Resource Potential of Landfill Mining – A National and Regional Evaluation

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EXECUTIVE SUMMARY

Considering the increasing scarcity and raising prices of both, energy raw materials and other raw materials, such as metals and minerals, the recycling and recovery of these materials from anthropogenic deposits is of increasing relevance. Regarding dumped sewage sludge, predominantly the contained phosphorus is a precious raw material. Assuming 10 million Mg of landfilled sewage sludge in Germany, the phosphate portion in landfills can be estimated to approximately 1 million Mg (as P_2O_5).

Annually, more than 16 million Mg of metallurgical slag in the form of blast furnace slag (8.35 million Mg), LD-slag (3.62 million Mg), electric furnace (1.91 million Mg), secondary metallurgical slag (0.98 million Mg), stainless steel slag (0.62 million Mg) and metal slag (1.44 million Mg) are generated from the production of iron, steel and nonferrous metals in Germany. Since part of the metals remains in the form of metallic inclusions, agglomerates of alloys or in oxidic form in the mineral slag, old dump sites offer an interesting valuable material potential.

In old landfills, the particularly high portions of mineral content, but also the metallic components (e.g. ferrous scrap, aluminum, waste electrical and electronic equimpent, copper cable) could be recycled. From the energy point of view, the high calorific waste components such as wood, plastics or paper and cardboard could act as substitute fuel. Estimations show that 178 million Mg of plastics, 83 million Mg of iron and 13 million Mg of nonferrous metals have been disposed of in landfills since 1975. An estimation of the energetic potential for landfills in Germany, Bavaria and Austria showed that in Germany the potential energy content stored within the landfills is approximately 7,700 PJ. This energy quantity corresponds to about 50% of the annual primary energy consumption of the Federal Republic of Germany. For Bavaria an energetic potential of approximately 1,100 PJ has been calculated and 1,300 PJ for Austria.

Since the recovery of the raw materials stored in the landfills is only possible by use of technically and logistically complex systems, the economics of such projects are key tied to the price level of raw materials in the world market. If a noticeable raw material scarcity

with corresponding price fluctuation at the international raw material markets occurs, then the potential and importance of urban mining will also increase.

1 INTRODUCTION

Urban Mining covers all types of anthropogenic created deposits of material resources and is thus not only limited to urban areas. Based on the increasing scarcity and costs of different raw materials, the meaning of anthropogenic deposits as a source for raw materials becomes is rising steadily. Urban Mining is also a term established in the field of waste management and is here particularly related to landfills, „the Landfill Mining“ [Mocker et al. 2009a]. The landfills, or dump sites, in Germany were filled until the 90's with untreated and unsorted waste streams, which contained a large number of today's valuable resources. Since then, the Closed Substance Cycle and Waste Management Act (1994) and the Waste Disposal Ordinance (2001) have changed waste management to a resource management, which is focused on the recycling and recovery of secondary raw materials. Today, with the help of modern technologies, metals, plastics, paper, wood, bio waste and minerals can be separated from the waste stream and re used. The separate collection of paper, glass, packing waste or bio waste contribute to a recycling ratio of over 70% and put Germany in a leading position in Europe [SRU 2008]. Therefore, waste management has a special meaning on the way to a resource-efficient industry [Faulstich et al. 2009].

While current generated waste streams are already materially and energetically used to a large extent, it is clear that the waste streams disposed of until the 70’s and 80’s in landfills still have the entire potentially recyclable materials. This historical background makes the numerous old waste dumps appear as possible sources of raw materials. In this article, different raw materials, scarcities and potentially recyclable resources from landfills will be pointed out on the basis of the current known geogenic resources. Finally, the energy potential of high calorific waste for the municipal waste of Germany, Bavaria and Austria is determined and compared.

2 AVAILIBILITY OF RESSOURCES

To clarify the scarcity of energy raw materials, metals and minerals in Germany, their static life time has to be pointed out and discussed. As shown in the following chapters, the availability of some fossil energy sources, metals and minerals from natural sources is limited to a short time period. In addition the existence of these lie often in the hand of few countries or companies. The situation of the supply of raw materials was examined in a study done by the Cologne Institute for Economic Research (IW) [Bardt 2008]. Due to a beginning scarcity of single resources and a drastically rising consumption, particularly in the developing countries China and India, resources underwent an immense price augmentation at international markets. In the last years, the prices have fluctuated a lot. Neither high price phases originated from various speculation strategies nor the dramatic price decline in the past months can be seen as representative.

2.1 Energy Raw Materials

The static life time of energy raw materials was determined both regarding the reserves and the total resources (sum of reserves and resources) from data of the Federal Institute for Geosciences and Natural Resources [BGR 2009] and is shown in Figure 1.

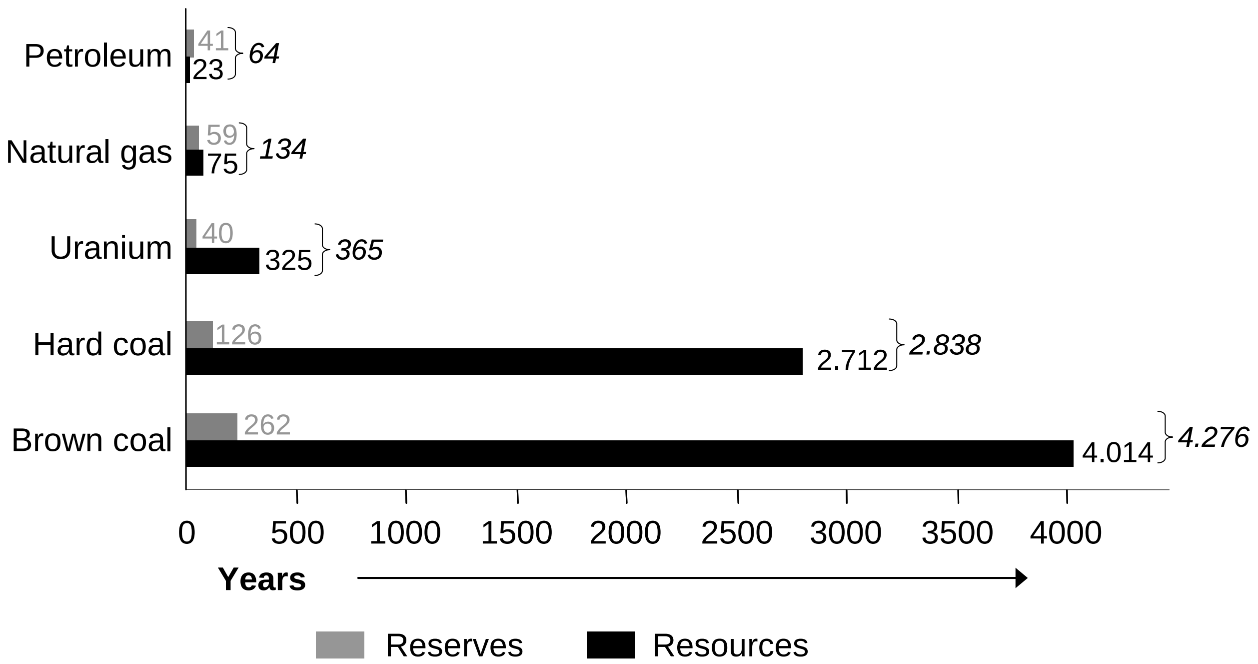

Figure 1: Static life time of non-renewable energy resources [BGR 2009]

Figure 1 shows that the limitedness of Germany's most important energy sources, crude oil and natural gas, is the most critical, while the different coal sorts last still far into the future. However, the main restriction is not only given by the availability of the raw material itself, but also by the climatic problems related to the incineration of fossil fuels.

Despite the recent decrease of raw materials prices, long-term price augmentation should be expected. Thus, at the same time, energy savings as well as the production of alternative fuels from renewable sources should be pushed. Under these criteria the unused energetic potential of wood and plastics in old waste dumps becomes especially interesting. Furthermore wood, paper and textiles belong to renewable sources of energy.

2.2 Metals

For many years the public discussion was exclusively focused on the availability of the energy raw materials. However, the strong economic development and rapid growth of large national economies in Asia has brought other raw materials into discussion, too. Figure 2 shows the static life time of the reserves of selected metals [USGS 2010]. Many of these chemical elements, with a static life time lower than 50 years, are applied as pure metals or as alloy metals in the electronic, machine and equipment construction industries.

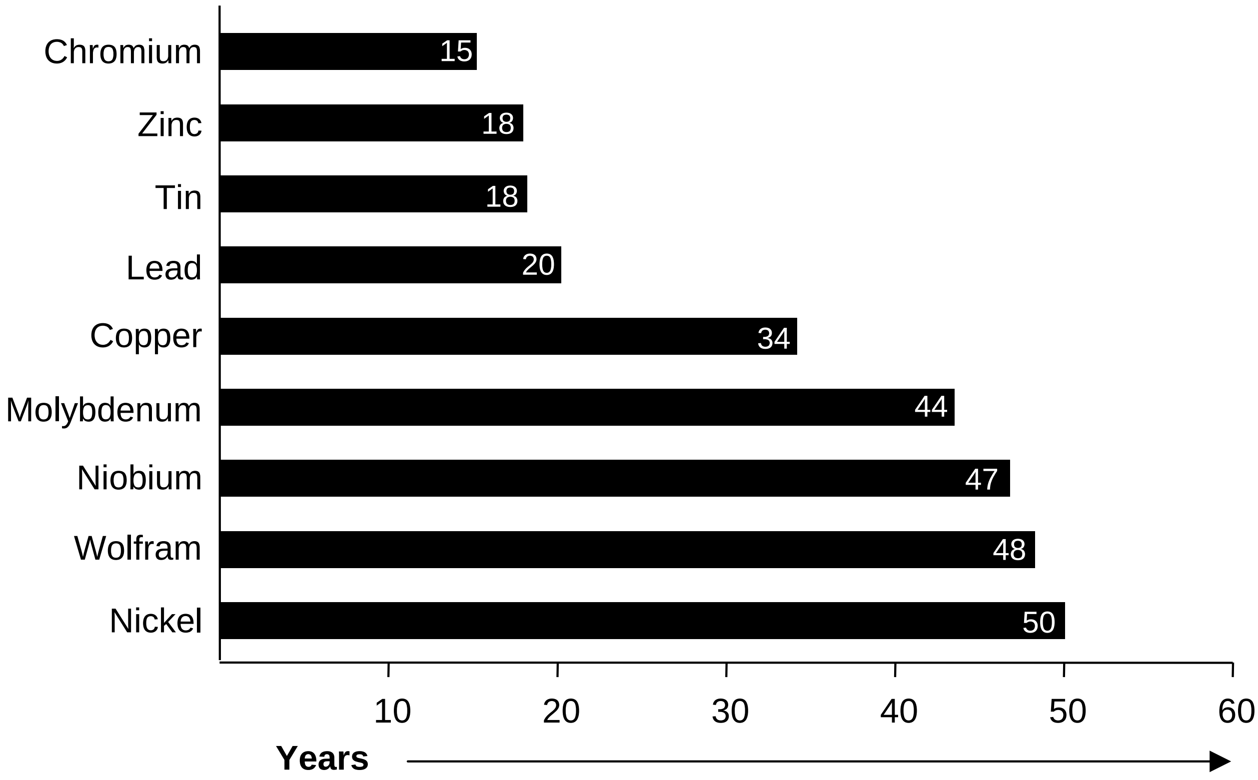

Figure 2: Static life time of selected metals (related to reserves) [USGS 2010]

For example, the world-wide copper reserves are estimated to be approximately 470 million Mg and are located mainly in Chile (30%). In the meantime German copper resources have been completely exhausted, meaning that copper has become an exclusively imported good. In addition, the average ore grade of the mined copper has declined in recent years to less than 1%, whereby the energetic expenditure and the Figure 3 shows seven technically important minerals with short life times, again related to the reserves. Fertilization-related elements (e.g. phosphorus, potassium), which cannot be substituted with other substances, are included in this list. Here the realization of an efficient closed loop recycling is indispensable. Despite comparatively long life times, long term procedures which ensure the return of these elements to the agriculture must be developed. Furthermore, stronger restrictions for the exploitation of natural phosphate are foreseeable due to its association with cadmium and uranium.environmental intensive materials in the world [Lucas et al. 2008]

2.3 Industrial Minerals

Figure 3 shows seven technically important minerals with short life times, again related to the reserves. Fertilization-related elements (e.g. phosphorus, potassium), which cannot be substituted with other substances, are included in this list. Here the realization of an efficient closed loop recycling is indispensable. Despite comparatively long life times, long term procedures which ensure the return of these elements to the agriculture must be developed. Furthermore, stronger restrictions for the exploitation of natural phosphate are foreseeable due to its association with cadmium and uranium.

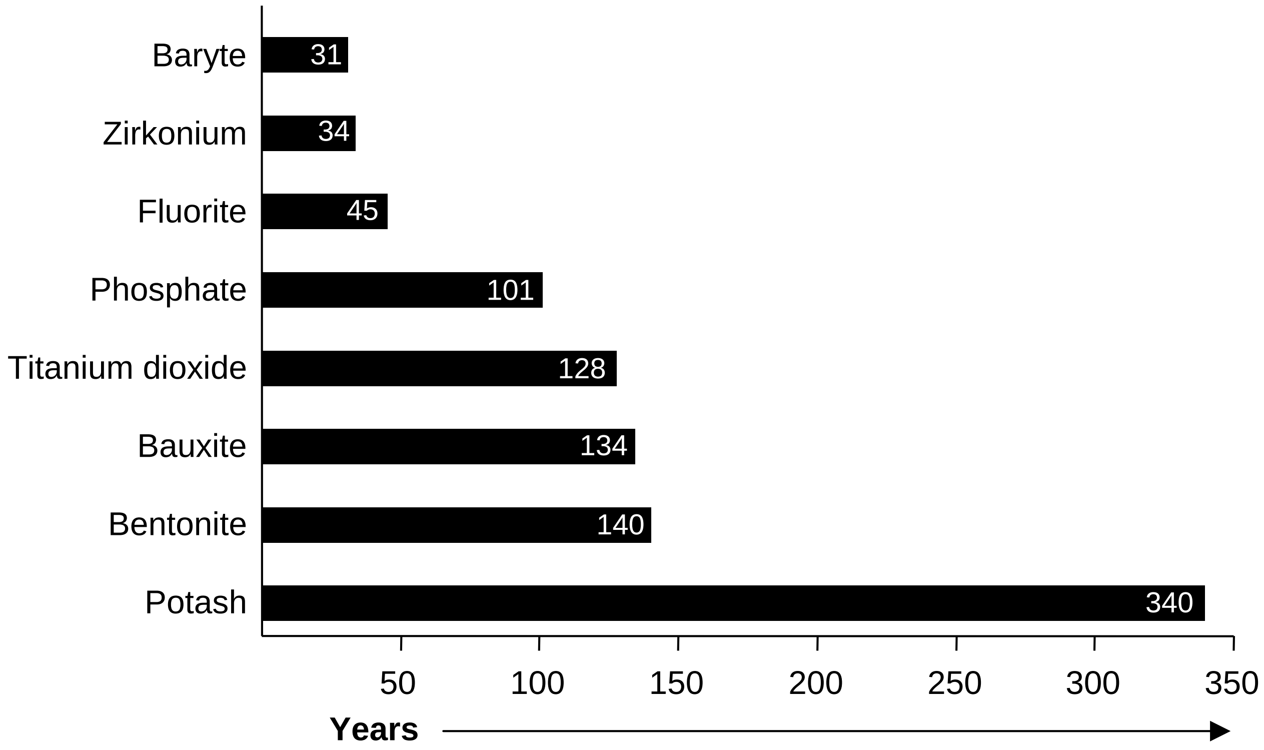

Figure 3: Life time of selected minerals (related to reserves) [Bardt 2008, USGS 2010]

In Germany, more than 240 million Mg of mineral waste is produced annually. This corresponds to about 60% of the entire waste stream. Particularly interesting for the recovery of metals and minerals are the 33 million Mg of ash and slag from power stations and incineration plants for waste, biomass and sewage sludge, as well as the more than 16 million Mg slag and dust from the metal production [Reichenberger et al. 2008]. The biggest quantity of the mineral waste consists of 140 million Mg of soil and stones as well as the 73 million Mg of inert construction waste and roadway rubble.

3 Raw Materials and Energy Potential in Dumpsites

3.1 Material Potential

Sewage sludge

In 2006 in Germany, 2.3 million Mg DM of municipal sewage sludge were produced, a further 1.4 million Mg DM were produced at industrial sites [Reichenberger et al. 2008]. From it the majority was disposed of in landscaping and agriculture, as well as in combustion plants. Since 2005 sewage sludge may not be deposited untreated in landfills, thus only minor parts of the sludge have been dumped at landfills since 2005. However, in the past, about half of the municipal sewage sludge has been landfilled [Hanßen 2007]. From this it can be measured that more than 10 million Mg were disposed in landfills. Considering the restrictive assumption that only since the 1980's purposeful phosphorus elimination from the waste water took place, approx. more than 1 million Mg of phosphate (converted to P_2O_5) have been withdraw from the material cycle. Even after further decomposition of the organic portions, the phosphorus in the sewage sludge should be still contained in the old landfills.

Waste from Metallurgical Processes

During the production of iron, steel and non-ferrous metals a part of the metals remains in the form of metallic inclusions, agglomerates of various alloys or in its oxidic form in the mineral slag. In Germany, over 16 million Mg of metallurgical slag is produced annually in the form of blast furnace slag and/or granulated blast-furnace slag (7.92 million Mg), LD-slag (3.45 million Mg), electrical arc furnace slag (1.89 million Mg), secondary metallurgical slag (0.96 million Mg), stainless steel slag (0.62 million Mg) and slag from non-ferrous metal production (1.44 million Mg) [Merkel 2009, Weitkämper et al. 2008]. The blast furnace slag and the granulated blast-furnace slag are used meanwhile to more than 100%, i.e. previous stock levels are also regenerated again. Currently steelwork slag is deposited at a rate of about 10% [Merkel 2009]. Thus, it can be assumed that the deposited portion in earlier decades is clearly higher. Hence, smeltery dumpsites offer an interesting valuable material potential. Table 1 shows the typical compositions of selected steelwork slag [Arlt 2005, Heindl et al. 2005].

Table 1: Chemical analysis of different steelwork slags [Arlt 2005, Heindl et al. 2005]

Slag	**CaO**	**P_2O_5**	**MgO**	**TiO_2**	**Cr_2O_3**	**K_2O**	**Fe**	**Mn**	**V**	**S**
Granulated slag	31,8	k.A.	10,4	0,4	k.A.	0,8	0,5	0,15	k.A.	k.A.
OBM-Slag	38,3	1,5	1,6	k.A.	1,2	k.A.	18,2	2,0	0,4	0,24
HO-Slag	40,3	k.A.	7,8	0,5	k.A.	0,6	0,3	0,3	k.A.	1,2
Furnace gas dust	4,1	0,2	1,1	0,1	k.A.	0,8	31,3	0,2	k.A.	0,4
Converter dust	5,4	0,1	0,2	0,0	k.A.	0,0	64,9	0,3	k.A.	k.A.
HO-blast furnace .	1,9	0,1	0,7	0,1	k.A.	0,5	28,3	0,15	k.A.	1,1
LD-Slag	45,3	1,4	2,6	0,5	k.A.	< 0,1	20,0	2,9	k.A.	k.A.
E-Furnace slag	34,3	k.A.	3,4	k.A.	2,2	k.A.	28,4	2,7	k.A.	0,2
Pot slag	56,8	< 0,1	4,5	k.A.	2,2	k.A.	0,8	0,3	k.A.	1,1

Apart from the appreciable phosphate content, other elements like chromium and manganese are found in particular in the steelworks slag (OBM, LD and E-furnace slag). In addition the utilization of the wastes from metallurgical processes takes place to a large extent in the construction material industry, where no recovery from metallic valuable material takes place.

Municipal Solid Waste

Based on literature data and after a first estimation, since 1975 about 2.5 billion Mg of municipal, construction and commercial wastes were landfilled [Mocker et al. 2009]. This estimation can serve as basis for a rough quantitative determination of dumped materials. For the results shown in Figure 4, waste analyses in different eras were carried out and taken into consideration. Because before 1975 dumped wastes have not been registered and documented at the landfills, the calculated quantities have to be understood rather as of lower delimitation.

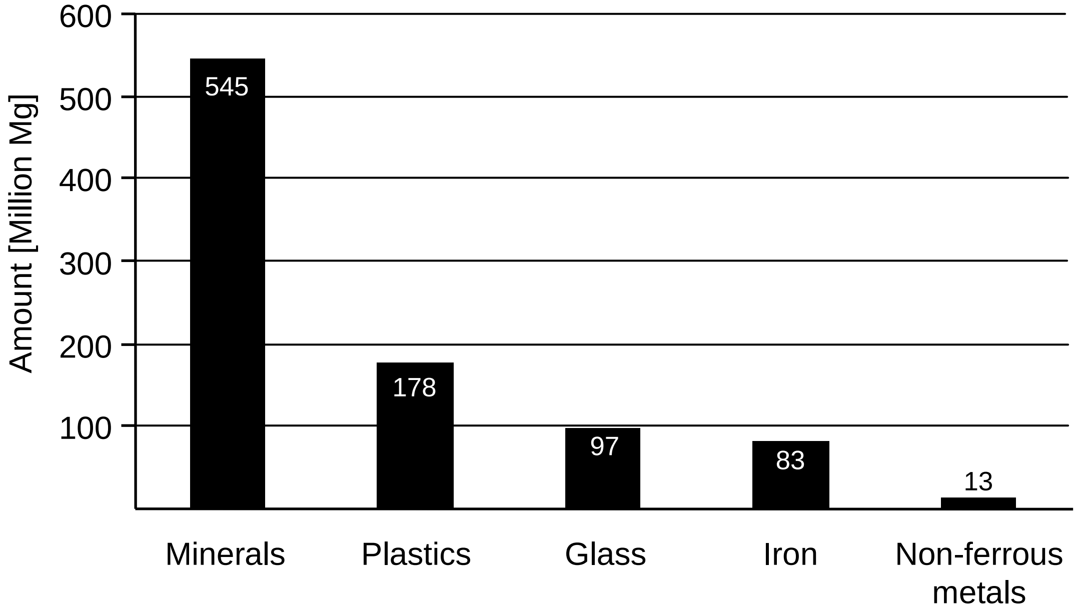

Figure 4: Estimation of quantities of individual groups of materials on waste dumps in Germany [Mocker et al. 2009]

Rettenberger [Rettenberger 2009] gives similar estimations for household and hazardous industrial waste including sewage sludge on a total of 750 million Mg with a calorific value of more than 8 million TJ, 26 million Mg scrap iron, 850,000 Mg copper scrap, 500,000 Mg aluminum scrap and 650,000 Mg phosphate. Based on this data, figure 5 shows the calculated theoretical contributions of this fractions to the annual consumptions in Germany,. As it can be seen in figure 5, theoretically 50% of the annual German consumption of aluminum scrap, 124% of the iron, as well as 142% of the copper could be covered by the materials deposited in the landfills.

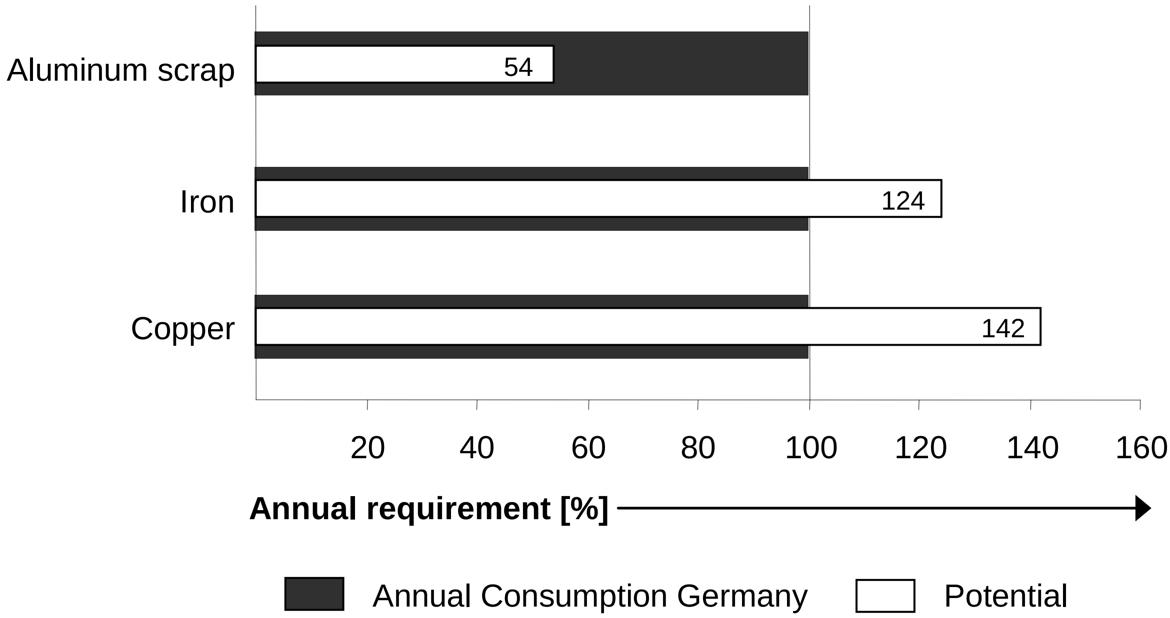

Figure 5: Potential of raw materials contained in German waste dumps related to the annual requirements of the German Federal Republic [Rettenberger 2009]

The recovery of metals from old landfills seems also reasonable in respect to the strongly increasing prices of raw materials. For example, between 2002 and 2007 the price for copper had quadrupled [DKI 2009]. In a similar way, in the meantime, the scrap metal price had also increased. The scrap metal price in 2008 was around 4.500 - 5,300 €/Mg for copper and up to 1.550 €/Mg for aluminum. For scrap steel in 2008 up to 370 €/Mg were paid [EUWID 2008].

3.2 Energetic Potential

Besides the material potential described before, the high calorific waste in landfills and old dumps can also make a considerable contribution to the energy production and thus substitute conventional fossil energy sources. A rough estimation of the energy potential is done in the following for Germany, Bavaria and Austria. In addition, average calorific values of different high calorific waste components were comprised and multiplied by the deposited amounts of waste. In order to estimate the proportions of the various elements, the results of nationwide household waste sorting analysis were used.

According to the Federal Environment Agency, approximately 106,000 old dumps exist in Germany, most of them were already closed in 1975. Since then the number of landfills in operation has decreased continuously. In 2006 only 1,740 landfills were in operation, from them 272 can be assigned to Landfill Class I and 196 to Landfill Class II [UBA 2010]. In 2010, the Bavarian Environment Agency calculated that there were 11,682 closed landfills [LfU 2010] and 812 landfills still in operation, from them seven are assigned to Landfill Class I and 29 to Landfill Class II [Drexler 2009]. The Austrian Environment Agency currently reports 5,014 closed landfills [UBAÖ 2009] and 666 still in operation, most of them are used for the disposal of inert construction waste and excavated material, in addition 30 residual and 58 mass refuse landfills with considerable proportions of high calorific value content are reported.

Rough estimation based on the literature previously cited for waste amounts since 1975 [Mocker et al. 2009] combined with extrapolations based on the population trend between 1950 and 1975, it results that about 4.7 billion Mg of wastes were generated in Germany since 1950. From this amount approx. 1.6 billion Mg belongs to municipal waste. For a rough quantitative determination of high calorific materials these values were used as basis. Additionally, German and Austrian domestic waste analyses from different epochs were used and taken into consideration. The waste amounts for Bavaria were calculated from the development of the Bavarian population and the proportional amount of waste calculated for Germany. This methodological approach results in a landfilled municipal waste proportion of 247 million Mg. However, in Bavaria, the incineration of residual waste started earlier than in the other federal states. Its ratio has been for many years over 90 % [Drexler 2007]. This means that the actual deposited quantities are likely to be smaller than calculated.

For the estimation of the landfilled quantities in Austria since 1950, the German waste generation rate per capita was calculated using the development of the Austrian population. This gives a landfilled quantity of MSW of approx. 158 million Mg. The proportions of high calorific value fractions were determined using the waste composition studies from different years [UBAÖ 2001, BMLFUW 2006]. Figure 6 shows the calculated quantities of the individual materials together with the population numbers for Germany, Bavaria and Austria.

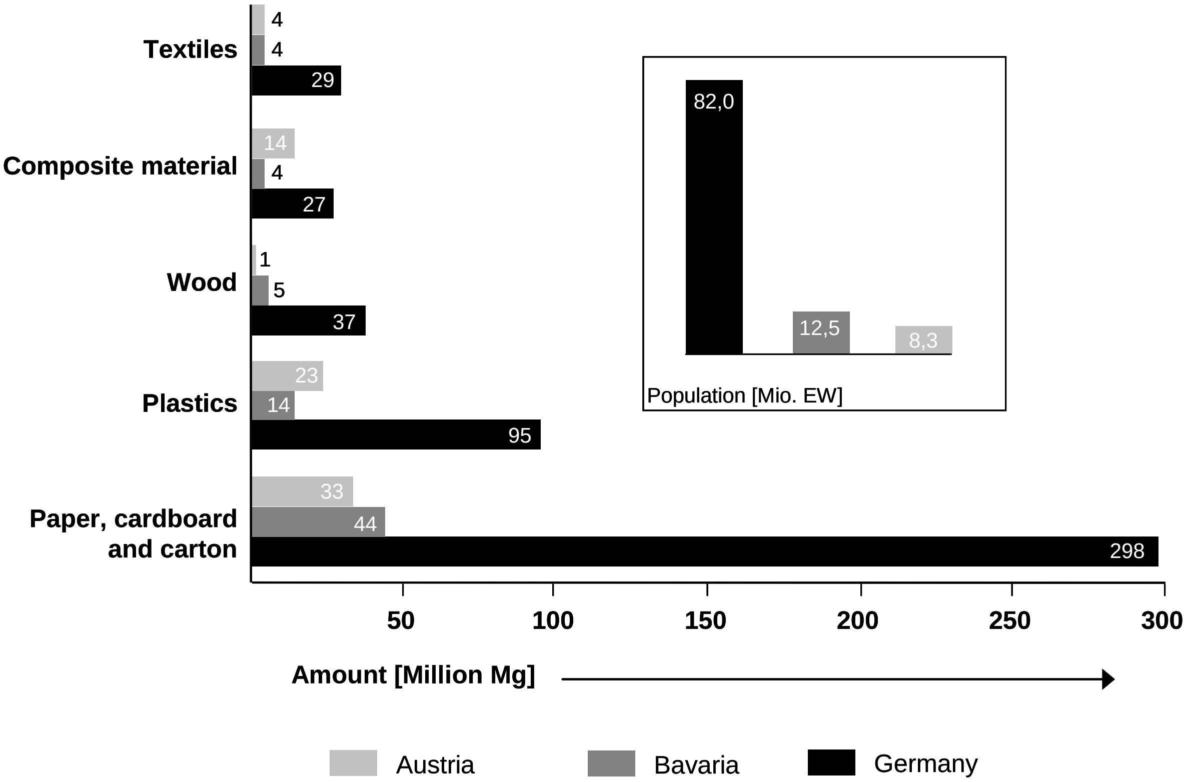

Figure 6: Estimation of high calorific material amounts in landfills in Germany, Bavaria and Austria

The energy potential of the waste quantities represented in Figure 6 was determined based on the heat value of the single fractions. The results are shown in Figure 7 together with the estimated heating values of the fractions. .

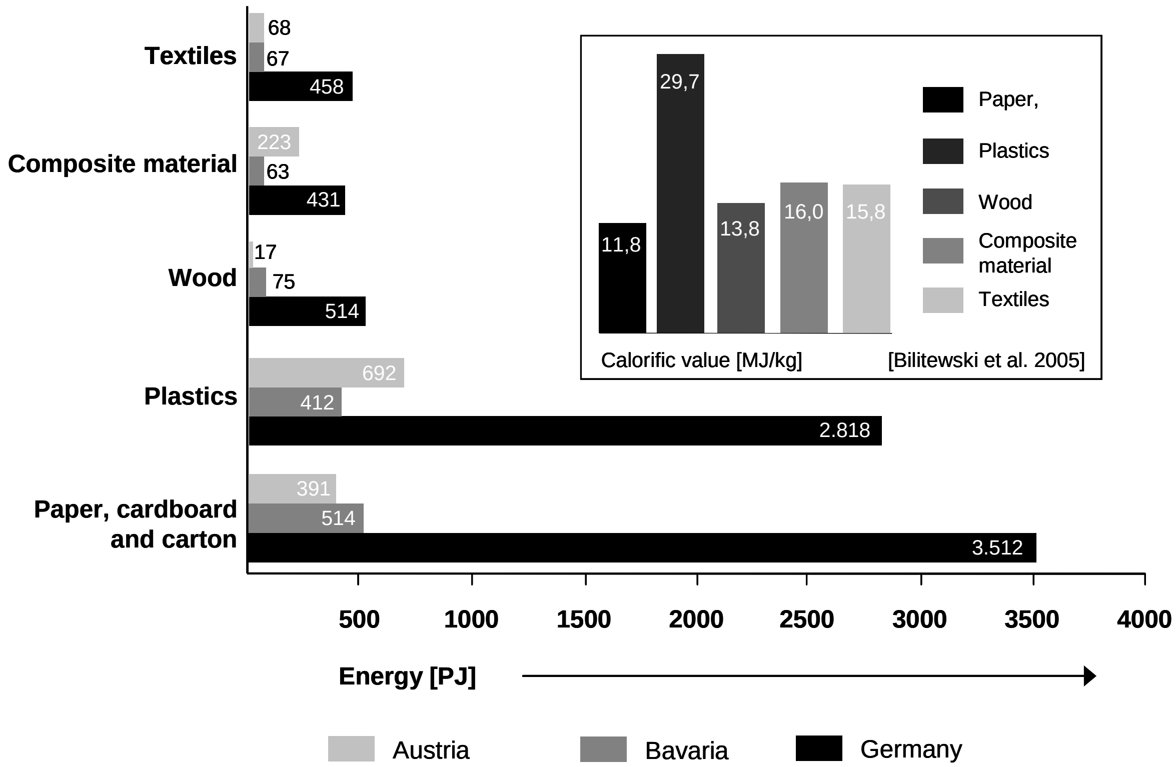

Figure 7: Estimation of the energy potential of the high calorific content materials for waste dumps in Germany, Bavaria and Austria

The estimation of the calorific values is complicated by the decomposition process running in the landfills. For example, for paper and cardboard 12 years of half life are given and for wood this value is 23 years [UBA 2008]. This would lead to a significant reduction of the calculated heat values. On the other hand, depending on the moisture and oxygen balance in the waste dump site, such degradation processes may run slower or even disrupt. Investigations of old landfills composition have evidenced that even after many years a high proportion of high calorific value fractions were still present, like for example wood and plastics. For example, in a landfill containing 50% of MSW and 50% of construction waste, the proportion of paper, cardboard, carton and textiles was 35.4% and the proportion of wood was 5.8% after a time period of 36 years [Rettenberger 2009]. Figure 8 shows the results of this analysis. The calorific value of the materials was determined to be at least of 20,000 - 22,000 kJ/kg [Rettenberger 2009].

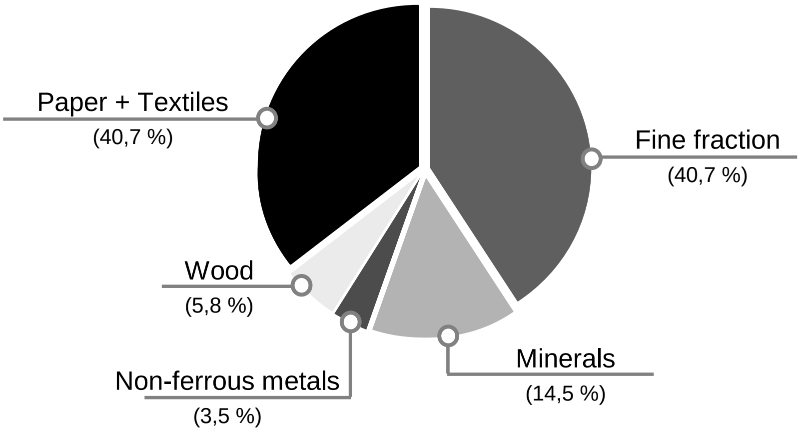

Figure 8: Composition of a 36 years old dump inventory in accordance with sort analysis [Rettenberger 2009]

During the deconstruction of a landfill in Berlin, at which primarily domestic waste (approx. 600,000 Mg/a) has been dumped since 1977, the sorting analysis revealed a proportion of high calorific fractions of 19.2%, from which 6.7% were plastics/rubber and 7% wood [Bothmann et al. 2002]. Bachmann and Cordes also found in sorting analysis of old landfills 6% plastic, 10% wood, 8% paper and 21% thermally-recoverable waste (composites, textiles, organics) [Bachmann and Cordes 2007].

If the energy content of the different fractions shown in figure 7 is summed, then a potential of approx. 7,733 PJ is obtained for Germany. This amount of energy could represent about 50% of the German annual consumption of primary energy. The energy potential for Bavaria would then be approx. 1,131 PJ and for Austria a potential of approx. 1,391 PJ could be expected.

4 CONCLUSION

Landfills offer promising potentials for both, energy recovery as well as raw material recovery. However, the relevance of urban mining from landfills is strongly related to the price level of raw materials at the international markets. While the predominant reasons for landfill deconstruction in the past have been environmental contaminations, in the future another motivation could be the recovery of raw materials.

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