experienced metals scarcity and had to cope with it firsthand.

My study of how business and state actors experienced and coped with metals scarcity might potentially have benefitted from adding further perspectives. At times this thesis acknowledges chemists and scientists who worked within the industry, but for the most part the perspectives of scientists have only a limited presence here. While scientists have contributed to the discovery and use of metals, they needed only limited quantities to experiment with, and did not need to worry about gaining access to large quantities in the future to manufacture a product. Also, in keeping with Nathan Rosenberg’s argument that technological knowledge was ahead of scientific knowledge around the turn of the twentieth century, focusing first and foremost on engineers and industrialists appears highly relevant.\(^\text{21}\) Thus this thesis focuses on manufacturers, who needed to develop technology and who were highly dependent on access to metals. In this context, I did not further research the extent to which extent mining, purification and refining technologies affected actors’ perceptions, but merely acknowledged that they can be contributing factors when they expressed concerns about access to sufficient supplies.\(^\text{22}\)

\(^\text{21}\) Rosenberg 1982, p. 141-159.
\(^\text{22}\) See Sheller 2014, p. 35f, for a discussion about how the smelting process influenced the possibilities to extract aluminum.
Another group of actors with only a limited presence in this thesis is geologists. They are a crucial category in the history of metals, as they identified deposits, and judged their concentrations and spatial distribution based on their knowledge, instruments and assays. Their mapping is often the basis for estimates about whether domestic production can meet demand. Hence they can clearly affect perceptions of scarcity – but again, they are not the ones who actually experience it.

An alternative possibility would have been to focus on large trading houses and their role in international trade. The London Metal Exchange, for example, could have been interesting to study, since it was here that many metals prices were determined. But again, such actors and arenas were hardly the ones who experienced or had to cope with metals scarcity. Another, related focus would be on how international trade agreements, tariffs and import duties affected perceptions of scarcity and high prices. While these are interesting and relevant aspects, I chose not to prioritize this perspective. Only when actors mentioned them as reasons for perceiving metals as scarce were they included in this dissertation.

One aspect that has been much discussed in the literature, by researchers such as Ian Lesser and Phillip Le Billon, concerns resource access related to wars. Here I chose to study neither countries directly involved in war, nor access to resources as a means of starting a war. However, as metal flows are transnational, they are undoubtedly affected by wars, civil and global conflicts. This aspect is, of course, included in my research and a factor in the perception of metals as scarce. But direct involvement in armed conflict on resources is beyond the scope of this thesis.

In addition, it might have been interesting to study scarcity in relation to environmental activism. Local organizations and people were sometimes able to hinder or delay the development of mines, for instance, or put political pressure on state involvement in foreign countries. The views of environmental organizations and the voices of local populations are largely missing from my thesis. Experiences of metals scarcity could potentially originate from planned mining projects not being realized as a consequence of environmental protests. In Greenland, for example, there

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23 Their knowledge is often perceived as a hard fact, while it is in fact continuously revalued and based on social norms and factors. See e.g. Westermann 2015.
24 See further Le Billon 2012; Lesser 1989.
were numerous protests against lifting a ban on uranium mining in order to allow the mining of rare earth elements (see Article V for further details). A deeper analysis of such aspects could have supplemented the story, but was excluded in order to obtain a more focused narrative.
Summary of articles
This compilation thesis contains five articles. Together they explore how state and business actors experienced and coped with metals scarcity from 1870 to 2015. Taken together, they show how perceptions of metals scarcity are intertwined with their distinct historical contexts. The articles focus on actors’ experiences and perceptions of scarcity, and their fears of future shortages (often related to new technological trends). Such fears contributed to various actions, through which actors hoped to avoid ending up actually facing a real shortage. Hence, these actions and strategies are another crucial part of the thesis.

Article I analyzes why engineers in Sweden perceived metals as scarce during the period from 1870 to 1918. Articles II and III focus on why certain manufacturers – in the incandescent lighting and the steel industries, respectively – feared shortages, and how they dealt with metals scarcity. Article IV explores which metals were listed as critical in Sweden from 1917 to 2014, why they ended up on such lists and how state actors thought that metals scarcity could and should be coped with. Article V explains why the global mining industry became interested in exploiting a specific region’s – Greenland’s – metal riches.

Article I. A Scarce Resource? The Debate on Metals in Sweden, 1870–1918
Which metals were viewed as scarce in Sweden during the period from 1870 until 1918, and why? This question is the focus of this article, which deals with the time period of Sweden’s industrial breakthrough, when manufacturing, infrastructure development and consumption expanded and industries therefore began to use a greater amount and variety of metals. I closely analyzed all metal-related articles in a prominent Swedish engineering journal – Teknisk Tidskrift – to understand why metals were perceived as scarce and how actors coped with such shortages.

Metals scarcity was a recurring topic in the journal. In total, the authors in the journal reported on twenty metals they perceived as scarce during this time: aluminum, antimony, cerium, chromium, copper, lead,
magnesium, mercury, molybdenum, nickel, platinum, radium, tantalum, thorium, tin, titanium, tungsten, uranium, vanadium, and zinc. I found that seven factors influenced the actors’ perceptions of scarcity: geological scarcity, technical difficulties in extracting the metals, the lack of substitutes, price variations, the limitations of transport infrastructures, domestic unavailability and legal regulations. Many of the factors were interconnected, and they often reinforced each other, contributing to strong perceptions of scarcity. For example, in cases where a lack of domestic mining was combined with disrupted infrastructure and high international prices, the scarcity experiences of industrial actors became extremely intense.

Most of the metals that were described in *Teknisk Tidskrift* as scarce were elements that were used in new technologies, and which were not mined domestically. Platinum, for instance, was repeatedly described as scarce; it was increasingly used in a number of industries from chemical to dental technologies as well as in incandescent lighting. Similarly, throughout the period alloying metals for steel manufacturing were also considered to be scarce. Other metals were described as scarce at certain occasions, such as cerium, which was used in gas mantles, and uranium, which during a brief period of time was used in steel manufacturing.

**Table 2. Metals perceived as scarce in Sweden, 1870–1918**

<table>
<thead>
<tr>
<th>Years</th>
<th>Scarce metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1870–79</td>
<td>aluminum, nickel, tin, tungsten, vanadium</td>
</tr>
<tr>
<td>1880–89</td>
<td>copper, molybdenum</td>
</tr>
<tr>
<td>1890–99</td>
<td>cerium, chromium, lead, magnesium, platinum, titanium, thorium, uranium, zinc</td>
</tr>
<tr>
<td>1900–09</td>
<td>nickel, platinum, tantalum</td>
</tr>
<tr>
<td>1910–14</td>
<td>radium, platinum</td>
</tr>
<tr>
<td>1914–18</td>
<td>aluminum, antimony, chromium, copper, lead, mercury, molybdenum, magnesium, nickel, platinum, tin, tungsten, vanadium</td>
</tr>
</tbody>
</table>

While metals extracted in only a few places clearly concerned the actors – platinum from the Urals in Russia was a case in point – the resulting dependencies on certain countries was not described as a geopolitical
problem until the outbreak of World War I. In the midst of the war there was an acute shortage of resources. The transnational flows which had long sustained the industries were disrupted. A side effect of this was that the far-reaching dependencies became visible.

It should be emphasized that Swedish scarcity experiences and the list of metals that Swedish manufacturers perceived as scarce would certainly be different in another country. Many of the metals which the Swedish engineers described as scarce were metals used in the manufacturing of special steel – a crucial industry in Sweden. In countries without a prominent steel industry the list of metals described as scarce would look quite different. Scarcity is a national or even regional experience and needs to be understood in its specific geographical context.

Another important point is that when the actors experienced a shortage they, unsurprisingly, tried to find a solution to alleviate it. Hence, most perceived deficiencies led to activities such as increased geological exploration or searches for substitutes, domestic or non-domestic.

**Article II. The Struggle for the Perfect Glow: Metals Scarcity and Incandescent Lighting, 1880–1914**

This article explores the history of light bulbs from the perspective of metals scarcity. It covers the period from the 1880s, when manufacturers and inventors were developing various types of electric bulbs, until 1914 when the tungsten light bulb had taken over the market. The questions at focus are: how did metals scarcity affect the evolution of incandescent lighting technologies? Where did the lamp manufacturers get their metals from? What strategies did they use to acquire them? And to what extent did the evolution of lighting technologies shape resource extraction – and resource scarcity perceptions – around the world?

Numerous earlier studies have targeted the lighting industry. Most studies, however, do not account for the materiality of lighting. Light bulbs were introduced to society along with electrification, and inventors experimented with manufacturing various bulbs in the late nineteenth
The Specter of Scarcity

One of the critical problems was the metal filament, on which the character of the bulb’s glow depends. The inventors faced a daunting challenge: to manufacture a cheap lamp with a pleasant glow. Several of the metals they experimented with were extracted in only a few places worldwide, and had never before been used commercially. This made lamp companies perceive of numerous metals as scarce.

At the time two different competing systems were in place, gas and electric lighting, and manufacturers of both types of lamps struggled with metals scarcity. In the end, metals scarcity became a factor shaping the technological path of the light bulb. The pleasantness of the glow was dependent on the metal, and the manufacturers had to balance consumer expectations in this respect with profit considerations and issues relating to accessing raw materials.

The period in focus here was formative in shaping the light bulb, on a market where there were many different competing lamps. One of the first electric bulbs had an osmium filament. Lamp manufacturers continued to search for alternatives, but it was difficult to find a metal with such specific properties. In 1902–3 German chemists at Siemens & Halske managed to purify tantalum, which became the basic raw material for a new lamp that competed successfully on the market for some time. However, the manufacturers of both the osmium and the tantalum lamps considered these metals to be scarce and expensive, and they had to struggle hard to secure their metal needs. One reason behind their scarcity experiences was related to the lack of an extraction system. This, in turn, had to do with the fact that the metals in question had never before been used commercially – and thus not mined before in large quantities.

Meanwhile, the threat from the electric carbon light created an incentive for the already established gas light manufacturers to improve their gas mantles and reduce production costs. One of the reasons why they succeeded was that they were able to use a specific mineral – monazite. Monazite made for a different kind of glow that the customers found more pleasant. The triumph of the monazite lamp resulted in radically increased demand for this mineral. It was found in only a few places, and the best deposits were located in Brazil. By 1903, a German syndicate

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1 Kaijser 1986, p. 184.
The Specter of Scarcity

acquired a monopoly on Brazilian monazite, and the price quickly doubled. This troubled many non-German manufacturers – the syndicate kept prices high – and they feared scarcity.

Clearly, there was a large, constantly expanding market, to be conquered with a successful product. But to manufacture profitable bulbs and filaments, the manufacturers needed to keep metal prices down. They attempted to do this through resource savings, substitution, by improving extraction methods, as well as through vertical integration, the exploration of new resource frontiers and by opening new mines. Yet it proved difficult to get a functional and profitable system in place.

Eventually, General Electric managed to manufacture and patent a bulb based on tungsten in 1907. The tungsten bulb was more efficient than the previous ones. It soon drove all other lamps from the market, including the osmium and tantalum lamps as well as the gas mantles. While the tremendous success of the tungsten lamp was largely a result of General Electric's marketing strategies, patents and hard-working chemists, I argue that one important reason behind its victory was that tungsten was not a scarce resource to the lamp manufacturers. In contrast to most other metals tried out previously, there was already an extraction system in place for tungsten. This was because the metal was already used on a significant scale in steel manufacturing, where it had come to play the role of a key alloying metal.

Article III. Swedish Steel and Global Resource Colonialism: Sandviken’s Quest for Turkish Chromium, 1925–1950

This article deals with the emergence of chromium as a strategically important and scarce resource in the manufacturing of stainless steel. More precisely, it explores how Sandviken’s Jernverk – a leading Swedish steel company – coped with chromium scarcity. How did a company from a country without overseas colonies manage its supply of this metal in an age of resource colonialism, where the British Empire controlled a majority of the chromium deposits?
In the 1920s chromium emerged as a crucial constituent in stainless steel. To manufacture such steels, manufacturers had to add ten to twenty percent chromium to the iron and coal. Swedish steelworks became highly concerned about their future chromium supplies as the British Empire controlled around two-thirds of production.

At the same time, Gustav Wallenberg at the Swedish legation in Constantinople had identified a growing export market for Swedish industry in the newly established Republic of Turkey. Wallenberg had identified chromium imports as a possible way of maintaining the desired trade balance. He played an active role in informing the Swedish Foreign Ministry and later the Swedish steelworks about this opportunity – and in convincing them to take action. Additionally, the Turkish government, lacking capital itself, wished to avoid becoming dependent on the large imperial powers. Instead, Turkey sought cooperation with “small, neutral” countries, a description which the Swedes thought matched them perfectly. The latter leapt at the opportunity. Operating through a consortium comprising several Swedish steel companies, Sandviken decided to secure the chromium ore reserves it needed for its stainless steel production by prospecting and opening chromium mines in Turkey. Turkey’s chromium resources were among the largest in the world, and in

Figure 5. Orhan Brandt.

Source: Photo provided by Bo Selander
contrast to other important chromium-mining regions – such as Rhodesia and Baluchistan – it was not controlled by the British. Thus it was one of the few possibilities to avoid dependence on Britain and become more self-sufficient, a major trend in the protectionist interwar era.

![Figure 6. Chromium mining in Turkey around 1930. This photo from around 1930 shows Turkish workers extracting and transporting chromium ore from one of the Swedish-controlled mines.](image)


Initially, Swedish steel manufacturers were very optimistic. They founded a Turkish company to prospect and mine large volumes of chromium, employing as the company’s managing director a Turk with ancestors from Sweden, Orhan Brandt (see figure 5). The prospects seemed promising for the Swedish steel industrialists: based on their acquisitions of Turkish chromium mines, it may be suggested that they could have ended up as a large chromium producer. The consortium received offers from interested chromium buyers from various countries. Brandt eagerly supported the consortium’s growth. The Swedish steel industrialists, however, were reluctant to invest enough to become a large player, a rival
to the British on the global arena. That arena, they thought, being dominated by the large imperial powers, did not suit small “mill owners” who lacked experience with working in “faraway colonies.” Soon the Swedes encountered a range of problems. The small scale of the mining operations was precisely what made the venture unprofitable (see figures 6 and 7). After some time the steelworks and the Swedish legation also began to distrust Orhan Brandt. To make matters worse, the world economic crisis caused metal prices to plummet. They replaced Orhan Brandt with other mining directors. However, none of them was successful and some even ended up in jail, under arrest for fraud and embezzlement.

Figure 7. Oxcarts transporting chromium ore. Oxcarts were the main mode of transportation for the Swedish-controlled chromium ore on its way from the mine to the nearest railway station


The Swedes desperately tried to pull out of the affair, having given up all hopes that it could become a success. Another reason for their withdrawal was that the British Empire’s dominance on the world chromium market had diminished. By the mid-1930s it was no longer perceived to present such a serious threat to the steelworks. However, it proved difficult to withdraw from the business, and only in 1950 did Sandviken officially let
go of the mines. The Swedish steel industry actually continued to import Turkish chromium ores in the postwar era – though now without any direct involvement in their mining operations.


World metal production has increased at an exponential rate over the last hundred years. In spite of this skyrocketing abundance in terms of supply, however, access to metals has continued to worry manufacturers and states. This has been evident particularly from World War I on, when the disrupted flows and radical price increases suddenly made international dependencies visible and industries stood before great supply problems. In this context, actors began to classify crucial metals out of their immediate reach as critical or strategic. While research on the history of critical metals has focused on the needs and strategies of actors from large countries, and the United States in particular, this article explores which metals Swedish actors classified as critical from 1917 until 2014, why they experienced them as such and how they coped with scarcity.

The article is based on four different Swedish reports/meetings published/held at different points in time: the Swedish Industrial meeting in 1917, the report “The free world’s resources” of 1954, the Swedish Official Investigations of the State, “Mineral Politics” of 1980, and a report by the Geological Survey of Sweden from 2014. In all four cases, the debate on critical resources was burgeoning internationally as well. All of these sources bring up the issue of Swedish critical metals and have either lists or tables outlining which metals were more critical than the others (see table 3).
Table 3. Sweden’s critical metals, 1917–2014.²

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<tbody>
<tr>
<td>Aluminum</td>
<td>x</td>
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<td>x</td>
<td>x</td>
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<tr>
<td>Antimony</td>
<td>x</td>
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<td></td>
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<tr>
<td>Boron</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
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<tr>
<td>Chromium</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Cobalt</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
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<tr>
<td>Copper</td>
<td>x</td>
<td>x</td>
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<td></td>
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<tr>
<td>Lead</td>
<td>x</td>
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<td></td>
<td></td>
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<tr>
<td>Magnesium</td>
<td>x</td>
<td></td>
<td>x</td>
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<tr>
<td>Manganese</td>
<td></td>
<td>x</td>
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<tr>
<td>Mercury</td>
<td>x</td>
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<tr>
<td>Molybdenum</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Niobium</td>
<td>x</td>
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<tr>
<td>Nickel</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Platina group metals</td>
<td>x</td>
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<td></td>
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<tr>
<td>Rare earth elements</td>
<td>x</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>x</td>
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<td></td>
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<tr>
<td>Tin</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Titanium</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td>Tungsten</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Vanadium</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Zinc</td>
<td>x</td>
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</table>

In Sweden, alloying metals for steel production have been the main concern over the last hundred years, as the steel industry was crucial in Sweden throughout the time period studied here. Other metals made an appearance on the “critical” list and then disappeared. However, with the digital revolution, several new metals used in electronics became listed as critical as well. What is interesting to note is that in Sweden, actors from

² The 1954 report does not provide a table of critical metals, thus those listed as critical are my interpretation of the way the concept of critical metals was discussed.
industry were the ones to call increased attention to these issues by the state in 1917 and in 1954, while the reports from 1980 and 2014 were initiated by state actors. Clearly, the state became more active in mapping Swedish metals scarcity over time.

The reasons why actors feared for the future supply of certain metals were largely connected to price increases, potential supply disruptions because of war or political instability, and soaring demand. Often, the metals were needed either in new products or in products experiencing high demand. During World War I shipping routes were suddenly disrupted. As a result, most metals not extracted domestically were perceived as scarce. In 1954 the situation was different. This time prices had soared because of the Korean War and actors projected a future increased demand. Additionally, they feared that the Soviet Union’s influence might lead to disruptions in the flows of resources. The anxieties regarding the Soviet Union’s influence in resource-rich arenas, particularly in Southern Africa, were even greater in the 1970-80s. In the twenty-first century, metal prices once again skyrocketed, and the geopolitical dilemmas concerning metals supply were increasingly evident, but now it was not so much Russian influence as China’s dominance that the Swedes feared.

The actors envisaged that they could manage shortages though increased domestic production, technological development, stockpiling, international agreements, and recycling. The relative popularity of these strategies varied over time. Throughout the period domestic prospecting was at the fore, reflecting a belief that being more self-sufficient in times of crisis was an essential part of coming to grips with scarcity. Substitution was particularly important during World War I, in 1917, whereas from the 1980s on actors believed international agreements together with stockpiling held great promise to decrease vulnerability. As of 2014, recycling was by far the most prominent strategy. The specter of scarcity thus drove actors to attempt different strategies at different times.
Article V. From Cryolite to Critical Metals: The Scramble for Greenland’s Minerals

Greenland’s minerals are becoming available as a result of global warming, global media claimed around 2010s, with the melting of the island’s vast glaciers being seen as a driving force for prospecting and mining on Greenland (see figure 8). But is that the real reason why international mining companies are interested in investing there? This article, which analyzes all Greenland-related articles in the Mining Journal, sets out to challenge that notion by exploring why mining companies actually wanted to exploit Greenland’s minerals from the 1980s up to 2015.

“Climate change may also help speed the development of new mines, making minerals more accessible as Greenland’s ice-cap melts”
- BBC

“as rising temperatures expose more land for exploration, prospectors are rushing to the far north in the hope of carving out a new mineral frontier”
- The Guardian

“vast new deposits of minerals and gems are being discovered as Greenland’s massive ice cap recedes, forming the basis of a potentially lucrative mining industry”
- The New York Times

“global warming and the thawing of sea ice open up new sea lanes, minerals and oil fields – drawing the interest of world powers from China to the United States”
- Reuters

Figure 8. Media’s perceptions of Greenland as a mining hot spot

Source: Hanna Vikström³

The article’s main claim is that Greenland’s minerals would have attracted attention independently of the melting glaciers. Clearly, the narratives about global warming have increasingly created a global awareness about Greenland’s mineral resources. However, the mining companies’ interest in Greenland’s minerals has to be understood first and foremost in relation to (geo)politics, technological trends, and economic conjectures.

From the 1980s on, metals used in digital technologies have become highly sought-after. Besides increased demand, a key problem for manufacturers was that these metals were mainly sourced from South Africa and Zaire. From the perspective of Western buyers, the future supply of metals from such countries was uncertain at best, due to the ongoing Cold War struggle between the United States and the Soviet Union for dominance in Africa. In this context Greenland appeared to be an interesting and more secure alternative source of supply. The competition between South Africa and Greenland continued in the post-Cold War era. In 1994, for example, prospecting companies became interested in Greenland’s deposits of zirconium, a metal that was extracted primarily in South Africa at the time. However, as South Africa had just abolished the apartheid system, the political climate was uncertain, potentially endangering the country’s mineral exports. More recently, in the 2010s, manufacturers in the West have been increasingly concerned about China’s dominance as a supplier of rare earth elements (see introduction), and concerned about dependence on conflict minerals from the Democratic Republic of Congo (see the section on metal shortages in historical perspective).

This has created increased interest among mining companies in turning to alternative, more reliable countries. Again, one possibility here was Greenland. The island had a unique geology with promising deposits of several metals viewed and listed as critical or strategic – tantalum, niobium, as well as molybdenum, platinum, and rare earth elements. The European Union, too, began to support and encourage mining operations on Greenland around 2010. To the EU, Greenland was a stable political partner (it had even been part of the European Economic Communities until 1985). Additionally, its mineral deposits were located relatively close to continental Europe. The European Union, looking for ways to become more self-sufficient, promoted Greenland as a mining hot spot, regarding
it as a promising possibility for diversifying the supply of critical minerals to its member states.

Figure 9. View from Qullissat. An abandoned coal mining settlement, Disko Island, Greenland, summer 2015.

All this would have been in vain, however, had it not been for Greenland’s government. Like the European Union, it encouraged mining, but its motive was another: it wanted Greenland to become economically independent from Denmark, and regarded mining as a tool to achieve this goal. The government of Greenland skillfully made use of the narrative that climate change, and in particular the melting of sea and inland ice, were making minerals in Greenland more accessible and thereby more profitable to extract. But they also eased mining regulations to attract mining companies. Surprisingly, in its attempts to make the island attractive to international mining companies, in 2013 Greenland’s government even repealed a uranium ban from 1988, to allow the mining of rare earth elements which occur together with the radioactive metal. All in all, the experience of scarcity in an age of high technology and geopolitical tensions made Western actors eye Greenland’s mineral
deposits as an interesting option, in a way that the Greenlanders simultaneously viewed as a major political opportunity.
Concluding Remarks

To judge from the case studies in this thesis, metals scarcity has for the most part not resulted in any acute crisis in which business or state actors actually suffered from not having access to metals. Occasionally, during extreme times, notably World Wars I and II, manufacturers have had to cope with radical price hikes, and supply has been disrupted or limited for a shorter or longer period of time – but these are the exceptions that prove the rule. In spite of the relative lack of actual crises, however, over the years, many actors have acutely experienced the specter of metals scarcity.

Table 4. Factors contributing to actors’ scarcity experiences

<table>
<thead>
<tr>
<th>Factors/articles</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological scarcity</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Technical and economic difficulties in extraction and purification</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Limited or disrupted transport infrastructure</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Legal regulations</td>
<td>x</td>
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<tr>
<td>Price variations/high price</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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</tr>
<tr>
<td>Domestic unavailability</td>
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<tr>
<td>Lack of substitutes</td>
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<tr>
<td>No extraction system in place</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Dependence on a specific supplier</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Increased demand following technological trends</td>
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<td>x</td>
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<tr>
<td>Fear of supply disruptions</td>
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<td>x</td>
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<td>Labor strikes</td>
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<td>Environmental conditions</td>
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A main argument in this thesis has been that scarcity experiences cannot be explained merely in relation to geological depletion or available ores. A range of other explanations for actors’ experiences of scarcity have to be taken into account, as shown in my articles. Several factors – the underlying reasons, appearing in my articles – why business and state actors have come to experience metals scarcity are listed in Table 4. When actors have experienced scarcity they have tried to alleviate it in various ways. In Table 5 I have listed the strategies business and state actors have used to cope with scarcity in my case studies.

**Table 5. Actors’ coping strategies**

<table>
<thead>
<tr>
<th>Factors/articles</th>
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<th>II</th>
<th>III</th>
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<tbody>
<tr>
<td>Geological exploration</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Substitution</td>
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<td>Amending mineral laws</td>
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<td>International agreements</td>
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<td>Diversification</td>
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<td>Vertical integration</td>
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<tr>
<td>Recycling</td>
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<td>Resource savings</td>
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<td></td>
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<tr>
<td>Technical development of infrastructure</td>
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<td>New technological paths</td>
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<td>Developing friendly relations</td>
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<td>Stockpiling</td>
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I asked three overarching research questions at the beginning of this thesis, and these will structure my conclusions as well.

**Smaller nations’ scarcity experiences**

First, concerning scarcity experiences in small countries, my findings indicate that **there were generally minor differences in how actors within a small country such as Sweden experienced and coped with metals scarcity in comparison to larger ones**. For
example, light bulb manufacturers in the United States expressed concerns regarding the scarcity of tantalum, monazite, and osmium in the early twentieth century, and the same debate was echoed in Sweden (Articles I and II). Because of the uneven distribution of some metals, small and large countries, at least in Western Europe and North America, became equally dependent on the vast territories in sub-Saharan Africa, Asia and Latin America, at times viewed as politically unstable. Swedish state actors, alongside American ones, also worried about imports of metals from South Africa in the 1980s in the midst of the Cold War, because they feared that the Soviet Union’s influence would disrupt supplies from that country. Many countries, not only Sweden, were concerned about nickel supplies when Canadian nickel miners went on strikes in 1979, temporarily restricting exports (Article IV). Local events in large exporting countries could lead to restricted exports, and this came to influence actors’ experiences of metal shortages in both smaller and larger states.

But **there were also some notable differences between the scarcity experiences of small and large countries**. To judge from the Swedish case, smaller countries were more likely to be dependent on suppliers in regions they did not control. By contrast, the larger nations, especially the British Empire, could source most of their metal needs from within their imperial domains. Smaller countries were often dependent on precisely such imperial nations for their metal supplies. As a result, smaller countries – especially those lacking colonies – often had less control over the supply chain. Among other things, this meant that they had greater reason to fear price hikes – if a large supplier, such as the British Empire, controlled the majority of a resource it could also control the market price. This led to intense scarcity experiences in a small country with a projected increase in demand (Article III).

**For the most part, industrial and state actors in smaller and larger nations dealt with scarcity experiences in similar ways.** Industries continuously attempted substitution, resource savings and recycling to cope with shortages – no matter whether they were based in larger or smaller countries. In a similar way, state actors in both small and large nations pursued strategies such as amending the mineral laws and negotiating trade agreements. In small and large countries, both state and business actors also initiated geological explorations.
However, there are some notable peculiarities in how small countries handled shortages. Imperial countries like Great Britain or great powers like the United States were able to negotiate or exercise control through economic, military or political means to gain access to their desired resources; smaller countries lacked such means. They had to tread more carefully on the global arena. Judging from my research, smaller countries (and companies) were less successful in vertical integration, that is, controlling the whole supply chain, making them more dependent on others (Articles II, III). Swedish steelworks failed in their vertical integration in the Turkish chromium industry because they were hesitant to invest the necessary capital and take the corresponding risk. Also, Swedish state actors in 1980 claimed that small countries could not make bilateral agreements, as these were possible only for nations with very large demand. Smaller countries like Sweden had significantly lower demand, and a limited domestic market. This made it difficult for Swedish industry to secure long-term contracts with exporting nations (Article IV). The solution was to aim for multilateral agreements, in which many smaller – and larger – nations cooperated.

It is important to remember that natural resources are closely linked with political relations. Raw materials are but one piece of a larger puzzle. In this sense, attempting to acquire mines in foreign lands, vertical integration, and forming partnerships are in fact often part of a greater vision for the state and business actors in both small and large countries that are interested in conquering new markets or establishing trade relations. This is just as important for smaller countries as it is to larger ones. In the case of Turkish chromium, for example, Swedish ore imports were regarded by Swedish diplomats as one possibility of increasing Swedish exports to the newly established Turkish state, since the Turks aspired to an overall balanced trade relation (Article III).

Many small countries tried to stay out of the great power conflicts. Sweden did not participate in armed conflict during the period of study in this thesis; it was neutral during the two World Wars and in the Cold War as well. In some instances, this neutrality gave rise to difficulties in accessing metals. During World War I, the Swedish War Material Commission observed with fear how the belligerents attempted to keep neutral nations out of trade, creating difficulties for Sweden precisely because it was not part of any alliance or bloc (Article IV). However, at
times neutral states were presented with opportunities that non-neutral states did not enjoy. Sweden, at least, played its “neutrality” card in gaining access to resources, and benefited from it. For example, Sweden was given an opportunity to mine Turkish chromium in the 1930s partly because it was a small and neutral state. As mentioned above, however, the Turkish chromium venture failed partly because the Swedish steelworks decided to withdraw. They could not – or did not want to – compete on the international arena with colonial powers such as Britain, Germany and France, perhaps unwilling to risk the loss of Sweden’s international reputation for being small and neutral (Article III).

**Scarcity before World War I**

Second, turning to the question about scarcity experiences before World War I, my research showed that industries struggled with metals scarcity long before 1914. Scarcity was a problem, at least, from the Second Industrial Revolution on. Based on the findings in my thesis, the underlying reasons why business and state actors described metals as scarce remained much the same throughout the time period of study: a lack of substitutes, price variations, and dependence on certain suppliers, along with increased demand (see table 4). The war did not alter perceptions significantly.

Labor strikes were another phenomenon that gave rise to scarcity experiences through the period of study in this dissertation, and World War I was not a turning point here, either. Unsurprisingly, labor movements have affected whether mines can stay open, and this has been an issue over and over again, as in the case of platinum workers in Russia in 1905, Rhodesian copper miners in the 1950s, as well as Canadian nickel miners in 1979 (Articles II, IV). Clearly, strikers’ and labor movements’ contribution to scarcity experiences is not limited to certain nations or time periods.

However, I also identified a couple of differences in scarcity experiences between the period before and after World War I. From 1870 until 1914, one major reason why business actors experienced and feared shortages was the fact that manufacturers experimented with and found new uses for metals for which there were no extraction system
in place. Industries began to use metals such as tantalum, osmium, platinum, as well as titanium and magnesium, which had never before been mined in large quantities, and there were barely any mines in operation at the time. In many cases the ore deposits had not yet been found. Hence industries often interpreted shortages in terms of geological scarcity. They were unaware of locations of deposits, especially of metals never used before, since there had never before been any reason to prospect for them (Articles I, II).

Historically, difficult environmental conditions have often contributed to scarcity experiences. Over time, however, the development of infrastructure and extraction technologies has largely eliminated environmental conditions as a factor precluding the mining of metals in certain places. To take just one example, in 1905–6 the Russian platinum mines could not operate in wintertime, but as of 2010, environmental conditions do not seem to scare away businesses when it comes to mining in Greenland (Articles II, V).

Interestingly enough, limited infrastructure was rarely pointed to as a major problem in my case studies before World War I. In the context of the war and its aftermath, however, limited or disrupted transport infrastructure became a crucial issue. Disrupted shipping routes largely explain scarcity experiences during World War I (Article I). But this was not the only time such problems occurred. In Rhodesia, mine workers found themselves unable to extract copper because of shifting water supplies and coal shortages in the 1950s (Article IV) – creating fears of shortages among the importing countries. Similarly, in the 1950s it was simply impossible to develop tin deposits found in Bolivian mines due to limited infrastructure and rugged terrain, contributing to scarcity experiences (Article IV). High transport costs contributed to the Swedish steelworks’ difficulties in operating chromium mines in Turkey profitably (Article III). In the 1980s, Swedish state actors listed magnesium as critical, fearing that the metal would become prohibitively expensive due to high electricity prices (Article IV).

The business and state actors tried to solve their pending shortages in a similar manner over time, and World War I did not change strategies much; industries attempted technological development, substitution (particularly during World War I and II), and the state
attempted amending mineral laws were strategies frequently applied (see table 5). However, the relative importance of certain strategies changed over time. For instance, large-scale geological exploration activities were more prominent in the nineteenth century and in the early twentieth century. The increased use of metals previously not used commercially inspired both state and business actors to hire prospectors to travel to foreign territories to explore the terrain (Articles I, II). The mapping of resources became a high priority, later even for governments, who began to realize the importance of access to minerals. For example, the global trend of scarcity perceptions made prospectors search for monazite when demand for its use in gas mantles increased, in Sweden as well as in Brazil and the United States.

As for prospecting, notably, businesses around the turn of the century strived for vertical integration – to actually gain access to the metals which were not extracted, and to secure their supply. Lamp manufacturers in the late nineteenth and early twentieth centuries clearly aspired to control the entire supply chain, from mining of the crude mineral to the finished product (Article II). Further, many large manufacturing companies aspired to independence in their quest for resources during the protectionist interwar era. However, companies became more specialized over time, and in our own age only mining companies and state actors focus on prospecting and mining.

Recycling, while always important, was viewed by the European Union and Swedish state actors as the main way forward in the 2010s. Stockpiling also continued to play an important role, although this strategy appears to have been most popular from the 1930s up until the 1980s. International trade agreements gained importance over time. In my case studies I did not see any such strategies discussed before World War I, nor in the interwar era. After World War II, by contrast, they figured prominently. For Sweden’s part, international agreements were crucial, especially after the 1970s resource crisis (Article IV).

World War I is often viewed as an event that changed perceptions of the world and geopolitical relations. However, experiences of why metals were perceived as scarce and how actors coped with this scarcity changed surprisingly little. Many of the previous supply problems the actors had encountered were merely exacerbated during World War I. They became
visible and more severe with the disrupted transnational flows, but they were not new. Important to note is that, while metals scarcity was not described as a geopolitical problem before World War I, the manufacturing industries in both Sweden and United States worried about some nations monopolizing the supply of some metals well before the conflict – especially platinum, which was sourced exclusively from the Urals in Russia around the turn of the twentieth century. And for a short period they were concerned about Germany’s dominance of the monazite market. Nevertheless, after World War I, geopolitics in relation to resources became much more evident (Articles I, II).

**Metals scarcity began to receive much more attention from state actors from World War I onwards.** From then on, not only industrial actors aired their concerns regarding metal shortages. In 1917 Swedish industry leaders called for the state to take responsibility and become financially involved in the mining and manufacturing industries. State actors increasingly began to classify metals as critical and/or strategic, and also attempted to secure access, one reason being that the scarcity experiences were ever more related to dependence on specific suppliers. From this period on, there was also a recurring fear of supply disruptions due to political relations, together with increased demand for crucial technologies and price variations (table 4). World War II intensified these concerns. Numerous countries worried about supplies. In Sweden, metals including antimony, molybdenum, copper, platinum, and many more came under the watch of the *Industrial Commission*, which decided to ration civil use.¹ The Swedish state’s involvement became greater over time (Article IV). State and business actors in general became increasingly concerned that shortages of critical metals, and high prices, could hinder the nation’s industrial expansion. In the Unites States, access to strategic metals affected the nation’s foreign policy early on, increasingly from World War I on. It took a little longer for the Swedish state to engage in securing access to critical metals. Not until the 1970s was a consensus reached in Sweden that coping with scarcity was simply too important a task to be left to industry alone.

All in all, in assuming that metals scarcity and critical metals only began to be a problem by World War I, researchers neglected important

¹ The Industrial Commission was also involved in securing access to metals during World War I.
developments during the Second Industrial Revolution. As I showed here, metals scarcity clearly affected the incandescent lighting industry (Article II) and was a much debated issue among Swedish engineers from the 1870s onwards (Article I). It is plausible to assume that other industries and other countries had similar scarcity experiences before World War I, and were similarly affected.

**Metals scarcity and technological development**

Turning to my third research question, technological development undoubtedly affected – and was affected by – actors’ experiences of metals scarcity. This is evident in all articles, I-V. Throughout the time period analyzed in this thesis, different technological trends permeated the view of metals scarcity. The radical technological development in the decades around 1900 is one example. While chemists had discovered a range of new metals in the eighteenth and nineteenth centuries, it was not until the Second Industrial Revolution that they became more commonplace in industry, whereby they were transformed into resources through technological processes. For instance, when the incandescent lighting industry began to gain momentum, access to metals emerged as a key issue that shaped technological choices. Similarly, after World War I, and continuously on into the 1950s, lighter metals such as aluminum, along with alloys for steel manufacturing, chromium, molybdenum and tungsten, were viewed as scarce in the context of major new technological trends. And from the 1970-80s on, the digital revolution, the development of superconductivity, renewable energy and other new technologies created new worries among actors.

Technological trends, in combination with actors’ scarcity experiences and fear of shortages due to politically unstable suppliers, made alternative suppliers and deposits in other countries highly interesting. This is already apparent in the lighting industry’s quest for monazite not sourced from Brazil around 1900, and the Swedish steelworks’ appetite for chromium in Turkey during the interwar era in order to realize their ambition to develop stainless steels. Similarly, from the 1980s on, deposits of tantalum, niobium, cobalt, zirconium and rare earth elements in Greenland became attractive because of the increased demand for
more special metals, linked to the key technological trends during that period.

Sometimes it may appear as if **metals scarcity is ‘resolved’ thanks to the development of new technology – and hopes that this will happen may thereby also stimulate technological innovation.** Of course, metals scarcity is not the only reason why new technologies develop; it is not “the mother of all inventions.” However, it is an important stimulating factor. As shown in my case studies, metals scarcity has not really hindered industries in their manufacturing processes. Rather, scarcity has often forced them to devise technical solutions or, more radically, embark on new technological paths. This is especially expressed in Article II: incandescent lamp manufacturers tried their best to solve scarcity by developing new filaments. Furthermore, they managed to manufacture a “lead-in wire” to the bulb which did not contain platinum, motivated by the fact that this metal was expensive and scarce. For the most part though, industries instead substituted scarce metals for more common ones, a strategy closely related to technological development.

Technological development in mining and prospecting technologies also helped to ease scarcity perceptions. For example, thanks to new technology such as airborne mapping, it became possible to identify ore deposits in Greenland’s rugged terrain (Article V). Mining companies also learned, by developing more efficient technology, to extract lower ore grade deposits, making it possible to operate mines that had previously been considered “depleted.” The creation of new transport infrastructure, particularly from the 1870s on, comprises another important technological achievement with implications for scarcity perceptions, as it enabled a greater transnational flow of metals.

Technological “fixes” were sometimes able to ease perceptions of scarcity, as shown in the case studies here. At least, actors have commonly argued that technological fixes could indeed offer a solution to scarcity experiences. Accepting this line of thinking, scarcity would be a problem for only a limited period of time, and industries and state actors would never really have to worry. Advancing such arguments, however, is to disregard the problems of accelerating consumption patterns. In my opinion, this kind of reasoning is highly problematic. Metals are, in fact,
limited resources, extracted in places where populations do not have the power or ability to protest, and the extraction processes contaminate their local environments. This aspect, while not in the foreground of this thesis, should clearly also be considered. Inevitably, as shown in this dissertation, technology can ease scarcity perceptions to some extent. It would be too simple, however, to say that scarcity can be “resolved” through technological innovation. There are much more complex relations to be considered.

Looking at the world through the lens of metals scarcity allows us to begin to unravel the entangled relations between resources, politics, economics and technology. The case studies in this thesis confirm, both empirically and theoretically, that it is useful to analyze scarcity as a perception – or experience – in local, national and transnational contexts, rather than as a fact or as a simple mismatch between supply and demand, and that such perceptions vary over time and space. Scarcity is constantly shaped and reshaped. The lingering fear of metals scarcity caused concerns among business and state actors throughout the time period studied here, and made them respond in various manners. In view of our increased use of technologies and the uneven distribution of metals worldwide, it is not a far-fetched guess that the specter of scarcity will continue to loom over industrial and business actors for the foreseeable future.
Appendix I: Contribution to co-authored articles

Article III
This article was co-authored with Per Högselius and Dag Avango. I was the author primarily responsible for collecting the archival material, and read, analyzed and summarized the Swedish material, except the documents regarding general diplomatic relations between Turkey and Sweden. I was the main author of "Sandviken's emerging chromium supply strategy," "From cooperation to confrontation," "Epilogue" and "Conclusions," and also contributed to the introduction and theoretical and methodological point of departure.

Article V
This article was co-authored with Per Högselius. I was responsible for collecting the empirical material and the main author of the sections "Introduction," "Mining on Greenland before the climate change debate," and "New trends in prospecting and exploration." Together with my co-author I wrote "Theoretical and methodological perspective."
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