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Environmental Technology & International Affairs

# Urban Mining and Resource Management in Times of Raw Material Shortage (Using the First World War as an Example)

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Univ.-Ass. Dr. Johann Fellner

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Vienna, 23 June 2009

# Affidavit

I, **MANFRED KLINGLMAIR**, hereby declare

1. that I am the sole author of the present Master's Thesis, "URBAN MINING AND RESOURCE MANAGEMENT IN TIMES OF RAW MATERIAL SHORTAGE (USING THE FIRST WORLD WAR AS AN EXAMPLE", 43 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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*Manfred Klinglmair*

**Urban Mining and Resource Management in Times of Raw Material Shortage (Using World War I as an Example)**

## ABSTRACT

Surpassing the common notion of “recycling”, the recently coined term “urban mining” denotes the recovery of recyclable raw materials from anthropogenic sources (i.e., usually from waste). Unlike “classic” recycling, the term includes not only the re-use, but also the active prospection for stocks of the materials in question (e.g. metals or phosphorous) in the infrastructure, information about which is crucial for future recovery of these resources.

At the centre of this thesis stands the question of how and to what extent our infrastructure can be utilized as a secondary source for those raw materials (e.g. metals) which already form a part of the anthropogenic metabolism, but for which a situation of more or less acute shortage may arise, leading to the need of treating the anthroposphere as a raw material deposit to be exploited.

The issue of shortage of primary resources has already been a problem in the past, for example during war or due to embargoes. Therefore, this thesis will treat the problem mainly by analyzing the example of the Austrian war economy during World War I, when raw materials had indeed to be substituted by secondary sources.

By means of material flow analysis, the cases of two important raw materials will be looked at: iron, as the most extensively used and most important metal, and copper, as the scarcer and most important non-ferrous metal. It will be shown that the cases of copper and iron strongly differed. On the basis of these differences, and the different approaches taken for recovery of iron and copper, issues of efficiency, effectiveness and sustainability of “urban mining” strategies will be highlighted.

*For my family.*

**CONTENTS**

## 1. INTRODUCTION

"We are in a transition between the 'cowboy economy' of the 19th century and the future 'spaceship economy' of the latter part of the 21st century. In the cowboy economy economic growth was largely driven by the exploitation of cheap and readily available extractive resources, and use (or misuse) of the environment was a free good. […] The spaceship economy, by contrast, will be one in which all resources – including the environment – are scarce and must be treated as depreciable assets." (Ayres 1997)

Surpassing the common notion of "recycling", the recently coined term "urban mining" denotes the recovery of recyclable raw materials from anthropogenic sources (i.e., usually from waste). Unlike "classic" recycling, the term includes not only the re-use, but also the active prospection for stocks of the materials in question (e.g. metals or phosphorous) in the infrastructure, information about which is crucial for future recovery of these resources.

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Two substances will be looked at: iron, as the most extensively used and most important metal, and copper, as the scarcer and most important non-ferrous metal.

The reasons for choosing this particular situation are twofold: first, a war situation such as Austria's in World War I will reduce import and export flows from the system (i.e. Austria), thereby rather acutely limiting supply and narrowing down the number of individual material flows which have to be looked at. While one may object to treating issue of sustainability by looking at war, it may just as well be argued that this particular situation accentuates existing issues with raw material supply and simplifies the situation to a certain extent. This becomes especially clear in the case

[1] The anthroposphere has been defined as the "human sphere of life", as opposed to – or rather complementary to – the environment, by Brunner/Rechberger (2004:48).

of metals: on one hand, a war situation such as Austria's in the First World War greatly diminishes the possibilities for meeting domestic demand by external trade; on the other hand, military requirements lead to a massive increase in just this demand, thereby leading to a more pronounced shortage than, for example, a mere trade embargo. Second, data availability is relatively good in this particular case, since there is existing literature on the economy of metal supply during the period in question, that is to say, data are largely available in sufficiently aggregated form to meet the scope of this study.

By means of material flow analysis, this thesis will attempt to establish a picture of the development of flows and stocks (i.e. the mass balance) of iron and copper over the examined period, thereby seeking to answer the following questions:

What was the supply situation and consumption of iron and copper prior to 1914? How did the war-induced narrowing down of import and export flows change supply patterns? Which role did "urban mining" play in countering raw material shortages? Which strategies were used for resource recovery from the anthroposphere? How effective were those strategies, and can they be called sustainable? If we look at the present supply situation and potential raw material shortages, which lessons can we draw from the past?

To address these questions, first, a brief description of the method of material flow analysis as utilized here, definitions of key terms, and an outline of data sources will be given. Second, historical data on global and domestic Austrian iron and copper production will be looked at to establish an overall context of the supply situation before 1914. Third, the iron supply situation in Austria between 1914 and 1918 will be examined by identifying and quantifying iron flows and stocks a well as their changes over time, to arrive at a conclusion about the significance of recovery strategies that can be termed "urban mining". Fourth, the same will be done for the mass balance of copper. Finally, the present mass balance of iron and copper in Austria, as well as present recovery rates and strategies, will be looked at, to identify lessons that might be learned for the present from the past.

## 2. METHODOLOGY, DEFINITIONS & DATA SELECTION

### 2.1. Material Flow Analysis

Material flow analysis, as defined by Brunner and Rechberger (2004; see also Brunner et al. 2004), whose methodology will be used for the present thesis, "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 matter allows for the establishment of a balance of a materials, as well as for the identification of the flows, stocks and stock changes, and processes pertaining to the material in question within the system.

Graphical presentation of these flows and stocks facilitates the understanding of the functioning of a material flow system. "[W]e reduce the 'system' we are considering until it can be interpreted as a mechanism. It has inputs, outputs, and some working parts. Within this narrow view, simple values can then be brought to bear on the problem. The mechanism can be said to 'do something', that is, to transform inputs into outputs." (Allen 1994: 81).

Material flow analysis, therefore, is used in this thesis as a tool for visualizing the quantitative and temporal development of two crucial resources, iron and copper, during a situation of exceptional shortage.

Several terms have to be defined for the purposes of material flow analysis: first, *substances*, *goods*, and *materials* have to be distinguished. A *substance* is "any (chemical) element or compound composed of uniform units. All substances are characterized by a unique and identical constitution and are thus homogeneous." (Brunner/Rechberger 2004: 35) Thus, a substance has a clearly defined composition. A *good* is an entity which possesses either positive or negative economic value. Drinking water, in this respect, is a good with a positive economic value; waste water is a good with a negative economic value. The term *material*, with respect to material flow analysis, encompasses goods as well as substances and may be used for both. In the present thesis, goods such as iron/copper ore, brass, or bronze will be looked at to determine the flows and stocks of the substances iron and copper in the Austrian war economy.

The system examined is designated by a *system boundary*, designated by a dashed line, encompassing "a group of elements, the interaction of these elements, and the boundaries between these and other elements in space and time. It is a group of physical components connected or related in such a manner as to form and/or act

as an entire unit." (Brunner/Rechberger 2004: 43). Due to the law of conservation of matter, a difference between input and output of the system must have its reason in a change of stocks (positive or negative) of the material in question within the system, in order to arrive at a balance.

Within a system, materials are transported, transformed, or stored in *processes*, represented schematically by rectangles with a continuous outline. Typical processes for the purposes of this examination would be the process of metal production from ores, or the acquisition and collection of scrap metals.

A process can include a *stock* of a material, with either a positive or negative stock change per unit of time. Where workable figures on stocks and stock changes could not be quantified in this study, question marks are inserted in the diagram.

*Flows* or *fluxes* of materials connect processes. Each flow has one starting process and one target process. The term *flow* denotes a mass flow rate (i.e. a mass flow per unit of time) of a material, whereas *flux* denotes a cross-sectional flow (e.g. per capita figures, flow through a cross section of a pipe or through a certain area of land surface). Since per capita figures will be utilized in this study, fluxes will be looked at. Flows/fluxes are denoted by arrows, with flow/flux rates in ovals. Here as well, a question mark in the diagrams presented in chapters 4 and 5 below designates an unknown quantity.

### 2.2. System Boundaries

As a *horizontal* system boundary shall, for practical purposes, be defined the Austrian half of the Austro-Hungarian Monarchy, which was considerably larger than present-day Austria, with a population of about 29 million in 1914 and encompassing the present *Länder* (except Burgenland, which was part of Hungary), as well as Bohemia, Moravia, Bukovina, Carniola (*Krain*), Galicia, Silesia, the Austrian Littoral (*Küstenland*, Istria and the hinterland of Trieste), and South Tyrol as part of Tyrol. Since separate data on raw material management are available for Austria and Hungary, it does not seem meaningful to include the Hungarian economy in this text. Due to the changes in front lines, for example in the southern Alps, over the course of the our years examined here, the front lines were strictly speaking not always outside the horizontal system boundary defined here. For practical purposes, however, and due to the largely dissipative use of iron and copper supplies in military operations, it seems workable designate transports of material to the front line as export flows.

The *vertical* system boundary is defined as not including the lithosphere, i.e. stocks of iron and copper in natural deposits. Mining processes and ore deposits, therefore, are not examined, with ores entering the system as import flows.
The *temporal* system boundary is given here as one year. Material flows will be looked at for each of the years of 1915-1918 separately. For reasons of consistency, 1914 is not included, since 1915 was the first full year of the war economy, while the economic situation in 1914 still rather resembled peacetime. Although 1918 also saw the transition from war to peace, and data availability is generally bad for that year due to the political upheaval and administrative reorganization in Austria, it is reasonable to include 1918 in this study to show the increasing exhaustion of the raw material economy.

## 2.3. Selection and Definition of Processes

Since detailed data on e.g. individual private household consumption of particular metal goods are difficult to come by, as discussed in chapter 2.4., the number of processes looked at here will have to be limited; in some respect, the material flow analysis will be of a rough preliminary nature, identifying major issues rather than specific individual quantities to give an idea of the orders of magnitude of material flows involved. Only processes and flows pertaining to metal acquisition and recovery are the subject of this thesis. While processes are the same for both iron and copper, flows in the two systems are slightly different.

### *2.3.1. Raw Material Production*

The process “raw material production” is the production of pig iron and steel or copper raw products from ores and recovered metal.
*Inputs* to this process are ores from domestic Austrian mines, ore imports (also including imports from Hungary) and recovered metal.
*Outputs* comprise the output of refined metal raw products to the production of finished goods, and exports of raw products.

### *2.3.2. Production of Goods*

“Production of goods” denotes the further processing and production of finished goods from metal raw products.
*Inputs* are metal raw products from the process “raw material production” and imports of raw products.

*Outputs* comprise the sale to both civilian and military end users and exports of finished goods.

*2.3.3. Consumption (Military)*

The end use by the military of iron and copper in finished products is of importance here since, as it will be shown, this process took in a significant share of metal supplies during the examined period.

*Input* comprises the flow to this process are finished goods destined for military use.

*Output* is invariably the use in military operations.

*2.3.4. Consumption (Civilian)*

"Civilian consumption" denotes all end use of finished iron and copper products not destined for military use. Infrastructure, is also part of this process, as are scrap traders.

*Inputs* to the process are finished products from domestic industry and imports of finished products.

*Output*, in the case of iron, is scrap recovered from end users. In the case of copper, the two output flows are copper goods from end use purchased by the authorities, and copper goods confiscated.

*2.3.5. Recovery & Acquisition*

This process is defined as all the measures instituted during wartime to acquire, recover, confiscate, purchase, collect, and allocate metal resources.

*Inputs*, for copper, are purchased copper and confiscated copper, copper imports, and copper recovered from the front.

Inputs, for iron, are recovered scrap from the production of goods, recovered scrap from civilian consumption, recovered scrap from the front, and imported scrap.

*Output* flows are scrap exports and the total of recovered iron and copper.

**2.4. Data Selection**

For present purposes, data compiled in earlier publications will be used, since the amount of first-hand statistical data would be beyond the scope of this thesis. Generally, figures on the iron industry tend to be more abundant than those for copper, so that a slightly more detailed analysis of iron flows was possible.

As these data are usually organized along the lines of production figures and import/export statistics, thereby yielding not much quick insight into the situation, it is worthwhile to utilize them for the establishment of material balances, so as to clarify and accentuate the organization of resource supplies by identifying material flows.

Three major volumes will be drawn upon for acquiring data. Statistical figures on the war economy of the Austro-Hungarian monarchy during the First World War, with a significant regard to metal supply, have been first compiled in comprehensive form by Richard Riedl (1932), General Commissioner for War and Transition Economy (*Generalkommissär für Kriegs- und Übergangswirtschaft*) in the Trade Ministry in 1917, in the Carnegie Foundation's series on the economic and social history of the First World War. Riedl's work combines a concise overview of the highly complex administrative framework for resource management, as well as a considerable number of aggregate figures distilled from the massive amount of specific data on the metals industry. The volume contains treatises on a variety of different important raw materials of the time; however, data contained on iron and copper supplies have proved useful for the outline attempted in this text.

The dissertation on the Austrian war economy 1914-1918 by Robert Wegs (1979) contains two chapters dealing specifically with the iron and non-ferrous metal industries, making available additional data and information about administrative processes while drawing, in some part, upon Riedl's earlier work.

Mejzlik (1977), while also frequently referring to Riedl, deals exclusively with the iron economy during the war, offering arguably the most detailed account to date of laws, regulations, administrative processes, and supplies pertaining to iron production during the war. Since, however, Mejzlik puts his emphasis on the administrative and legal side of the subject, data found in the volume are sometimes sketchy.

Data on production and consumption figures (see chapter 3 below) prior to 1914 will be partly based on the volumes just described, partly on Apelt (1899), who gives a useful overview of historical production and consumption figures for Great Britain, Belgium, France, Austria-Hungary, Germany, and the United States.

In certain cases, appropriately detailed and specific data could not be obtained; where possible, an estimate based on the literature will be 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, and are to be understood *cum grano salis*.

Iron and copper contents of goods, since not given in the existing literature, will be estimated mainly on the basis of Keller and Eickhoff (1955) and comparable goods listed in Brunner et al. (2004).

## 3. PRODUCTION OF Fe & Cu BEFORE 1914: HISTORICAL DATA

### 3.1. European Production of Iron & Copper before 1914

Before the turn of the century, Austria-Hungary[2] was among the smallest iron producers in Europe, as Fig. 1 shows. This situation had not changed by 1913, although Austrian production of pig iron had doubled more than doubled to 1,710,000 t annually (excluding Hungary) on average between 1911 and 1913. A similar trend can be assumed for steel[3], production of which had reached 1,820,000 t (Riedl 1932: 269) at the same time. In the case of both iron and steel, the Austrian part of the monarchy produced by far the largest share, with 73.3% and 69.2% respectively. The remaining production was mostly located in Hungary, with only a diminutive amount (2.2% of pig iron, 1.5% of steel) produced in Bosnia.

Great Britain was leading in European iron production, producing close to 5.5 million t already in the period 1871-75 (more than eleven times the corresponding figure of Austria-Hungary, at 489,000 t). Only from the 1890s onward has Great Britain been surpassed by the United States.

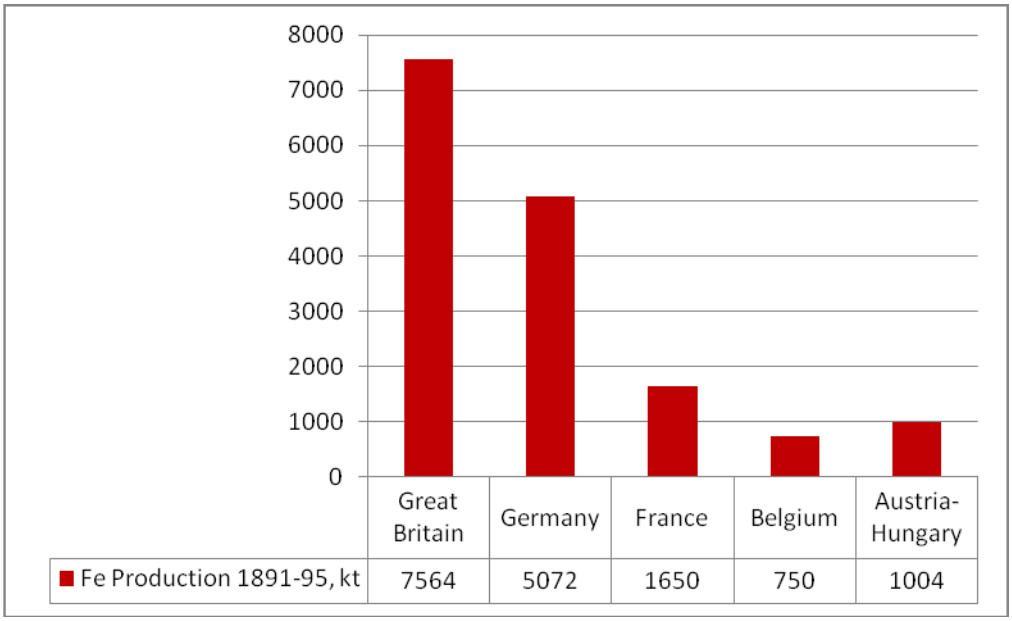



Fig. 1: Pig iron production in Europe 1891-95 (Apelt 1899)

[2] No separate data for the Austrian half of the monarchy could be obtained here; however, to establish the historical context this should be sufficient.

[3] Brunner et al. (2004) give an iron content of 95% for pig iron and 98% for steel. Apelt (1899) does not provide data about steel.

Great Britain, moreover, was the only European country with pig iron production consistently surpassing consumption in the latter half of the 19th century, and as such stayed the largest net exporter in Europe, which can be attributed to the availability of cheap coal (Apelt 1899: 175). As Fig. 2 shows, per capita consumption did not necessarily correspond to production in a country-by-country ranking, with Belgium showing the largest discrepancy. In the case of Austria-Hungary, while consumption was slightly higher than production (1.07 versus 1.004 million t in 1891-95), this rather small dependence on imports should become important, as will be seen in chapter 4.

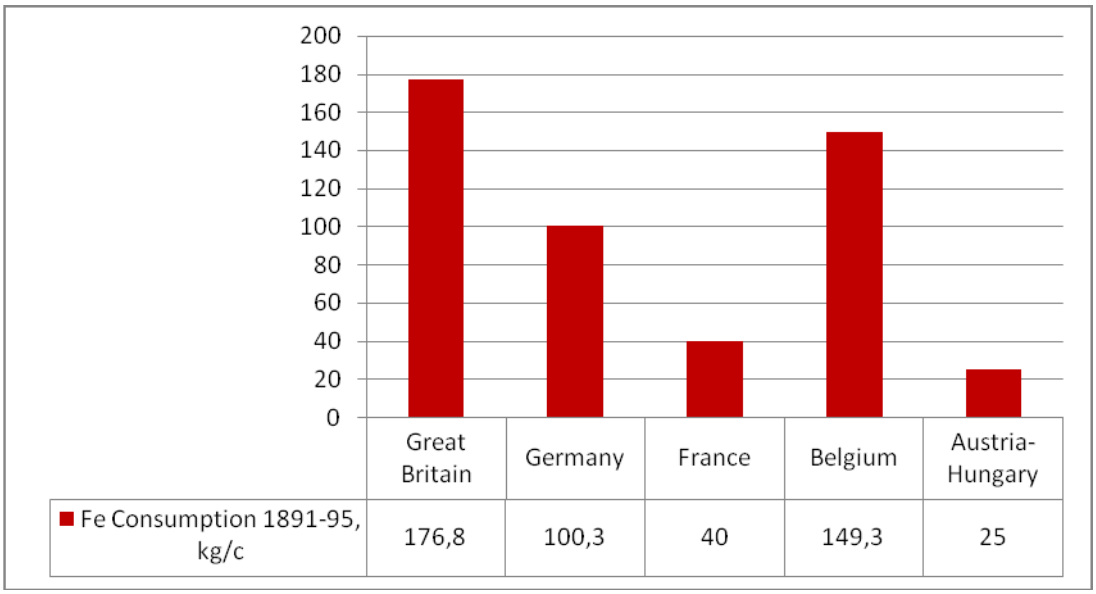



Fig. 2: Pig iron consumption in Europe 1891-95, kg per capita (Apelt 1899)

In most European countries, production and consumption of iron increased considerably during the latter half of the 19th century. Only in France, both figures remained stagnant until the 1890s, with both production and consumption at about 1.5 million t. By the eve of the First World War, however, France's production had increased more than threefold to 4.9 million t. At that time, production of pig iron stood at 17.6 million t in Germany, 10.2 million t in Great Britain, 4.9 million t in France, 2.3 million t in Austria-Hungary, and 2.1 million t in Belgium. Figures for steel can be deemed similar (Riedl 1932: 269).

Production of copper was much less evenly distributed, with Great Britain and Germany producing the vast bulk of copper in Europe. British, German, and Austro-Hungarian production of copper had moreover steadily increased throughout the second half of the 19th century.

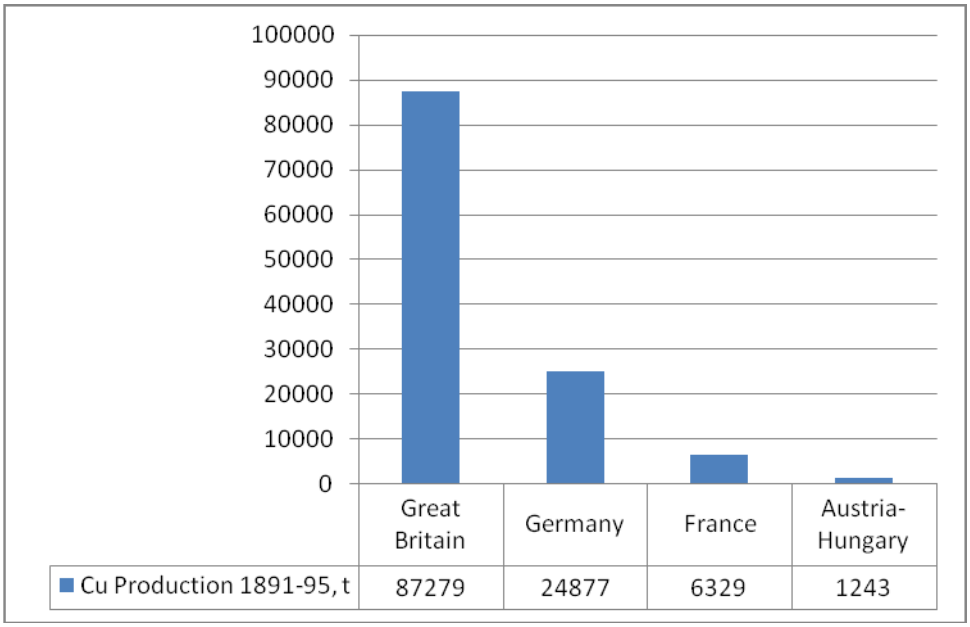


Fig. 3: Copper production in Europe 1891-95 (Apelt 1899)

Consumption, on the other hand, reveals a much higher import dependence on copper of European countries, as a look at Figs. 3 and 4 shows. Only Great Britain barely met domestic demand, while in Germany, France, Austria-Hungary and Belgium, copper consumption by far surpassed demand, especially in France, where copper production shrank from 22,986 t (1871-75) to 6 329 t (1891-95). Copper had to be imported, therefore, mainly from Spain, Chile, and Argentina (Apelt 1899: 186).

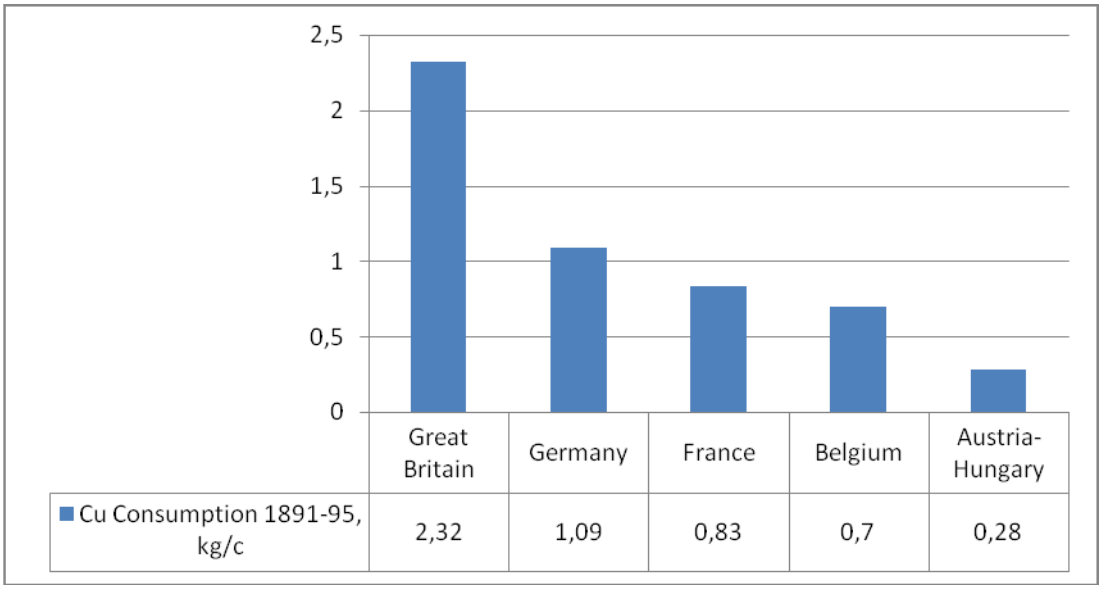


Fig. 4: Copper consumption in Europe 1891-95, kg per capita (Apelt 1899)

### 3.2. Production of Iron in Austria before 1914

Riedl (1932) gives a good overview of production, import and export figures on the eve of the First World War. It can be seen from Fig. 5 that pig iron production in Austria has been rising consistently since the 1880s. As mentioned above, between 1911 and 1913 production had risen to a yearly average of 2.3 million t of pig iron and 2.63 million t of steel.

Ore demand could mostly be met domestically, with 2.85 million t of ore being mined in Austria, 0.5 million t in Hungary, and 0.68 million t being imported[4]. Austria's iron and steel industry may well be described as self-contained. Riedl (1932: 270) claims that the industry was, in fact, independent from ore imports, since the mines in Styria and Carinthia would have been able to make up for missing foreign ores. At the same time, ores were only exported to Germany, and in insignificant amounts[5]. As regards scrap iron, the demand of 350,000 t in 1912 was met domestically by roughly two-thirds (235,000 t), with the remaining third (115,000 t) having to be imported[6].

Consumption, it can be learned from Fig. 5, while exceeding production figures, was rising at a faster rate. While the raw material demand of the Austrian industry could largely be met, iron consumption relied on the import of pig iron[7] and (raw and finished) iron products (Riedl 1932: 271f.).

Compared to figures on copper (see chapter 3.3), the increase rate of iron consumption was much less pronounced. This difference became more salient, as shall be shown, in the supply situation of copper and iron during the war.

[4] Imported ores came mostly from Sweden (70%) and the Mediterranean (25%) (Riedl 1932: 270).

[5] Exports amounted to 10,000 t annually from 1911-1913 (Riedl 1932: 271).

[6] Of these 115,000 t, all but 6,000 t (from Hungary) were imported from Germany. 8,000 t of scrap iron were exported to Hungary, 4,000 t to other countries.

[7] 150,000 t of pig iron were imported in 1913 (Wegs 1979: 55).

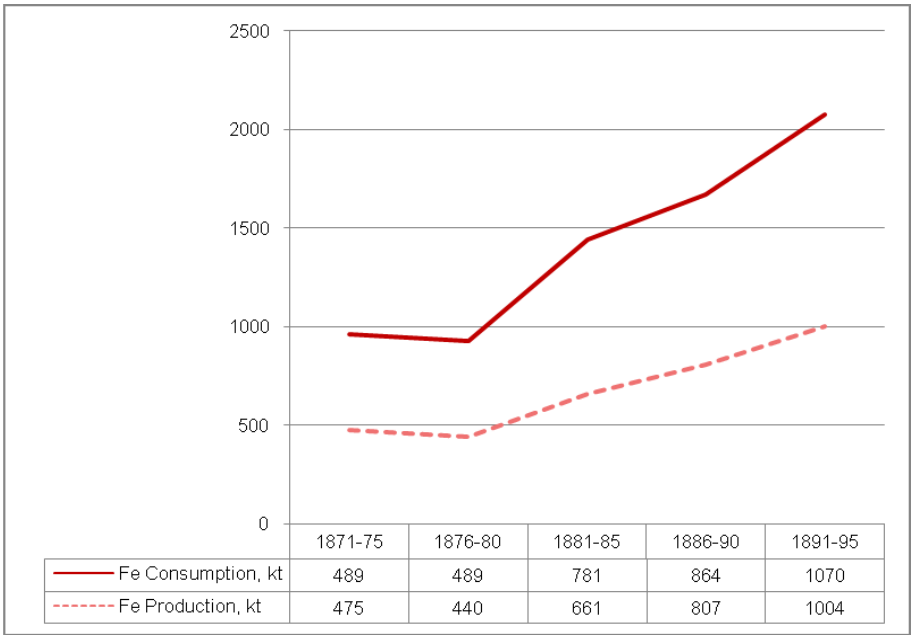



Fig. 5: Pig iron consumption and production in Austria-Hungary, 1871-1895 (Apelt 1899)

It can be learned from Figure 6 below that increases in consumption were, moreover, to some extent due to an increase in population. Per capita consumption remained fairly stable between the 1880s and 1890s.

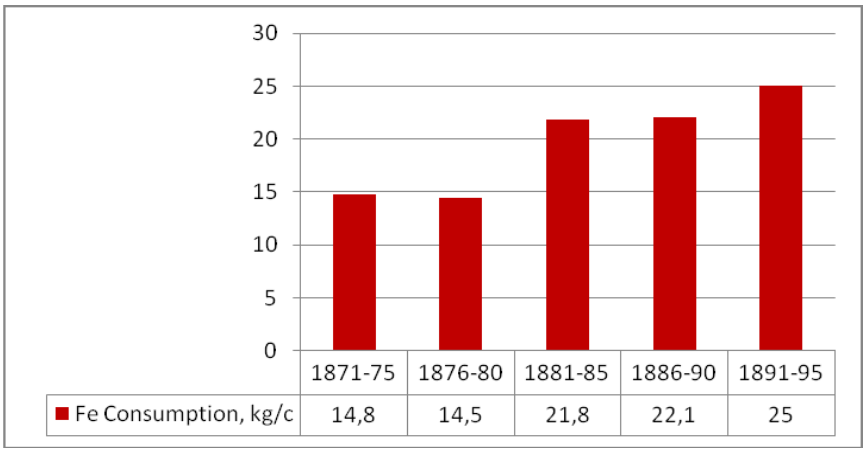


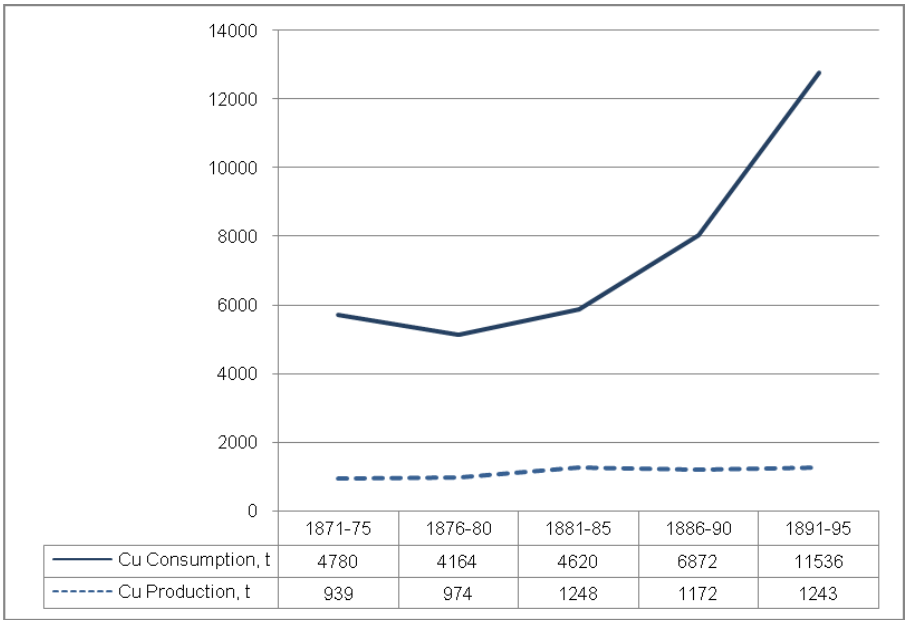

Fig. 6: Pig iron consumption in Austria 1871-95, kg per capita (Apelt 1899)

Historical stocks of iron could not be quantified. It can nevertheless be safely inferred from the above that iron stocks in the anthroposphere had been continually rising. In combination with the fact that raw material demand could largely be met domestically, the iron economy was in a much more favorable situation on the eve of the war than the copper industry.

### 3.3. Production of Copper in Austria before 1914

Copper production in Austria, which only amounted to 4,007 t by 1914 (Wegs 1979: 66), relied on three copper mines in Salzburg (producing roughly 16,000 t of ores annually between 1911 and 1913; Riedl 1932: 288). The vast bulk of copper then had to be imported as mentioned in chapter 3.1 above, with import figures hitting 36,500 t on the eve of the war. Exports only amounted to 1,400 t annually in 1911-1913. Consumption had reached 39,200 t, with Austria alone accounting for 30,000 t of copper use.

Looking at Fig. 7, it can be seen that the consumption trend indicated had not changed since the 1890s in the two decades leading to he war. Only copper production overcame the stagnation of the 19th century and more than doubled until 1914; however, it is obvious that this production increase fell far short of meeting demand.




| | 1871-75 | 1876-80 | 1881-85 | 1886-90 | 1891-95 |
|---|---|---|---|---|---|
| Cu Consumption, t | 4780 | 4164 | 4620 | 6872 | 11536 |
| Cu Production, t | 939 | 974 | 1248 | 1172 | 1243 |

Fig. 7: Copper consumption and production in Austria-Hungary, 1871-1895 (Apelt 1899)

Unlike the case of iron consumption, copper consumption seems attributable to population growth to a lesser extent. The trend indicated in per capita consumption below (Fig. 8) indicates a similar development as the overall trend in Fig. 7, with per capita consumption also rising sharply from the 1880s onward. Apelt (1899: 185) attributes this to the massive extension of telegraph networks in the late 19th century; it can be assumed that electrical appliances may also have played a considerable part in the latter decades.

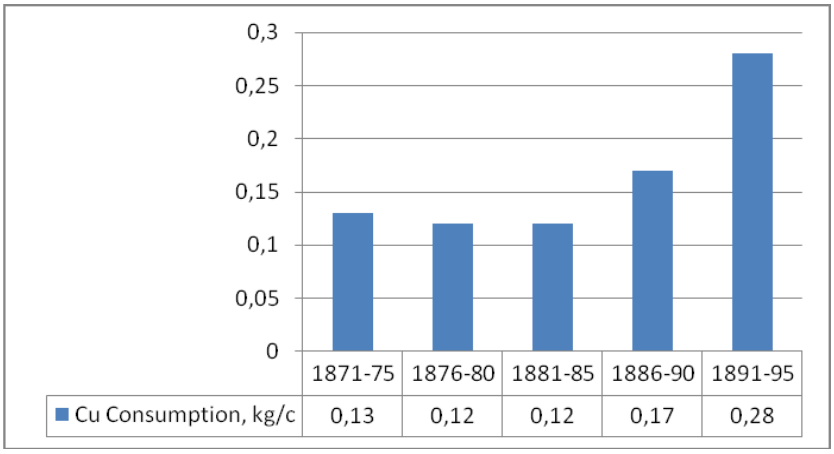


Fig. 8: Copper consumption in Austria 1871-95, kg per capita (Apelt 1899)

Wittmer (2005: 63) calculated the per capita stock of copper in Switzerland as a cumulative figure of net imports per capita since 1900[8]. In 1914, per capita stock had reached about 25 kg. It seems reasonable to assume a similar figure for Austria-Hungary at the time.

A much sharper increase in copper stocks, compared to iron, is obvious. Combined with the overwhelming dependence on copper imports, which practically ceased during the war (see chapter 5 below), and domestic production inadequate, the anthroposphere was predisposed to provide the bulk of Austria's copper supplies between during the war years.

[8] Graedel et al. (2006) give a copper stock in the United States of about 50kg per capita for 1911. Since copper consumption was much higher in the US than in Austria-Hungary at the time (Apelt 1899: 187), it does not seem to make sense to assume a similar figure here.

## 4. RAW MATERIAL MANAGEMENT IN AUSTRIA, 1915-1918: *Fe*

Figs. 9 to 12 show the per capita fluxes of iron for the years from 1915 to 1918 in one-year steps. Figures include only the territories listed in chapter 2.2. Where appropriate data could not be obtained, or a reasonable estimate could not be made, question marks are shown in the diagram. In the following, the individual processes will be explained in their context.

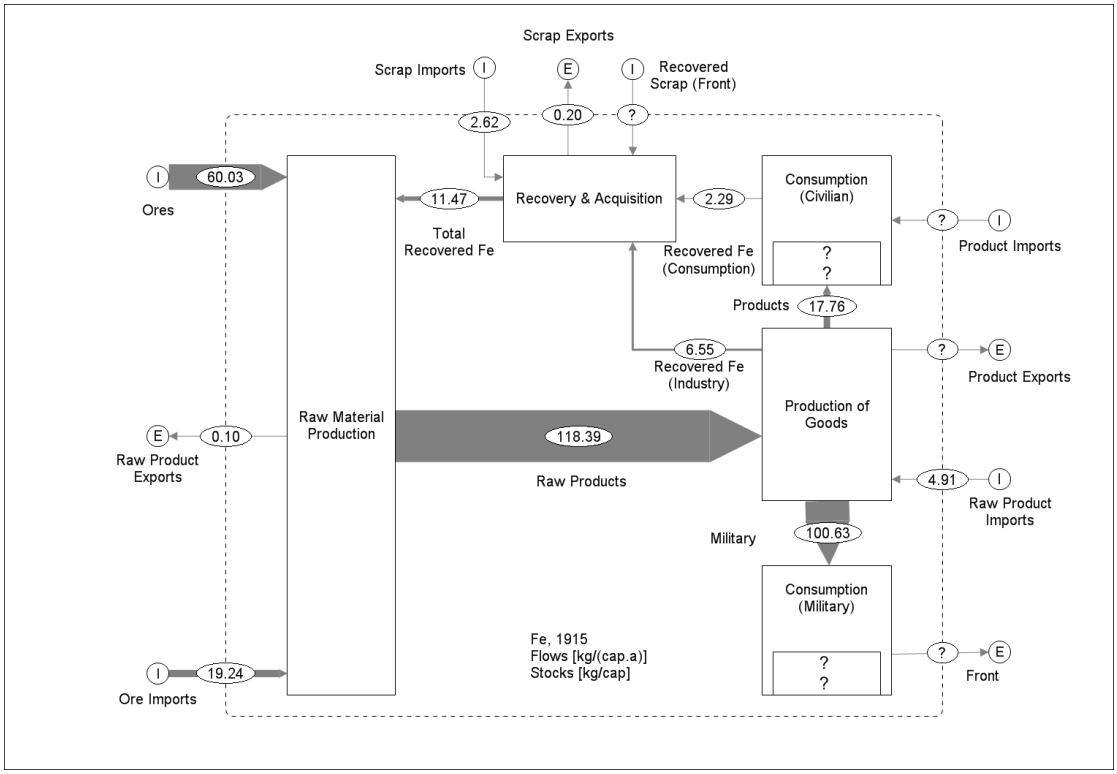



Fig. 9: Fe flows in Austria, 1915

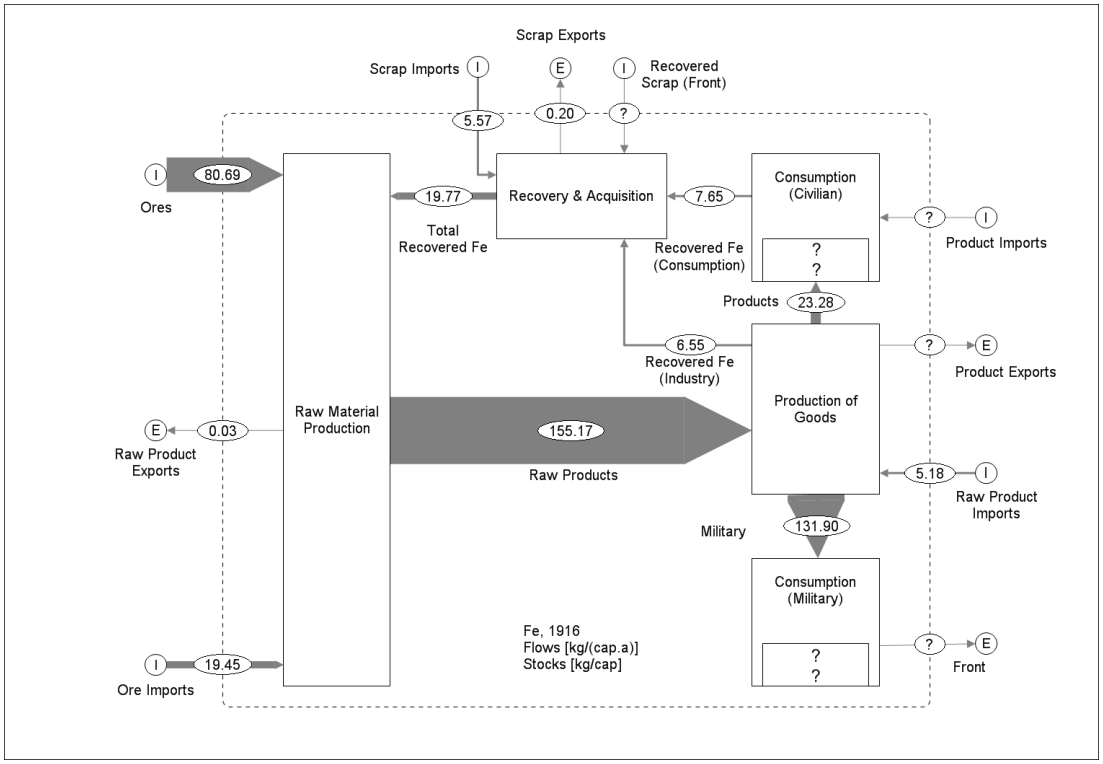



Fig.10: Fe flows in Austria, 1916

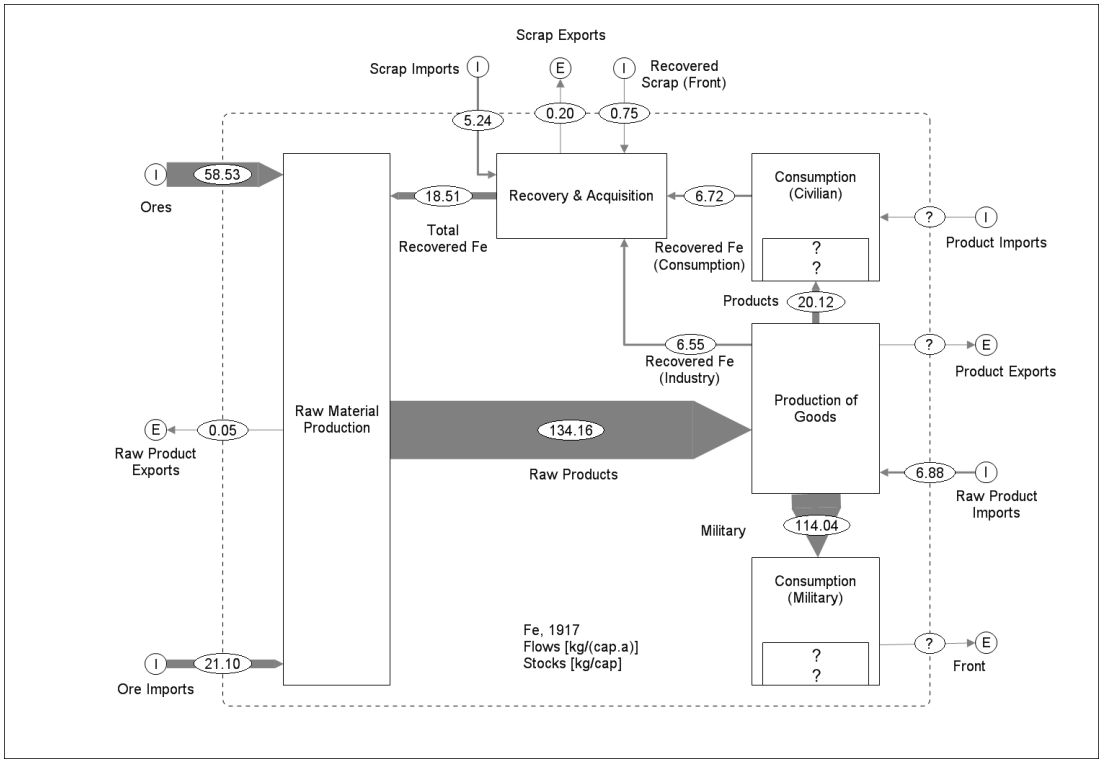



Fig. 11: Fe flows in Austria, 1917

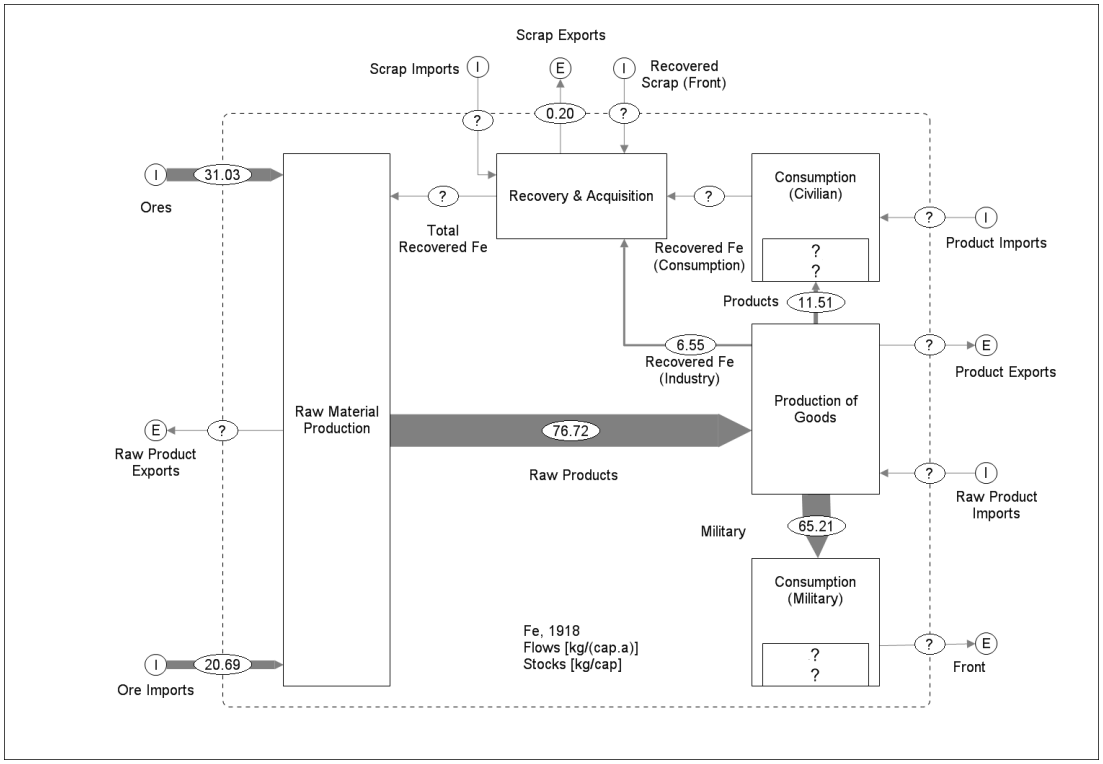



Fig. 12: Fe flows in Austria, 1918

### 4.1. Process: Raw Material Production

After the outbreak of the war, production of both pig iron and steel[9] decreased considerably, with only 1,632,874 t of pig iron (minus 13%) and 1,539,000 t of steel (minus 16%) produced in 1914 (Wegs 1979: 54), a fact that Riedl (1932: 271) attributes to an initial slump in demand in the second half of the year and the shortage of labor resulting from the military draft. For arguably the same reason, ore production had decreased from 3.3 to 2.5 million tons in 1914.

By 1915, however, production seemed to have made the transition to a war economy, showing slight increases in ore, pig iron (plus 5%) and strong increases steel production (plus 22%), with steel production surpassing peacetime figures.

According to Wegs (1979: 55), military requirements had risen from 5% in 1914 to 85%[10] in 1915, showing the fundamental change that iron use underwent in the war economy. It is safe to assume that this ratio did not change much in the latter two years of the war, since these amounts were deemed insufficient by the military,

[9] For steel, an iron content of 98%, for pig iron, 95% are used here, based on typical figures given in Brunner et al. (2004).

[10] Also in 1916, 3.1 millions t of the 3.6 million t of steel produced in all of Austria-Hungary was earmarked for military uses (Wegs 1917: 60).

which kept demanding more (Wegs 1979: 55; Riedl 1932: 278ff.). In 1916, production hit a record high, due to the 'Hindenburg Program' as an attempt, along with Germany, to push military supplies even further.

Moreover, the Austrian economy was subject to the War Provisions Law (*Kriegsleistungsgesetz*) of 1912 (see Riedl 1932: 7-15), which, in the case of war, transforming the country's economy into a militarized planned economy, with production in all major sectors taking place under military supervision and with entrepreneurs and workers being subject to military jurisdiction.

The strain put on the industry in 1916, however, led to a considerable downward trend in output until 1918. This may be attributable to transport problems as well as decreased work efficiency from food shortages, as Riedl argues; in 1917, annual output per worker in iron and steel production had fallen by nearly 40% compared to the previous year.

As regards supplies for the output of raw products[11], it has already been said above that Austria was largely self-sufficient in this respect[12]. 600,000 t of ore[13] could be imported annually during the war years (Mejzlik 1977: 98), so that at the beginning of the war, an reorganization and rationing of raw material supplies for iron and steel production was not deemed necessary (Riedl 1932: 18f.), since this was not a considerable reduction of imports compared to the pre-war figure of 680,000 t. Exports of raw products practically ceased during the war, amounting to no more than 1000 t per year (Wegs 1979: 55). Domestic ore production had sunk by 25% to 2,509,375 t from 1913 to 1914, but by 1915 had reached 2,901,599 t (about 60 kg/cap) again, rising above peacetime figures due to the increased production efforts of 1916, when a record 3,900,000 t (almost 81kg/cap) of iron ore were produced in Austria. The effort, as mentioned above, could not be sustained however; by 1917, ore production had fallen again under 1915 levels, and although no figures are available for

[11] There seems to be a clear discrepancy between process inputs and outputs in the figures for all four years; the reason for this could not be determined.

[12] Ore exports, however, did decrease more than tenfold by 1917, reaching a negligible 10,000 t compared to the pre-war annual export of 110,000 t (Riedl 1932: 273).

[13] An iron content of about 60% is assumed for iron ores based on percentages given in Brunner et al. (2004), Bundesanstalt für Geowissenschaften und Rohstoffe (2006) and typical concentrations of export-grade ores given by the Steel Index website. Riedl (1932: 270) mentions that Swedish ores were of roughly the same quality as Austrian ores, so the same ore content is used here.

1918, it can be inferred from the sharp decline of iron and steel production that the output of the Austrian mines had followed a similar trajectory.

The second major source of raw materials for iron and steel production was scrap[14]. As can be seen in Figs. 9 to 12, the supply of iron and steel scrap to Austria's furnaces remained at a relatively stable level during the war years; in 1915, there was no shortage of scrap at first. The outbreak of the war, with its ever-increasing metal demand, however, led to hoarding and speculation and resulted in a doubling of scrap prices by the end of the year. Scrap supplies could be sustained, however, because the Scrap Iron Commission (*Alteisenkommission*, AEK), formed in early 1916, was authorized to make requisitions to ensure stable supplies to the production of raw products (Mejzlik 1977: 218). This could be sustained at least until 1917; for 1918, as is the case with other figures as well, the insufficient amount of data and obvious changes in raw material supplies in that year do not allow for an exact figure or a reasonable estimate about the development of overall scrap recovery.

### 4.2. Process: Production of Goods

It has already been said above that iron and steel production in Austria had almost exclusively come to serve the production of military goods, with increases in iron and steel output being only attributable to rising military demands. To counter the expected, ever-increasing demands for the war effort, iron and steel processing industries started to demand larger volumes of raw material to avoid the difficulty of having to demand materials for production of civilian goods separately.

Foreign trade in finished goods also practically ceased in 1915-1918. Since Germany (which had become the sole potential source of imports) had met difficulties in meeting iron demand as well, substantial imports could rarely be obtained. Exports of finished goods likewise were reduced to minute amounts (Wegs 1979: 55; Riedl 1932: 279)[15].

Production of finished goods also proved, however, to be a considerable supplier of scrap that was channeled back to raw material production, with an estimated 200,000 t of scrap being recovered annually from industrial enterprises during the

[14] For scrap, the iron content was set at 95%, based on the types of wastes mentioned in the literature, and the iron content of similar types of waste given in Brunner et al. (2004).

[15] Conclusive numbers on specific amounts and types of products could not be obtained.

war years (Riedl 1932: 274)[16]. This amount consistently measured up to one-third or more of total scrap recovered[17].

### 4.3. Process: Consumption (Military)

According to military needs in wartime, production of all sorts of ordnance greatly increased and even expanded to smaller enterprises which had previously not been involved in the arms industry. Due to the restrictions placed on the acquisition of raw materials for civilian goods, production for military purposes was, in many cases, probably the only possibility to stay in business. As a consequence, production of rifles, machine guns and artillery increased about six-fold from 1914 to 1917 (Wegs 1979: 120). Since output plummeted in 1918, it can be assumed that the 85% of iron and steel production channeled into military use in 1915 and 1916, with that year's forced increase in production, were not surpassed in the latter two years of the war.

In addition to ordnance for direct military purposes, the military's plans also required an expansion of the supply of parts for railway engines and carriages, as well as helmets, spades, field cooking equipment and the like (Riedl 1932: 276).

Domestic stocks of military equipment, as well as yearly "exports" of such equipment to the front, are difficult to quantify. Since "basic" peacetime equipment of the military only required, as mentioned, 5% of the total output of iron and steel, it seems plausible that much of the iron appropriated by the military during the war was quickly deployed in campaigns outside the country, although no numbers on military iron stocks within Austria could be obtained. Conversely, not much of this material could of course be recovered. Mejzlik (1977: 225, 228) mentions 1916 as year where military operations had yielded a particularly good amount of scrap recovered from the front lines[18]: these 23,000 t, or 0.75 kg/cap of iron, were hardly significant compared to the almost 4 million tons, or about 129 kg/cap, used up by the military. Moreover, such scrap shipments were highly contingent on the course of military operations; most of the 1916 shipments arrived between February and April of that year.

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[16] An estimate for1918 is difficult due to the severe decreases in production and disruption of data availability due to the end of the war.

[17] Mejzlik's (1977: 223) list of scrap iron stocks of major enterprises from 1916 to 1918 does not show drastic change. Since scrap imports from Germany also remained fairly stable, it can be assumed that industry stocks of iron and steel were not significantly depleted.

[18] Scrap from military operations was recovered by the army in total number of three main collection posts in Belgrade, Krakow, and Vienna (Mejzlik 1977: 225).

### 4.4. Process: Consumption (Civilian)

Unlike the case of copper outlined in chapter 6, the "civilian" fraction of iron consumption was affected only insofar as trade in scrap iron was heavily regulated from 1916 on. Confiscation of machinery, tools, wire etc. in use was apparently either not deemed necessary or possible.

In 1915, scrap deliveries can be estimated at a relatively low level, since iron requisition (see chapter 5.5 below) was still organized along peacetime lines. As in 1912, overall demand of scrap by the iron industry had been 350,000 t (Riedl 1932: 271), it can be assumed that in 1915, this figure had not yet changed significantly. If then imports and exports of scrap are looked at, together with the amount of scrap recovered from the industry (Riedl 1932: 273-275), it can be inferred that about 70,000 t of scrap were recovered from civilian consumption this way. Due to the measures discussed below, this figure dramatically increased in the following year due to reasons discussed below.

The output of finished goods for civilian purposes was severely reduced, however, as a result of the military's iron and steel demands. This might not have posed such a problem in the case of luxury goods, but as Riedl (1932: 279) relates, this became a problem especially because agriculture. As a vital food supplier for the entire population (and, importantly at the time, the army), the agricultural sector felt the crunch of iron shortage on production of necessary tools and machinery, so that – since the military did not agree to cutting demands – production for other, less vital purposes had to be cut to avoid endangering harvests.

### 4.5. Process: Recovery & Acquisition

Even though scrap iron was by no means in short supply at the onset of the war, it has already been pointed out that expectations of rapidly increasing iron demand, and as a consequence rising prices, resulted in speculation on the part of scrap iron traders in 1915, dramatically driving up prices and endangering a safe supply of scrap to the iron and steel mills. The fact that no special measures had been taken already in 1915 to increase the supply of scrap iron is attributed by Mejzlik (1977: 42) also to the fact that the course the war would take had not yet been foreseen. During that first year, the trade in scrap was, just as in peacetime, managed by the Scrap Iron Trade Association (AHV), a trade cartel closely linked to the iron and steel industry (Mejzlik 1977: 43).

The hesitant, observant position of scrap traders seems to have resulted in supply shortages of an extent great enough to lead to the formation of the Scrap Iron Commission (AEK) by an ordinance of the Trade Ministry on 5 January 1916 (Mejzlik 1977: 43-45; Riedl 1932: 286). From then on, the AEK was not only authorized to dictate maximum prices, but it also became illegal to acquire scrap iron from any other source. Scrap iron traders had to declare their stocks on a monthly basis. Shipments were then allocated to the iron and steel mills after their declared demands had been validated by the commission. Even in this tightly controlled situation, Mejzlik (1977: 222) relates the fact that on control visits to scrap trading enterprises, sometimes amounts of more up to 200 train cars of scrap were being hoarded, with the apparent intent of obtaining a better price later on.[19]

On the other hand, the AEK was also authorized to not only organize scrap recovery, but also to order shipments from trading firms to the industry if need be (Riedl 1932: 286). While, however, items actually in use in the infrastructure were requisitioned to meet the shortage of copper, the authority of the AEK only extended to requisitioning stocks of scrap traders. Purchase of scrap by these traders remained outside of the commission's reach, and it seems that scrap iron was not in such short supply that scrap traders had trouble finding their sources.

Figs. 9 and 10 give an idea of the effectiveness of the AEK: together with recovered scrap from industry, the amount of recovered scrap almost doubled in 1916 (13% of overall iron production came from recovered iron), before declining a little again in 1917[20]. Most of this was due to the increase of scrap iron recovered from domestic traders. Another sizeable portion of scrap could be imported, mostly from Germany (Wegs 1979: 56; Riedl 1932: 274) and to a small part (8,000 to 13,000 t annually) from Hungary, with an insignificant amount of 6,000 t annually being exported to Hungary[21]. The third major flow was scrap recovered by industry, and channeled back to raw material production. As pointed out in chapter 5.2 above, it can be assumed that this flow of roughly 200,000 t annually (Riedl 1932: 274) also remained stable in 1918.

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[19] The mass unit "train car" used by Mejzlik denotes about 10 t (Mejzlik 1977: 433).

[20] . As with many other flows, data for 1918 become somewhat inconclusive. A meaningful figure cannot be given for this year, since data on German imports could not be obtained.

[21] A separate, similar organization existed in Hungary (Riedl 1932: 287).

### 4.6. Summary

The abundance of iron, compared to copper, allowed the authorities to meet iron demands by basically relying on requisitioning scrap that had been bought regularly by traders, without having to resort to further-reaching such as confiscation of installations, tools and machinery containing iron. Existing stockpiles of iron scrap were, as it seems, just about sufficient to meet the demands of the military.

While no iron was extracted from infrastructure and private use, civilian demand could nevertheless not be met due to the highly increased shipments of iron to the military, of which very little was recovered.

Pressure on the iron economy outside the military was, arguably, not so much due to exploitation of iron stocks in civilian infrastructure and consumption, but due to the sudden and drastic reduction in supplies of iron for other uses than the war effort. Much of the increased demand could moreover be met by increased production of iron ore, as the diagrams show.

Since, only scrap iron was requisitioned, while the purchase of scrap from consumers was not regulated by the AEK, it can be concluded that the war economy did, in fact, not diminish pre-war anthropogenic iron stocks, but rather led to stagnation thereof.

## 5. RAW MATERIAL MANAGEMENT IN AUSTRIA, 1915-1918: *Cu*

Figs. 13 to 16 show per capita fluxes of copper from 1915 to 1918 in one-year steps.

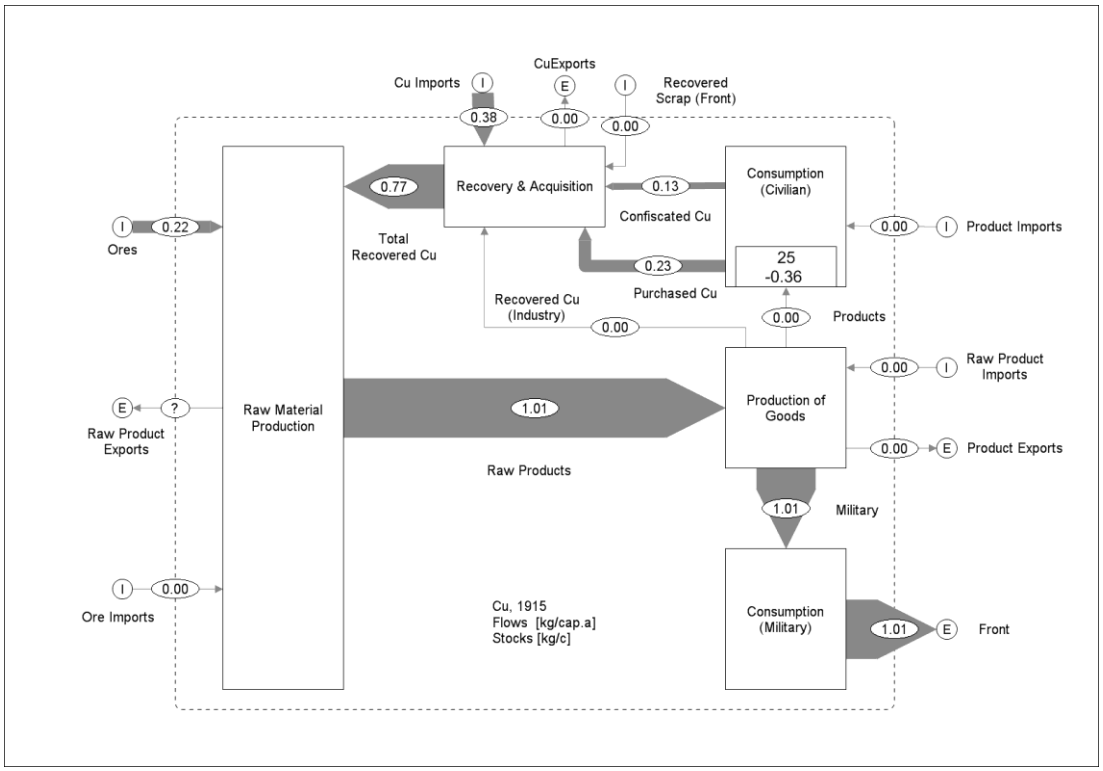


Fig. 13: Cu flows in Austria, 1915

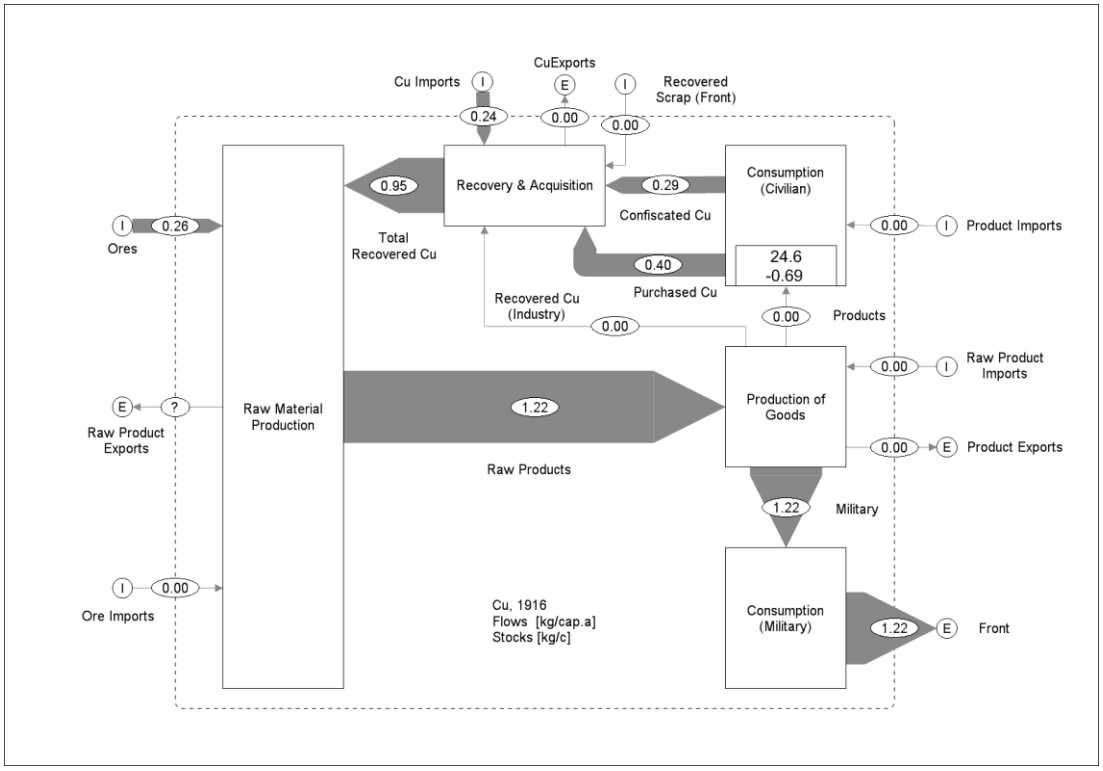


Fig.14: Cu flows in Austria, 1916

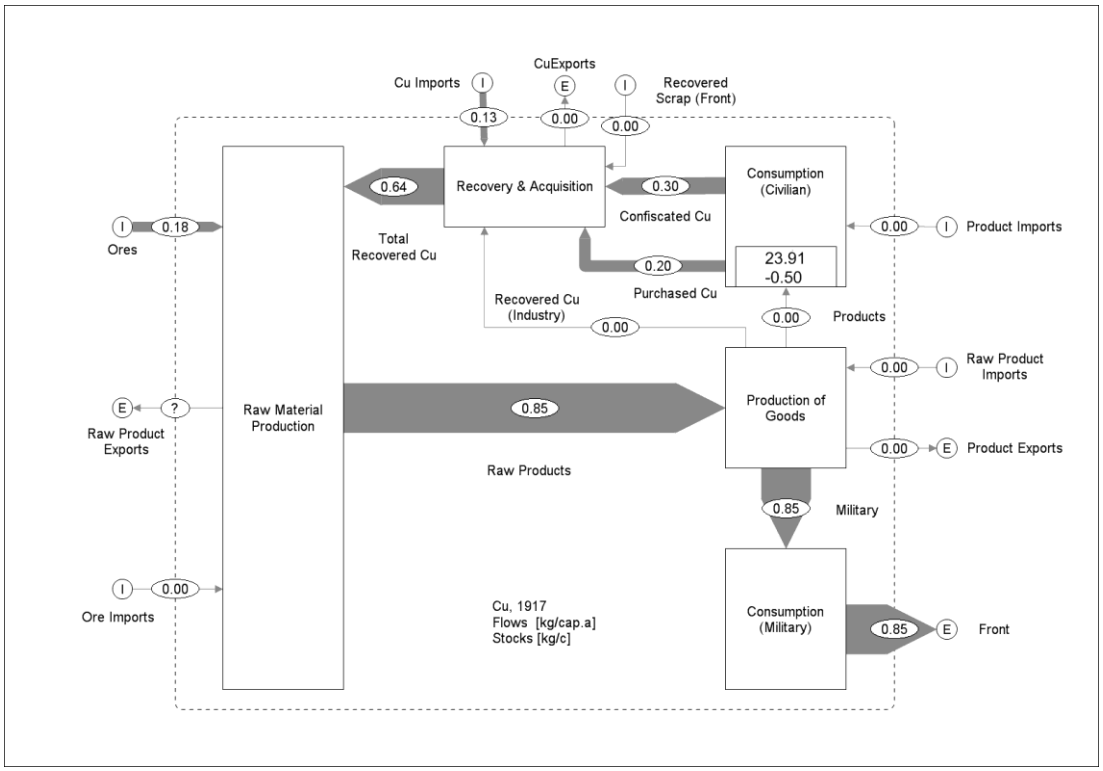


Fig. 15: Cu flows in Austria, 1917

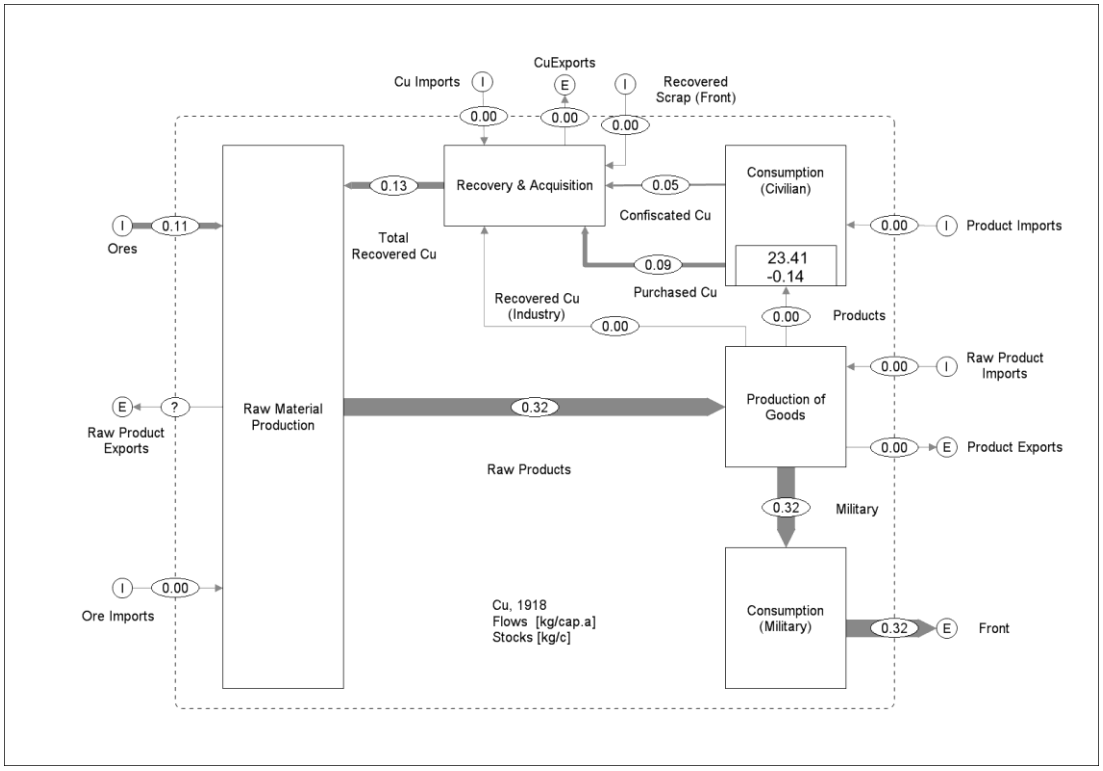


Fig. 16: Cu flows in Austria, 1918

### 5.1. Process: Raw Material Production

Since Austria-Hungary lacked sufficient copper deposits to cover domestic demand even in peacetime – with roughly 16,000 t of copper ores[22] being produced in three mines located in Salzburg and Tyrol (Riedl 1932: 288), it had already been heavily dependent on imports before the outbreak of the First World War. After 1914, imports (except those from Germany in the context of the war effort) ceased, so that now exploitation of the anthroposphere had to make up for them in, as shall be shown, increasingly creative ways.

In 1914, production of copper[23] had even slightly decreased from 4,100 t annually on average between 1911 and 1913 (Riedl 1932: 288) to 4,007 t in 1914. By 1915, production had increased by over one third, reaching 6,528 t, with a further increase to 7,774 t in 1916. From then on, production fell back to pre-war levels or below until the end of the war. Since no copper ore was imported throughout the war, this in-

[22] The ore copper content of about 16% was estimated based on Riedl (1932: 288), who mentions that 2569 t of copper were produced from 15,790 t of ores in Mitterberg, which produced the bulk of copper ore in Austria (15,790 t of 15,967 t annually).

[23] Refined copper has a copper 99% or above (Keller/Eickhoff 1955: 4).

crease in production has to be attributed to the amount of copper recovered[24], in part by confiscation (see chapter 5.4 below) from the anthroposphere.
Another part of the total amount of copper produced in the war years was imported from the theaters of war. Since this amount, like iron imports from the front lines, was contingent on the course of the war and does is not quantified in the literature, the amounts seem to have been of similarly negligible nature as the amounts of iron thus obtained.

### 5.2. Process: Production of Goods

According to Wegs (1979: 67), copper production of 1915 almost exclusively available for military purposes, although he gives no figure regarding the actual ratio of production for military purposes to production for civilian purposes. Riedl (1932: 304) only mentions that production for civilian purposes hardly played a role at the time.
No copper products were exported, however, and whatever material was imported from Germany came in the form of scrap or raw products, and under official supervision. Imports outside official channels meanwhile ceased altogether (Riedl 1932: 304f.). Austria had in fact promised Germany to reciprocate for German imports of copper, but continuously failed to meet its obligations and export any copper to Germany in turn (Wegs 1979: 67, 72). It seems therefore plausible, and in accordance with what Wegs relates as well as with the general shortage of copper, that indeed all copper-containing goods produced went to Austrian civilian or military end-use, with the latter taking the lion's share.
A large part of military supplies produced obviously went into rifle ammunition and artillery shells. Production of the former increased by over one-third from 1914 to 1916, while production of the latter increased almost seven-fold during the same period (Wegs 1979: 120). This can be attributed, like the similar increases in iron production, to the Hindenburg Program to increase German and Austrian production figures. Similar to the development in the iron industry, which was not affected by raw material shortages to such an extent, output strongly decreased from 1916 on. Apart from the obvious exhaustion of exploitable copper stocks in the anthroposphere, this may also be attributed to sinking productivity. Riedl (1932: 304) not only

[24] The copper content of recovered copper scrap – which to a considerable part conained alloys such as bronze (approx. 80% copper in church bells; Keller/Eickhoff 1955: 42) and brass (65% copper; Brunner et al. 2004) – has been estimated at about 75%.

mentions shortages of coal, but also malnourishment and the employment of untrained women and teenagers to make up for the workers drafted into the military.

### 5.3. Process: Consumption (Military)

Consumption, in the case of copper, was mostly military use. It is difficult to arrive at a reasonable estimate of stocks in the civilian or military Austrian anthroposphere. As copper was practically exclusively used for the production of ammunition, production figures for ammunition (made from brass) in 1916 (4 million rounds/day of rifle ammunition only; Wegs 1979: 120) make plausible the conclusion that practically all of the copper produced during the war found its way to the front lines. Wegs' (1979:67) assertion about military requirements in 1915 underlines this.

A look at Figs. 13 to 16, together with the increasingly desperate measures, outlined in chapter 5.4 below, to exploit anthropogenic copper supplies gives an idea of the amount of copper required by the military. This was to a large extent to be used in a dissipative, non-recoverable manner (i.e. as ammunition). Wegs (1979: 73) notes that a recovery of ammunition shells from battlefields was made impossible by a lack of railway carriages and disposable manpower, which resulted in the necessity of obtaining new copper for the front lines from the infrastructure and consumer goods. In light of the constant shortage of and demands for ammunition, it is plausible that no stocks of ammunition (for which copper was practically exclusively used) worth mentioning existed in military end-use.

### 5.4. Process: Consumption (Civilian)

From the above material flow diagrams it becomes clear that the Austrian infrastructure as well as consumer goods were "mined" for copper. If any amount of copper was actually earmarked for civilian use in the war years, it was a negligible amount. Conversely, the civilian part of the anthroposphere, rather than mining activities, served as the main deposit of iron and copper, being depleted by up to several dozen thousand tons per year, as is explained in more detail in chapter 5.5 below.

Wittmer's (2005:60) calculations for anthropogenic copper stocks in Switzerland make it safe to assume that these stocks had a similar dimension in Austria. Since practically no copper products flowed to civilian end-use during the war years, requisitions of scrap diminished in-use copper stocks.

### 5.5. Process: Recovery & Acquisition

In 1914, following the example of Germany, three 'Central Metal Bureaus' (*Metallzentralen*, MZ) were created, one for Austria, one for Bosnia, and one for Hungary. These bureaus were organized as private corporations with the aim of acquiring so-called 'war metals' (*Kriegsmetalle*) in a centralized, organized manner and ensuring the supply thereof. Capital for the MZ was to be provided by the ammunitions industry, but the organization remained under tight military control, since it was the military which supervised ammunitions production. Article 7 of the MZ 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: 28).

The authority of the MZ, therefore, extended only to the acquisition of metal supplies, 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 (*Militärverwaltung*). Due to a lack of methodical planning, according to Riedl (1932: 291), 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. In early 1915 then already, 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 MZ was responsible for the practical tasks of securing these supplies (Riedl 1932: 292).

Obligations to declare metal deposits were continually extended to ever new sources during the war. By the end of 1915, ores and raw products, scrap, and wastes were requisitioned, and unused factory equipment had to be declared, combined with a prohibition to sell the equipment. A cadastre of metals contained in factory equipment was compiled that same year, also extending to copper that could possibly obtained from electric machinery and electric or telegraphic cables and wires[25]. The material flow diagrams of copper show that while in 1915, the problems of bad planning and possibly a lack of inventories was still evident, the MZ had become increasingly effective by 1916. No amount of waste worth mentioning seems to have come from the production of finished copper goods, though. It might seem

[25] For this purpose, an 'electro-technical commission' (*elektrotechnische Kommission*) was formed in the Trade Ministry (Riedl 1932: 295).

plausible that due to the shortage of ammunition, not much waste from manufacturers was channeled back to the competent authorities.

In addition, a 'patriotic collection' of metal by 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 can be seen from the fact that apart from machinery and buildings, purchase (and after 1915 confiscation) by the MZ 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: 298). Also in 1916, copper roofs and lightning rods were confiscated. Overall, the amount of copper recovered from civilian end-use stocks reached as much as 78% of total copper produced in 1916.

In 1917, the anthroposphere had been depleted of copper to such an extent that small metal-work from doors, windows and furniture, were confiscated. The largest single share of copper confiscated that year, however, were bronze church bells, which amounted to almost 50% of all copper-containing goods procured that year (Wegs 1979: 69) and, at a total mass of 9,771 t (0.33 kg/cap) confiscated in 1917 alone, were the largest single source of copper tapped by the MZ during he war. By 1918, the only expendable anthropogenic copper deposits left were brass door handles and frames of shop windows, which were now confiscated. As Figs. 13 to 16 show, the amount of copper recovered had reached diminutive amounts in 1918 compared to the previous years.

With the extent to which copper was recovered from the anthroposphere, and due to the types of appliances with a high copper content, such 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, plants generating DC power, cables for which required comparably large cross-sections, were converted to rotary current, thus reducing the use of copper. Telegraphic wires made of copper were replaced with iron. Iron, in turn, replaced aluminum where possible, such as in kitchenware, so that the aluminum could be used for more vital purposes (see Riedl 1932: 291-300; Wegs 1979: 67-71). In order to ensure quick disassembly and reassembly, the MZ also collected stocks of wire and cable to

avoid unnecessary disruption in the operation of affected enterprises and installations (Wegs 1979: 68)[26].

### 5.6. Summary

Much more than in the case of iron, recovery of copper from the anthroposphere proved to have a massive influence on overall copper production during the First World War. As the material flow diagrams show, the extent of copper recovery actually proved more crucial to the production of copper raw products than mining activities, which had however followed the overall trend. In the case of iron, the situation seems to have been the opposite. 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.

Crucial to this was, it could well be argued, the availability or technical feasibility of replacing one metal with another one. In this respect, iron assumed a certain importance also for the rationing and requisition of copper, since the former, still more abundant metal, often served to replace the latter.

In comparison to the iron situation described in chapter 4, it becomes apparent that that pressure on civilian in-use stocks of copper not only came from the disruption in supplies of civilian goods, as was the case with iron. First and foremost, this pressure resulted from immense amount of copper goods requisitioned, while supplies of copper to civilian end-use practically ceased completely early in the war. What is remarkable is the fact that except in 1917, when church bells resulted in a considerable increase of the amount of confiscated copper material, confiscation proved a less abundant source of copper than purchase by the authorities.

[26] Usually, it took 14 weeks to extract copper from, for example, a power plant or a railway line.

## 6. AUSTRIA: THE PRESENT SITUATION

In the following part, a quick overview shall be given of the situation of the iron and copper balance in the present day to make possible a comparison of the past situation with the iron and copper balance of today's Austria. It has often been heard that soon the anthroposphere would have to be "mined" for scarce metals (see, for instance, Drakonakis et al. 2007) as geogenic stocks of those disappear (this is, however, not an immediate danger in the case of iron. It seems an interesting endeavor, then, to conclude this brief study by comparing the present to a past situation where, out of warmongering and/or necessity, no choice was left but the resort to "urban mining".

### 6.1. Material Flows of Fe in Austria: Past & Present

Looking at the present iron balance of Austria, a good quick overview can be gained from Brunner et al. (2004), who provide a material balance for iron, copper, zinc and aluminum.

Apart from the obvious increases in volume of nearly all flows, it is striking that production from mines has remained relatively stable, with an annual 89 kg/cap not surpassing the wartime record year 1916, with about 80 kg/cap of iron produced. Domestic output of raw products has only doubled compared to 1916; however, it has to be kept in mind that exports of raw products had ceased between 1915 and 1918, while they now make up the largest part of raw material output, necessitating an according volume if raw material imports. If the ratio of raw material imports and total output of raw products is looked at then, these imports make up for a far smaller share of total output of raw material production in 1916 (13% vs. 74% today). One has to bear in mind, however, that while the Austrian iron economy seemed more self-sufficient in the past, most of the iron produced was in fact "exported" (or deployed) in the form of armaments.

An interesting question is the rate of metal recovery from waste management processes to the production of raw materials. At present, 110 kg/cap of iron are recovered from waste management, amounting to 14% of total output of raw products. The figures from 1916 give a ratio 13%. That this figure is comparatively high has its reason, of course, in the increases in waste recovery due to the war effort, but also the flow of iron from civilian consumption, as the main source of scrap, was considerably lower at the time. If we look the ration

### 6.2. Material Flows of Cu in Austria: Past & Present

It is not easy to compare the copper economy of the First World War with the present, since the shortage had been so much more pronounced than in the case of iron. One major difference is of course the present volume of imports, lack of which had necessitated the depletion of anthropogenic resources in 1914-1918.

The copper economy is now mostly export oriented. Mining does not take place in Austria today, with most copper (19 kg/cap) being imported in the form of raw materials, to be processed and, to a large part, exported again. A second major export flow (10 kg/cap) is made up by exported raw products, which rely on the import of primary products (4.9 kg/cap).

In keeping with the rapidly increasing trend in copper consumption, which had already become apparent in the late 19$^{th}$ century, copper flows and stocks have increased at a much higher rate as was the case with iron, a fact that can be attributed to the increased use of electric appliances and electronic equipment.

An obvious difference to the iron economy is the high extent (63%; Brunner et al. 2004) to which copper is recovered from waste management for the production of raw materials. In 1916, the corresponding figure had been 78%, only that the "waste" consisted of requisitioned copper goods from civilian consumption. It has to be kept in mind that these comparatively high figures during the war could only be obtained by means of coercion (i.e. confiscation of goods).

## 7. RESULTS AND CONCLUSION

At present, worldwide iron reserves stand at about 12,000 kg per capita, copper reserves at only about 70 kg per capita (Bundesanstalt für Geowissenschaften und Rohstoffe 2006). In Austria, anthropogenic copper stocks amount to 5,000 kg/cap for iron and close to 300 kg/cap for copper (Brunner et al. 2004). Demand for metals is likely to rise in places like China, with only 2,300 kg/cap of in-use iron stocks, and 30 kg/cap of copper (Drakonakis 2007). Situations of considerable metal shortage are likely to arise again, and this work intended to give an overview over methods taken in a period of acute shortage, as well as the impact thereof.

Having shown how the supply of metals was organized and supply patterns for iron and copper were changed in Austria-Hungary during wartime, it can now be attempted to answer the questions, posed at the beginning of this work, about first, the role of "urban mining", second, the strategies used, and third, the question how effective and sustainable these strategies were in fact.

In the case of iron, the material flow diagrams show the increase in iron recovered after the initial neglect of he scrap trade had proved to exacerbate the pressure put on the industry by military demands. However, iron scrap could still be acquired by free-market by traders, who, however, had to declare their inventories. Together with increased output from iron mines and a high degree of Austro-Hungarian self-sufficiency in iron supplies, this did not necessitate active prospecting of the anthroposphere for iron deposits, apart from the "classic" recycling" as it was practiced in the scrap trade. The success of the authorities in increasing the output of recovered scrap had, it can be argued, more to do with ending speculation, which had driven up prices and led to an iron shortage in the first year of the war.

As to the question of sustainability, a look at the material flow diagrams in chapter 4 shows that probably, it would have been possible at the time to recover much higher amounts of scrap, had it not been for the large amounts of iron that went to military use. As the diminutive amounts of iron shipped back from the front lines show, iron use by the military can be assumed to have been of a mostly dissipative nature, making later recovery much more difficult. To the extent that the same amount of iron in civilian consumption stocks would arguably have led to less dissipative use of iron, the measures taken by the authorities could indeed be called sustainable. On the production side, however, the ever-increasing output of mines iron and steel

mills could not be sustained and by 1918 had led to what can be called a state of exhaustion of the entire industry.

In the case of copper, the authorities took a learning-by-doing approach, rather randomly confiscating copper raw material stockpiles from individual enterprises, until the demands of the war economy made it necessary to proceed with a higher degree of planning. The drawing up of a cadastre, an inventory of 'war metal' stocks of the country, in turn, seems to have been highly successful in meeting the requirements of the ammunitions industry. It also led, however, to a rapid depletion of available copper stocks, so that after door handles and shop windows had been obtained, the supply of copper, like the iron supply, had also nearly ceased by 1918 – the effectiveness of the measures taken in some way made it impossible for the campaign to be sustained.

The case of copper is a somewhat extreme, but very demonstrative example of "urban mining", with no recycling (in the sense of feeding an input good back to its source after use), little imports, and practically no production of copper goods for civilian use taking place. In this regard, the anthroposphere, infrastructure, fixed assets, and infrastructure alike, really came to resemble a copper mine. Still, it has to be kept in mind that even with the extreme measures taken, less than 10% of the anthropogenic copper stocks had been made available by 1918, which says something about the difficulty of such operations.

As Brunner et al. (2004) show, copper end-use stocks in Austria can be expected to rise to about 750 kg/cap by 2100, thus making it necessary to increase recycling rates. The strategies adopted by the military administration are certainly an extreme example, and in the case of iron, the situation is not as dire, but new strategies for recovering and reusing some of the scarcer materials such as copper certainly have to be considered – by advocating, for example, the mining of hazardous wastes, the copper content of which amounts to 5 to 10% of US copper use, or a more thorough recovery of copper from milling and smelting wastes, which could cover US copper demand for approx. 10 years (Rejinders 2003).

As should become clear from this work, however, necessity is the mother of invention.

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## APPENDIX: TABLES/DATA SOURCES

| | | 1915 | | 1916 | | 1917 | | 1918 | |
|---|---|---|---|---|---|---|---|---|---|
| | **Fe Content** | **Total, t** | **kg Fe per capita** | **Total, t** | **kg Fe per capita** | **Total, t** | **kg Fe per capita** | **Total, t** | **kg Fe per capita** |
| Ores | *60%* | 2,901,599.0 | 60.03 | 3,900,000.0 | 80.69 | 2,829,000.0 | 58.53 | *1,500,000.0* | 31.03 |
| Ore Imports | *60%* | 930,000.0 | 19.24 | 940,000.0 | 19.45 | 1,020,000.0 | 21.10 | *1,000,000.0* | 20.69 |
| Raw Products | n.a. | 3,551,325.0 | 118.38 | 4,650,000.0 | 155.17 | 4,019,000.0 | 134.16 | 2,295,800.0 | 76.72 |
| (Pig Iron) | *95%* | 1,572,325.0 | 51.51 | 1,900,000.0 | 62.24 | 1,595,000.0 | 52.25 | 834,800.0 | 27.35 |
| (Steel) | *98%* | 1,979,000.0 | 66.88 | 2,750,000.0 | 92.93 | 2,424,000.0 | 81.91 | 1,461,000.0 | 49.37 |
| Raw Product Imports | *95%* | *150,000.0* | 4.91 | 158,000.0 | 5.18 | 210,000.0 | 6.88 | n.a. | n.a. |
| Raw Product Exports | *95%* | 3,000 | 0.10 | 1,500 | 0.05 | | 0.00 | n.a. | n.a. |
| Military Products | *95%* | *3,018,626.3* | 100.63 | *3,952,500.0* | 131.90 | *3,416,150.0* | 114.04 | *1,951,430.0* | 65.21 |
| Front | *95%* | | 0.00 | | 0.00 | | 0.00 | | 0.00 |
| Products | n.a. | *532,698.8* | 17.76 | *697,500.0* | 23.28 | *602,850.0* | 20.12 | *344,370.0* | 11.51 |
| Product Imports | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Product Exports | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Scrap Imports | *95%* | 80,000.0 | 2.62 | 170,000.0 | 5.57 | 160,000.0 | 5.24 | n.a. | n.a. |
| Scrap Exports | *95%* | 6,000.0 | 0.20 | 6,000.0 | 0.20 | 6,000.0 | 0.20 | 6,000.0 | 0.20 |
| Recovered Scrap (Consumption) | *95%* | *70,000.0* | 2.29 | *233,500.0* | 7.65 | *205,000.0* | 6.72 | n.a. | n.a. |
| Recovered Scrap (Industry) | *95%* | *200,000.0* | 6.55 | *200,000.0* | 6.55 | *200,000.0* | 6.55 | *200,000.0* | 6.55 |
| Recovered Scrap (Front) | *95%* | n.a. | n.a. | n.a. | n.a. | 23,000.0 | 0.75 | n.a. | n.a. |
| Total Recovered Scrap | *95%* | *350,000.0* | 11.47 | 603,500.0 | 19.77 | 565,000.0 | 18.51 | n.a. | n.a. |

**Table 1:** Iron mass flows, in total mass and kg/cap. *Italics* are estimates based on the literature, all other numbers have been obtained directly.

| | | 1915 | | 1916 | | 1917 | | 1918 | |
|---|---|---|---|---|---|---|---|---|---|
| | **Cu Content** | **Total, t** | **kg Cu per capita** | **Total, t** | **kg Cu per capita** | **Total, t** | **kg Cu per capita** | **Total, t** | **kg Cu per capita** |
| Ores | *16%* | *40,123.0* | 0.22 | *47,782.0* | 0.26 | *32,447.0* | 0.18 | *20,467.0* | 0.11 |
| Ore Imports | n.a. | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| Cu Imports | *70%* | 15,901.0 | 0.38 | 10,027.0 | 0.24 | 5,280.0 | 0.13 | 0.0 | 0.00 |
| Cu Exports | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Raw Products | *99%* | 29,570.2 | 1.01 | 35,680.4 | 1.22 | 24,809.8 | 0.85 | 9,409.1 | 0.32 |
| Raw Product Imports | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Raw Product Exports | n.a. | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| Products | n.a. | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| Product Imports | *70%* | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | | 0.00 |
| Product Exports | n.a. | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| Military Products | n.a. | 29,570.2 | 1.01 | 35,680.4 | 1.22 | 24,809.8 | 0.85 | 9,409.1 | 0.32 |
| Front | n.a. | 29,570.2 | 1.01 | 35,680.4 | 1.22 | 24,809.8 | 0.85 | 9,409.1 | 0.32 |
| Recovered Scrap (Front) | n.a. | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | 0.00 |
| Purchased Cu | *75%* | 8,909.0 | 0.23 | 15,646.0 | 0.40 | 7,699.0 | 0.20 | 3,397.0 | 0.09 |
| Confiscated Cu | *75%* | 4,877.0 | 0.13 | 11,051.0 | 0.29 | 11,623.0 | 0.30 | 1,766.0 | 0.05 |
| Recovered Cu (Industry) | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |
| Total Recovered Cu | *75%* | 29,687.0 | 0.77 | 36,724.0 | 0.95 | 24,602.0 | 0.64 | 5,163.0 | 0.13 |

**Table 2:** Copper mass flows, in total mass and kg/cap. *Italics* are estimates based on the literature, all other numbers have been obtained directly.