Urban Mining In Times Of Severe Raw Material Shortage: Copper Management In World War I Austria

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EXECUTIVE SUMMARY

The present paper investigates to which extent and success urban mining, the recovery of resources from the anthropogenic stock, has been applied in the past during shortage of primary resources. As a historical example, the Austrian economy during World War I, when raw materials indeed had to be substituted by secondary sources to a wide extent, is analyzed in this study.

By means of material flow analysis, the management of copper resources, as a highly important and relatively scarce metal, is examined. The combination of dramatically increased demand for copper (for ammunition) and severe constraints on supply from sources other than the domestic anthroposphere highlights the importance of planning and surveying for urban mining activities. The results also indicate possible limitations to extracting, even when facing severe shortage, a large share of metals from the anthroposphere. Although extreme measures, such as confiscation, were taken, only 1.7 kg Cu/cap and thus less than 10% of the anthropogenic stock was made available till the end of the war.

INTRODUCTION

In the past decade, numerous studies on the anthropogenic resource cycle of metals were conducted (Bertram et al., 2002; Graedel et al., 2002; Rechberger and Graedel, 2002; Spatari et al., 2002; Müller et al., 2006; van Beers and Graedel, 2007). By quantifying the stocks and flows of a metal throughout its life cycle, useful information regarding the patterns of resource use and losses of metals into the environment was obtained (Spatari et al., 2005).

One major finding of the studies is the importance of anthropogenic metals stocks for the resource cycle (Müller et al., 2006). Due to ever-increasing goods in use, metals have been transferred from the lithosphere (in form of ores) to a large stock of metals-in-use in our infrastructure. After the life time of goods, some of the metal is recycled. Already now about 30% of the copper consumed in Europe originates from secondary resources (Graedel et al., 2004). In case of iron almost 50% of the U.S demand is covered by scrap recycling (Wang et al., 2007). In the future ore mining will likely be superseded by urban mining, the recovery of secondary resources from the anthropogenic stock (Brunner and Rechberger, 2004; Brunner, 2007). Unlike “classic” recycling, urban mining also includes the active prospection for stocks of the materials in question (e.g., metals) in the infrastructure, information about which is crucial for future recovery of these resources.
Arising shortages in the ore supply of many metals, at least at low contemporary prices (Tilton, 2002), will increase the utilization of the existing infrastructure as a secondary source of raw materials. Large per capita stocks in industrialized countries of up to 15 tons of metals (Gordon et al., 2006) indicate the future potential of secondary resource supply. However, to which extent the anthropogenic stock of materials could actually be recycled is rather unknown. Qualitative analysis of the stock (Wittmer, 2006) could assist in estimating the theoretical recovery ratio of materials in use. Nevertheless, theoretical considerations could differ significantly from reality.

The objective of this paper is to evaluate the potential of urban mining for resource supply during a historical period of raw material shortage, which frequently occurred during war times or embargoes. Here, the copper supply of the Austrian Empire during World War I (WWI) will be investigated.

The reasons for choosing this particular situation are threefold: first, domestic production of copper in pre-war times covered less than 10% of demand. The Austrian economy depended mainly on imports from Spain, Chile and Argentina (Apelt, 1899), which ceased during WWI and thus resulted in a severe shortage of copper. Second, a war situation such as Austria’s in World War I reduces import and export flows to and from the system (i.e. Austria), thereby narrowing down the number of individual material flows which have to be looked at. The third reason is simply data availability. The amount of data compiled by the administration of the Austrian empire made it possible to trace relevant flows of copper almost 100 years ago.

Methods and Materials

Material Flow Analysis (MFA) and Substance Flow Analysis (SFA) as defined in the frameworks of (Baccini and Brunner, 1991) and (Brunner and Rechberger, 2004) are used to characterize the copper cycle in the Austrian Empire. MFA/SFA is a systematic assessment of the flows and stocks of materials within a system defined in space and time. By defining the spatial and temporal boundaries of a system, the law of the conservation of mass allows for balancing of materials and substances, as well as for the identification of flows, stocks and stock changes, and processes pertaining to the material or substance in question within the system.

The spatial system boundary was defined according to the political borders of the Austrian Empire in 1914, which was considerably larger (around 300,000 km²) than present-day Austria, with a population of about 29 million in 1914 and encompassing the following present-day countries and parts of countries: Austria (with the exception of Burgenland), Czech Republic (with the exception of Hlučínsko area), Slovenia (with the exception of Prekmurje), Italy (Trentino-Alto Adige/South Tyrol and small portions of Friuli-Venezia Giulia), Croatia (Dalmatia, Istria), Poland (voivodeships of Lesser Poland, Subcarpathia, southernmost part of Silesia (Bielsko and Cieszyn), Ukraine (oblasts of Lviv, Ivano-Frankivsk, Ternopil (except its northern corner) and most of Chernivtsi oblast); Romania (county of Suceava), and Montenegro (bay of Boka Kotorska, the coast and the immediate hinterland around cities of Budva, Petrovac and Sutomore).

Due to the changes in front lines, for example in the Southern Alps, during the course of the war, the front lines were not always outside the defined horizontal system boundary. For practical purposes, and due to the largely dissipative use of copper supplies in military operations, material transports designated to the front line were considered as exports.
The vertical system boundary is defined as excluding the lithosphere, i.e. stocks of copper in natural deposits. Mining processes and ore deposits, therefore, are not analyzed, with practically means that copper ores (domestic and non domestic) are considered as import flows into the system.

The temporal system boundary is given here as one year. Material flows will be looked at for each of the years 1915 to 1918 separately. For reasons of consistency, 1914 is not included, since 1915 was the first full year of the war economy. Although 1918 also saw the transition from war to peace, it is reasonable to include 1918 in this study to show the increasing exhaustion of the raw material economy.

The system model comprising all sources, pathways, and sinks for copper is shown in Figure 2. It includes 4 imports, 6 internal flows, and 4 exports. The following 5 processes are defined: processing, fabrication & manufacture, civilian use, military use, and recovery & acquisition.

Beside some use of first-hand statistical data, mainly data compiled in earlier publications were used in this study. In certain cases, appropriately detailed and specific data could not be obtained; where possible, an estimate based on the literature was made. Especially for the year 1918, due to the massive political changes at the end of the war, some figures are simply missing. Even where figures are not based on estimates, diverging values are often given; numbers in this study are intentioned to present an outline of the situation.

Results
Production and consumption figures for Austria-Hungary from 1820 to 1912 (Czoernig 1861; Hofmann 1867; K. K. Statistische Zentral-Kommission 1915; Apelt, 1899; Rudolph, 1976; Heufler, 1856; Hertz, 1910; Stolper, 1918) lead to a per-capita stock figure of around 20±2 kg. This figure is close to the estimations of (Wittmer, 2006), who calculated a Cu
stock in Switzerland of approximately 25 kg/cap for 1915, based on import and export statistics. (Gordon et al., 2006) and (Spatari et al., 2005) give a per capita stock in the United States of about 50 to 70 kg for 1912. However, copper consumption was much higher in the US than in Austria-Hungary at this time (Apelt, 1899; Gordon et al., 2006).

Due to the fact that per capita consumption for other metals (e.g., iron) was quite similar in both halves of the empire, (Rudolph, 1976), the calculated per capita stock for the dual monarchy is also seen as representative for Austria only.

The majority (>60 %) of the Cu in stock in 1914 can be attributed to buildings (e.g., roofing, guttering, lightning rods, plumbing) based on production figures (Hofmann, 1867). Copper in use for electrical proposes is less than 2 kg/cap and thus below 10% of the total Cu stock of 20kg/cap. This figure was calculated using information about the approximated values of electric plants (e.g., electric machinery, cables, telephones) in use Austria in 1913 (Hudeczek, 1922), estimates about their average copper content and copper prices (about 400 US dollars/ton) at the time. Furthermore, data about power generation in Austria (März, 1981), estimates about the specific Cu demand per unit of installed power (100 to 200 kg Cu/kW based on data of (Mattere, 1908), own calculations using information about present Cu stocks for power supply (Wittmer, 2006), and power consumption figures were used to assess the Cu stock for electrical infrastructure. In 1914, around 900 plants with a total capacity of 540 MW were installed; this estimate also leads to an average per capita stock of 1 to 2 kg Cu. Smaller amounts of Cu can be found in transport equipment, telegraph wires, church bells, different alloys (e.g., brass, bronze), dishes, equipment for breweries or distilleries, and coins.

Less than 7 % of copper consumption was covered by domestic ore mining during the years before 1914. After 1914, imports (except those from Germany in the context of the war effort) ceased, so that from this time on exploitation of the anthroposphere and use of anthropogenic Cu stocks had to make up for them.

In 1914, Austrian production of copper from ores had reached 4 kt (Riedl, 1932), equaling about 0.14 kg/cap/a. By 1915, production had increased by over one third, reaching 6.5 kt, with a further increase to 7.7 kt (0.26 kg/cap/a) in 1916. From then on, primary production fell back to pre-war levels or below until the end of the war. Demand had to be covered by “urban mining” activities and by scrap imports, mainly from Germany.

Cu production of 1915 was almost exclusively available for military purposes (Wegs, 1979). (Riedl, 1932) mentions that production for civilian purposes hardly played a role at the time. Electrification of railways or tram lines, which had started in 1883, was halted during the war (Hofbauer, 1937). The rapid extension of the electric power grid in the pre-war years was almost stopped. Civilian Cu consumption can be assumed to have been less than 5% of the total production.

No copper products were exported. Whatever material was imported from Germany came in the form of scrap, and under official supervision. Imports outside official channels ceased altogether (Riedl, 1932).

A large part of military supplies produced went into rifle ammunition and artillery shells. Production of the former increased by over one-third from 1915 to 1916, while production of the latter increased almost seven-fold over the same period (Wegs, 1979). Copper production peaked in 1916 with approximately 35 kt/a (1.2 kg/cap/a), almost 80 % of which originated from secondary sources (scrap, and confiscated or purchased goods).
As copper was practically exclusively used for the production of ammunition (made from brass), corresponding production figures in 1916 (4 million rounds/day of rifle ammunition only (Wegs, 1979), which required about 20 kt of copper at an average mass of 18 g per cartridge) make plausible the conclusion that almost all of the copper produced during the war found its way to the front lines. Due to the fact that military copper use was to a large extent dissipative and non-recoverable, copper from the infrastructure and consumer goods had to be accessed. (Wegs, 1979) notes that a recovery of ammunition shells from battlefields was made impossible by a lack of railway carriages and disposable manpower, resulting in the necessity of obtaining new copper for the front lines from purchased and confiscated Cu goods.

The material flow diagrams (Figure 2) show that the civilian part of the anthroposphere was “mined” for copper and depleted by up to several thousand tons per year.

In 1914, following the example of Germany, three “Central Metal Bureaus” (CMB) were created for Austria, for Bosnia, and Hungary. The financial resources for the CMB were to be provided by the ammunitions industry as the main “beneficiary” of the effort. Article 7 of the CMB statute states that the war ministry was to secure the direct and indirect requirements of metals and metal alloys of the military and “to make available only certain amounts for private industrial purposes” (cited in (Wegs, 1979).

The authority of the CMB, therefore, extended only to acquisition, while distribution of metals remained in the hands of the war ministry. From 1915 on, metal was confiscated, at first under supervision and by the authority of the military administration. Due to a lack of methodical planning, according to (Riedl, 1932), this was not very effective at first and often resulted in ruining small metal processing enterprises whose raw material stocks were simply confiscated – the authorities were “groping blindly” for supplies were these were assumed to be. Already in early 1915, an ordinance on 7 February introduced an obligation to declare any stocks of „war metals,“ with a newly formed „Central Requisition Commission for Metals“ identifying potential supplies and organizing metal requisitions. The CMB remained in charge of the practical tasks of securing these supplies (Riedl, 1932).

Obligations to declare metal deposits were continually extended to ever new sources. By the end of 1915, ores and raw products, scrap, and waste were requisitioned. Unused factory equipment had to be declared, with a prohibition to sell the equipment. A cadastre of metals contained in factory equipment was compiled that same year, extending to copper that could possibly be obtained from electric machinery and electric or telegraphic cables and wires. The diagrams of Figure 2 show that while in 1915, the problems of bad planning and possibly a lack of inventories was still evident, the CMB had become increasingly effective by 1916. The amount of recovered copper doubled within one year form 10 to 20 kt.

In addition, a „patriotic collection“ of metal from the public was held, and a survey made of metal supplies to be obtained from buildings, ships, railway carriages, distilleries, breweries and the like. The extent of the copper shortage is evident from the fact that apart from machinery and buildings, purchase (and after 1915 confiscation) by the CMB of kitchen equipment was deemed necessary. All such equipment had to be turned in after mid-1916, with only manufacturers and retailers allowed to hand in just one third of their stocks (Riedl, 1932). Also in 1916, copper roofs and lightning rods were confiscated.
Overall, the amount of copper recovered from civilian end-use stocks reached almost 80% of total copper produced in 1916.

In 1917, the anthroposphere had been depleted of Cu to such an extent that small metalwork from doors, windows and furniture was confiscated. The largest single share of copper confiscated that year; however, were bronze church bells. They amounted to almost 50% of all copper-containing goods procured that year (Wegs, 1979) and, at a total mass of 9.7 kt (0.33 kg/cap) confiscated in 1917 alone, were the largest single source of copper tapped by the CMB during the war. By 1918, the only expendable anthropogenic copper deposits left were brass door handles and frames of shop windows, which were now confiscated. As shown in Figure 4 the amount of copper recovered had reached diminutive amounts in 1918 compared to the previous years.

Such vital installations as electric wires, cables and machinery could not simply be disassembled without providing for some sort of adequate replacement. Since aluminum was at the time cheaper and more abundant than copper, copper cables in power plants were replaced by either aluminum or iron if those cables could not be spared at all. Likewise, DC generators were replaced by three-phase (rotary current) generators, reducing the required cable cross sections. Telegraphic wires made of Cu were replaced with iron. In order to ensure quick disassembly and reassembly, the CMB also collected stocks of wire and cable to avoid unnecessary disruption in the operation of affected enterprises and installations (Wegs, 1979).

Recovery of copper from the anthroposphere proved to have a massive influence on overall copper production of Austria during the First World War. As the material flow diagrams show, the extent of copper recovery actually proved more crucial to the production of semi-finished Cu goods than mining activities. As can be seen from comparing 1915 figures with the following years, the efforts made in determining anthropogenic copper deposits and assembling a sort of inventory of such potential resources paid off well.

Regardless of this, less than 10% (around 1.7 kg/cap or 50 kt) of the total Cu stock in-use (the total Cu stock of Austria was roughly 560 kt) was accessible for urban mining activities throughout the war. This is remarkable considering the severe scarcity and the extensive efforts and measures undertaken to obtain copper from anthropogenic sources.
Figure 2 Copper flows of the Austrian Empire during the years 1915, 1916, 1917 and 1918
CONCLUSION

At present, global copper stocks in the anthroposphere are estimated at 50 kg/cap (Lichtensteiger, 2002; Kapur, 2004), which is almost equivalent to the lithospheric reserves of 70 kg/cap (U.S. Geological Survey, 2006). In the future, the proportion of the ore stocks in the earth’s crust will further diminish relative to the stock-in-use due to increasing demand for Cu in many places of the world (Gordon et al., 2006). How and to which extent and success urban mining and recycling activities have already been applied in the past in order to overcome severe resource shortages has been analyzed in this work via the example of World War I Austria.

Since Austria’s copper supply was heavily dependent on imports, which ceased after the outbreak of war, an acute shortage of Cu soon became evident. During the first two war years, an increase in Cu production in comparison to peace time could be observed, although imports had almost stopped. This was mainly achieved by intensive efforts on Cu recovery from the stock-in-use. The measures taken to this end encompassed the drawing up of a “resource cadastre” (an inventory of metal stocks of the country including information about its necessity for use), the purchasing and confiscation of Cu containing goods (e.g., church bells), and the reshaping of the infrastructure, including, for instance, the substitution of Cu wires by iron or aluminum. Actions in this context were organized by the Central Metal Bureaus set up in 1914. Their objective was to acquire “war metals”, ensuring the resource supply of industries (e.g., production of ammunitions) relevant for the war.

The efforts undertaken led to a rapid depletion of the available copper stock, so that already 1917 the production figures dropped significantly (by more than 30% in comparison to 1916) and almost ceased in 1918 due to exhaustion of potential Cu sources. Although extreme measures (e.g., confiscation) were taken, less than 10% of the anthropogenic copper stock had been made available by 1918. This admittedly exceptional case thus can serve as a cautionary example of the constraints on urban mining strategies. Most of the anthropogenic stocks of a scarce metal may well prove not recoverable; a large amount of this metal in the anthroposphere does not necessarily translate into a possibility for effective and sustainable urban mining on a large scale.

REFERENCES


