GLOBAL STUDY OF MATERIALS FLOW AND ENERGY CONSUMPTION

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Summary

A worldwide study of materials flow and energy consumption in the production of the commodities Al, Cr, Fe, Cu, Mn, Ni, phosphate and coal has been carried out by BGR. The results of the study should permit measures to be recommended to ensure sustainable development compatible with the environment. The study considered the materials flow and energy consumption in the mining, mineral processing and metallurgical operations involved in the production of marketable metals, phosphate and coal. The residues for which a potential for contamination could not be excluded were listed separately. Technological possibilities for avoiding or minimizing production of non-usable residues and avoiding mineral losses are discussed.

Introduction

The first step in a life cycle assessment and starting for an impact assessment is a material balance analysis. When the impact assessment has been carried out, a company can define the environmental objectives of its operations that allow sustainable development of the environment and define indicators of environmental quality that indicate the extent to which these objectives have been reached.

BGR has conducted, with support from the Volkswagen Foundation, a worldwide study of the materials flow (including input materials and residues) and energy consumption for the 1994/95 production (mining, processing, and metallurgical operations) of the eight most important mineral commodities (Al, Cr, Fe, Cu, Mn, Ni, P_2O_5, and coal). The residues from the production of these eight mineral commodities were roughly classified in terms of their potential environmental impact. The term production is defined here to include mining, processing and metallurgical operations. As a rule, figures were obtained for the study for more than 60 % of world mine production with an average of 70 %, figures for metallurgical operations even higher.

Results

The distribution of mineral deposits around the world is very irregular, with considerable differences between the industrial countries and the developing countries. Classification of mining areas according to vegetation zones provides an indication of potential land-use conflicts and the potential for ecological problems associated with mining (Table 1). For aluminium, chromium, nickel, phosphate, and coal, more than 40 % of mine production is in areas with intensive agriculture (type 2 land use). For these types of deposits, the possibilities for recultivation are often very good. Few areas in which tropical rain forests are endemic are of importance for mining (type 4 land use). Because copper occurs mainly as the sulfide together with other sulfide minerals, the potential for acidification is particularly high. However, copper mines are found mainly in areas of limited agricultural potential, namely in regions of high mountains or tundra (type 1 land use) and deserts (type 4 land use).

Table 1: Distribution of world production analyzed in this survey among the various vegetation or land-use zones

Commodity	Percentage of world production included in survey	Percentage of surveyed production in the different vegetation or land-use zones				
		Zone 1 (%)	Zone 2 (%)	Zone 3 (%)	Zone 4 (%)	Sum (%)
Aluminium	95.0	1.7	65.3	14.7	18.3	100
Chromium	92.5	6.5	40.5	53.0	0	100
Iron	100.0	8.4	33.0	44.7	13.9	100
Copper	70.0	39.7	17.8	29.7	12.8	100
Manganese	78.0	0	32.1	55.1	12.8	100
Nickel	100.0	26.7	60.9	8.4	4.0	100
Phosphate	100.0	9.0	47.0	41.0	3.0	100
Coal	100.0	13	68	15	4	100

Vegetation or land-use zones

1 Mountains, tundra, taiga (natural vegetation types 1–3, Times Atlas 1990)
2 Agriculture [conifer forest, mixed forest, broadleaf forest, monsoon forest, dry tropical forest, subtropical forest, and prairie (natural vegetation types 4–8 and 12–14, Times Atlas)]
3 Low-intensity agriculture [short grass, savannah, dry tropical scrub and thorn forest, desert (natural vegetation types 9, 10, 15, and 16, Times Atlas)]
4 Tropical rain forest (natural vegetation type 11, Times Atlas)

The data on the input and residues (solids) per tonne of product are a significant finding of the study (Table 2). The total residues includes both recycled, e.g., for recultivation purposes, and dumped residues. The amounts for which a potential for contamination cannot be excluded are also listed. Especially high amounts of residues are produced in the production of copper and nickel (400 t and 100 t per tonne of metal, respectively); a large proportion of these amounts contain potential contaminants, depending mainly on the sulfur content and the climatic conditions. The amounts include both sulfidic and oxidic copper ores and both sulfidic and lateritic nickel ores. The lower the proportion of nonrecycled residues, the larger the area needed for waste dumps. The figures can be used to develop indicators of environmental quality.

The energy required per tonne of commodity is given in Table 3. The primary energy and the actual energy used (i.e., taking into consideration the efficiency of the conversion) are listed. The mining of nickel and copper have the highest energy consumption per tonne of product. When smelting is included, nickel and aluminium have the highest consumption.

Worldwide, coal and copper production yield the largest total amounts of residues (13,720 million t and 3890 million t, respectively). Pig iron and aluminium have the highest total primary energy consumption (8110 PJ and 3800 PJ, respectively).

The total CO_2 emissions from production of these eight commodities amounted to about 8 % of the anthropogenic CO_2 emissions worldwide in 1995.

Reliable information on the areas used for mining was available only for bauxite and phosphate. Worldwide, 15 km² were used for 80 % of the bauxite mining in 1994. Phosphate mining areas totaled approximately 80 km². Approximately the same amounts of land are recultivated each year in the western countries, which is nearly 100 % of the areas no longer used for mining these commodities.

Considerable amounts of mineral resources are lost during production. With respect to the amounts classified as reserves, these losses are the lowest for aluminium (13 %) and the highest for manganese (53 %) and phosphate (36 %).

Conclusions

Mineral resources cannot be produced without affecting the environment in some way. The environmental impact, however, can be kept within limits. Major environmental impacts are loss of land for other uses, contamination, energy consumption, and loss of resources.

The amount of land used for mineral commodity production depends mainly on the location (shallow or deep), thickness, etc. of the deposit and the production method. An open-pit mine in a near-surface deposit, often soft rock, can usually be recultivated satisfactorily. The land is used for mineral commodity production mainly only for the duration of the mining. In the case of deep open-pit mines in solid rock (e.g. for porphyry copper ore), additional land is needed for waste dumps and tailings ponds, which remain after mining is abandoned. If the best available technology is used without consideration of cost, a mineral resource could be mined in an underground mine instead of an open-pit mine. Less mine waste is produced and less space is needed for the mine and waste dumps. If an underground mine is backfilled, subsidence at the surface is avoided and the loss of the mineral resource is less. Backfill methods can now even use flotation waste, reducing the area needed for tailings ponds. Contamination can be avoided by neutralization of tailings and mine waste in the case of acid production.

We are convinced that in ecologically sensitive areas (e.g., an area of untouched nature, densely populated areas), the best and most appropriate technology is the technology that respects the above-mentioned principles.

The greatest potential for reducing energy consumption is surely in the modernization of old facilities.

References

Kippenberger, C-M, 1999, Stoffmengenflüsse und Energiebedarf bei der Gewinnung ausgewählter mineralischer Rohstoffe – Auswertende Zusammenfassung, Geologisches Jahrbuch – Sonderhefte, SH 10: 52 pages

Table 2: Content of product in the ore (or raw coal), the tonnes of ore per tonne of product, tonnes of solid waste per tonne of product – averages for the surveyed part of world production

Product	ore content	t ore/t product	t mine waste/t product		t tailings/t product		t solid residues from smelting/t product		t solid residues/t product	
			total	potential contamination from this amount	total	potential contamination from this amount	total	potential contamination from this amount	total	potential contamination from this amount
Aluminium	44.6 % Al_2O_3 23.6 % Al	4.5	3.9	–	0.4	–	Al_2O_3 production: 3.1 refining: 0.1 3.2	Al_2O_3 production: 3.1 refining: 0.0 3.1	7.5	3.1
Chromium	37.3 % Cr_2O_3 25.5 % Cr	5.2	6.2	–	1.7	–	3.8	0.6	11.7	0.6
Iron	46.2 % Fe	2.6	2.3	–	1.0	–	0.4	–	3.7	–
Copper	0.94 % Cu	145.4	261.0	261.0	142.3[2)]	142.3[2)]	1.6[3)]	–	404.8	403.2
Manganese	35.7 % Mn	5.3	8.0	–	2.2	–	2.1	–	12.3	–
Nickel	1.35 % Ni + (0.4 % Cu)	72.7	51.7[1)]	16.0	45.6	29.4	29.5	5.2	126.8	50.6
Phosphate	15.6 % P_2O_5	9.5	21.8	–	6.5	–	–	–	28.3	–
Coal	64.0 % tce	1.6 (raw coal/tce)	4.7	–	0.3	0.2	–	–	5.0	0.2

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1) includes the screening residues of lateritic nickel ores
2) includes leaching residues
3) not including leaching residues

Table 3: Energy required for the production of metals, coal and mineral phosphate: Average of recorded world production in 1994 (not including the energy required to produce the input materials produced by other producers)

	percent of world production included in survey %	Mining: GJ/t product		Processing: GJ/t product		Metallurgical operations: GJ/t product		total GJ/t product		Transport to Germany: GJ/t product
		actual energy used [1]	primary energy[2]	actual energy used [1]	primary energy[2]	actual energy used[1]	primary energy[2]	actual energy used[1]	primary energy[2]	primary energy
aluminium	mining: 79 smelting: 96	0.2 incl. processing	0.3 incl. processing	–	–	105.2	151.8	105.4	152.1	4.9
chromium [3]	mining: 77 smelting: ca.100	0.7 incl. processing	1.5 incl. processing	–	–	38.4	63.6	39.2	65.1	5.3
iron[4]	mining: 65 smelting: ca.90	0.1	0.1	0.1	0.3	15.6	16.4	15.8	16.8	1.2
copper[5]	mining: 75 (rel. to capacity) smelting: ca. 94	7.6	9.6	6.8	17.0	13.9	20.2[6]	28.3	46.8	3.4
manganese[7]	mining: 51 smelting: ca.97	0.3 incl. processing	0.4 incl. processing	–	–	32.0	52.1	32.3	52.5	4.5
nickel	mining: 70 smelting: 70	16.3 incl. processing	23.1 incl. processing	–	–	228.9	287.4	245.2	310.5	3.7
phosphate P_2O_5	mining: 61	0.40	0.8	0.9	1.5	–	–	1.2	2.4	5.0
coal (tce)	mining: 91	0.20	0.4	< 0.1	< 0.1	–	–	0.2	0.4	1.1

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[1] Energy obtained from the fuel used (oil, gas, coal, or electricity)
[2] An efficiency of 55 % is assumed for the generation of electricity for aluminium and nickel production (percentage of hydroelectric power 60 %) and 40 % for the other products.
[3] Including the energy needed to make the electrodes.
[4] The iron in pig iron
[5] Percent of world mine production included in the survey: sulfide ores 65 %, oxide ores (leaching) 10 %; metallurgical operations: pyrometallurgy 84 %, hydrometallurgy 10 %
[6] Primary energy consumption: pyrometallurgy 19.65 GJ/t Cu-metal; hydrometallurgy: 25.92 GJ/t Cu-metal