Assessing the long-term supply risks for mineral raw materials—a combined evaluation of past and future trends

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A B S T R A C T

This paper develops a method for identifying and assessing long-term supply risks for mineral raw materials. The method is based on a combined evaluation of past and future supply and demand trends. By analysing raw material boom and bust cycles over the past 50 years, we have quantified indicators and defined benchmarks for identifying critical market situations. By applying the method, risks for supply shortage may be identified at an early stage. In addition, a numerical evaluation model has been developed for better comparison between various mineral raw materials. Compared to other assessment methods this method uses specific benchmarks for each raw material to better assess supply risks. The method is embedded within a systematic and comprehensive analytical approach.

Based on this model, companies can make better informed decisions for their market assessment and may use suitable risk mitigation instruments to counteract problematic developments.

Understanding future supply conditions is especially useful when selecting new technologies for products which require an intensive use of raw materials. As an example, the method is applied to the copper market as of 2006.

It is important to emphasise that nobody can foresee the future of raw material prices. But we may aim to better understand the weaknesses of these markets which may lead to future supply shortages thus influencing price.

Introduction

Supply and demand analyses for mineral raw material markets are widely used by public authorities, the banking sector, mining and consulting companies or manufacturers. Each of them use a different set of parameters to describe market developments—and they come to different and often wrong conclusions.

One of the official US reviews of the resource situation in the early 1950s was conducted by a commission appointed by President Truman, called The President’s Materials Policy Commission, organized in response to fears of raw-material shortages. It came to be known as the Paley Commission. Its report questioned whether “the United States of America has the material means to sustain its civilization” and gave specific recommendations on how the increasing supply of materials could best be assured. (Paley Commission, 1952). The Club of Rome report of 1972 (Meadows et al., 1972) constructed scenarios for the future that found exhaustion of resources at various dates, most of which have come and gone without the immediate consequences of societal or economic collapse they envisioned. The Paley Commission as well as the Club of Rome underestimated the mineral wealth of our globe and humans’ force to invent new technologies for extracting and for using these minerals. With the beginning of the 21st century and the Chinese growth in demand causing historic price hikes and delivery shortages the discussion about the finiteness of mineral resources is back on the table.

With the possible exception of conventional oil, mineral raw materials in general are not short. Just by the fact that our planet is large enough and only to a minimum explored, it still bears many hidden mineral deposits. This however does not mean that we should use our resources imprudently. It is not the finiteness but the criticality of a sustainable supply which is an important issue to our economies. For this reason, the Committee on Critical Mineral Impacts on the US Economy has recently published an experts report on critical minerals to the US with the aim to aid decision makers in taking steps to avoid restrictions in mineral supply (Committee on Critical Mineral Impacts of the US Economy, 2008). In November 2008, the European Commission...
has announced to define critical raw materials to the European Union in its new Raw Materials Initiative as well (European Commission, 2008).

For a similar reason, the Volkswagen AG and the Federal Institute for Geosciences and Natural Resources (BGR) have developed a method for identifying and assessing long-term supply risks for mineral raw materials. For manufacturers, all currently used raw materials of the value chain are critical for the production. In a joint research project we have decided to quantify indicators and define benchmarks to help recognising critical market situations. This method can help to better assess future developments in raw material markets and thus helps companies to make better informed decisions, to react in good time and to implement measures ensuring supply. Understanding future supply and demand trends is especially useful when selecting new technologies for products which require an intensive use of raw materials.

Today we are able to look back to developments at least over the past 50 years. The experience we made over these decades combined with decent databases makes us confident to be able to quantify early warning indicators based on identified critical supply situations from the past. In this study we present a systematic approach to evaluate mineral raw material markets, including time series analyses and a numerical evaluation model. Integrating such market indicators into a systematic set of manageable analytical instruments is a challenge and a prerequisite for a balanced judgment of future market trends.

Review of market instability and metal prices

Raw material prices are subject to economic cycles, also known as “hog cycles”. To put it simply: given a sudden increase in demand, the existing supply cannot meet the demand fast enough and prices rise, especially when the demand is inelastic. For many value chains, demand for raw materials tends to be very inelastic with respect to price changes in the short run; users of metals such as fabricators and manufacturers have limited ability to adjust their production levels and production equipment quickly. So they have to accept high prices. When prices keep high during an economic boom more investments are made in raw material exploration. However, their effect is delayed due to the high lead time for mining projects between five and ten years. At the end of such an economic boom period, recently released through the collapse of the financial markets, there is a surplus of raw materials and a drop in prices. This in turn leads to shut-downs and therefore to a reduction in supply, and the “hog cycle” restarts. Cyclical fluctuations in demand, supply and prices make it difficult to reliably plan the procurement of raw materials, especially as the amplitude of cycles is almost impossible to predict.

Looking at the long-term development of metal prices, as illustrated by the CRB metals sub-index, not only the cyclical nature of the markets, but also abrupt changes which often have occurred in the past are eminent (Fig. 1). Between the World War II and 1973, the CRB metals sub-index always tended to lie between 50 and 150 points. In the early seventies a series of events caused nominal prices for raw materials to rise significantly; since then it has never fallen below the 150 mark. In 1973 the OPEC oil embargo, the end of the Bretton-Woods system of fixed exchange rates and the abandoning of the gold standard as well as the Vietnam conflict led to a market situation which – additionally driven by the spirit of the Club of Rome – raised the price of raw materials to the levels of between 150 and 350 points until 2003. However, in real terms, prices have fallen continuously until 2003. With the China factor, we have entered a new era. The extent to which the current high raw materials prices represent a permanent departure from the old price structure is almost impossible to predict at present.

In the past, the raw materials market was reshaped by military actions, as well as by global political and economic changes of today’s industrialised countries. The current demand in emerging nations for raw materials is of comparable economic importance to those past events and cycles. Once the current financial and economic crisis is overcome, demand will pick up again and the next cycle starts. This means that the evaluation of mineral raw material markets and supply and demand mechanisms will remain important.

Systematics of supply and demand analyses

In 1929, Hewett identified four factors he deemed most important in influencing metal supply while reflecting on the effects of war on metal production (Hewett, 1929; Brown, 2002). He distinguished between geology (geological factors related to the minerals occurrence and problems of recovery), technology (technical factors of mining, treatment and refining), economy (highlighting cost and selling price), and politics. He also recognised that the four factors do not operate separately, but rather as parts of an integrated system including social constraints and drivers such as environmental issues and the structure of the mining industry.

Today, the factors described by Hewett are still the basic fundamentals to understand and analyse the supply side. However, since Hewett the world and the mineral markets have become more complex and the effects of environmental and social aspects are increasingly important.

Comprehensive supply analyses done by investment banks or independent market analysts consider production data, the development of stocks, production and investment costs, commodity prices, freight capacities (rail, harbour, vessel), capacity increases due to new exploration, mining and refinery projects, global reserves and resources, recycling, political and social unrest, etc. (Citigroup, 2005; Deutsche Bank, 2008; World Bank, 2006)
In their recent analysis, the Committee on Critical Mineral Impacts on the US Economy has identified several risks to supply, namely: (i) unexpected increase in demand meeting a production level at close capacity; (ii) small markets where production cannot be increased quickly; (iii) high market concentration at mines, company or country scale; (iv) dependence of a by-product to the main product; and (v) availability of recycled material.

As mineral markets are demand driven, studies of the growth in demand should include the analysis of new technologies influencing growth in demand, substitution, GDP, industrial production, population or migration into cities, regulatory or other public policy changes etc. (see Appendix 1 and methods in Barney, 1980; Sohn, 2006; IMF, 2006). However, analyses of supply and demand are at least very imprecise as Wassily Leontief, 1973 Nobel laureate in economics, once commented: “Regarding the projections, the only thing that I am certain about is that they are wrong”.

For this reason, we aim to quantify whether a market will be balanced within an overseeable future of five to fifteen years under certain preconditions of growth in supply and demand and whether other parameters such as political risk may affect supply. The strength of this study is to look back to the past 50 years, set benchmarks for problematic market situations and by using scenarios evaluate to what extend supply problems may raise in future.

For evaluating the developments in supply we suggest to follow a systematic procedure. Such a systematic approach is often missing so that early alerts cannot be derived easily. Therefore we suggest to look at more technical aspects which have an immediate impact to supply: (i) the current market balance, stock-keeping, mining/refining capacity utilisation (and freight capacity, e.g. for iron ore); (ii) costs in mining or shipping where relevant; (iii) geostrategic risks including country or politically related risk and concentration of production; (iv) execution of market power through company concentration; and (v) new exploration and mining projects, investment, and the reserves and resources situation.

Whereas the potential future production is fairly well predictable within a time period of five to ten years (lead time for exploration and mining projects) the demand side is not. Which new technologies and innovations or political decisions will influence demand? When are new technologies ready for the market? Which material intensive technologies will be substituted by other, less material intensive technologies? When is the next economic hausse or baisse coming? If we would have an answer to these questions, most analysts would not sit any longer in their office but rather on a tropical island enjoying lots of cocktails.

What seems to be legitimate is to take different demand scenarios and check whether supply is able to meet such demand. Historically, global demand for basic industrial metals has not changed rapidly within a ten to fifty years time horizon (Frondel et al., 2007). Over these periods, the change in global demand was not more than one or two percent annually up or down (see also this study for copper). As long as sudden technological revolutions or major global economic changes are not in sight, global demand will not apart from these systematics. This is the basis for our evaluation of the demand side.

As innovation cycles are developing more rapidly, new revolutionary technologies in exploration and mining as well as on the demand side will rise. Such technologies are to be integrated into scenarios of supply and demand. A good foresight study of demand driven by future technologies has recently been published for a broad range of industrial sectors (Angerer et al., 2009). The study, commissioned and funded by the German Federal Ministry of Economics and Technology, gives an overview about the possible future raw materials demand of around one hundred future technologies and its market impact.

Especially the automotive sector is facing challenging times in developing environment and consumer friendly cars. The availability of mineral raw materials is fundamental to this sector also with respect to forthcoming changes in technology.

### Methodical basics

#### Relevance analysis and data

Assessing the possible risk of supply shortages for mineral raw materials is based on a number of fundamental factors. These factors may however differ from one raw material to the other. A thematic list comprising the most important factors influencing the long-term supply and demand has thus been compiled (Step 1, Appendix 1). For each raw material under consideration, the relevant factors may be selected from this list. For example, the relatively low shipping costs as a percentage share of delivered prices to buyers are low for copper or tungsten. Therefore shipping price and port and see freight capacities only play a minor role in the assessment of this market.

One major constraint in the assessment is the availability of statistics. Our analyses are based on the evaluation of historic trends and developments compared with current market trends. Therefore, the availability of data series over a long period of time is essential (for example 1960–2005 in this study). For this, BGR possesses both its own statistical database and archives as well as selected commercial databases on: raw material production and consumption, new exploration and mining projects, raw material prices, production and freight costs, exploration and capital expenditure in the mining sector or country risks data. However, global statistics for some raw materials are unreliable or only available for a limited period of time.

#### Developing the indicators and benchmarks

Based on available data and factors selected in Step 1 we have formulated and calculated a set of indicators which we think are most important for analysing the supply risk. A main indicator usually combines several factors applied over a certain period of time (Step 2, Table 1). The method is also open for adding further indicators.

How do we recognise that the market may become imbalanced? To answer this question, we need to understand where we stay today. For this reason we review and evaluate past market trends and derive maximum and minimum values (benchmarks) for each indicator corresponding to problematic or relaxed market situations of the past. We then compare these developed benchmarks with current market trends and may thus conclude whether the supply risk may increase or decrease. As with other learning curves the developed benchmarks may have to be readjusted after some period of time. For each raw material under consideration the developed benchmarks are different. To better compare the supply risk among various raw materials, the results for each indicator are normalised on a scale from 1 to 9, subdivided into a “relaxed” (values 1–3), “moderate” (values 4–6) or “problematic” (values 7–9) market situation. A review of all indicators finally points to the major risks – labelled 7–9 – affecting security of supply (e.g. applied for complex metal compositions in new technologies). By using this method, analysts are able to use quantifiable data for their market outlook based on profound knowledge of the past.
Table 1: Indicators for the assessment of supply risks, rating scale with benchmarks and summary of rated results for the copper market.

<table>
<thead>
<tr>
<th>Indicator for market assessment</th>
<th>Situation in 2004 and trend</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Current supply and demand</td>
<td>Mc = 83,000 tonnes; trend problematic; Difference in production (P), change in stocks (ΔS) and consumption (Con).</td>
<td>100 ↓</td>
</tr>
<tr>
<td>Stock keeping (Sk) Stock keeping</td>
<td>Sk = 3.3%; trend problematic, Ratio of global stocks (S) and refinery production (RP).</td>
<td>15 ↓</td>
</tr>
<tr>
<td>Mine (Mcu) or refinery (Rcu) capacity utilisation Mine capacity utilisation</td>
<td>Mine capacity utilisation (red) = 92%, refinery capacity utilisation (blue) = 85%. Ratio of mine production (MP) and mine capacity (Mc) or refined metal consumption (RCon) to refinery capacity (Rc).</td>
<td>85 ↓</td>
</tr>
<tr>
<td>2. Production costs &quot;Cash costs&quot; (Cc) Cash costs</td>
<td>CC = 0.45 US$/lb; trend moderate (2005: 0.46 US$/lb), cash costs (CC) per pound (lb) of raw material produced</td>
<td>0.5 ↓</td>
</tr>
<tr>
<td>3. Geostrategic risks Country related risk (Cr)</td>
<td>HHI mining companies = 442, HHI refineries = 375, Herfindahl–Hirschman Index (HHI): sum of squares of raw materials production (in %) in each country (aICP)</td>
<td>7.0 ↓</td>
</tr>
<tr>
<td>Country concentration (HHIC)</td>
<td>HHI mine production = 1670, HHI refinery production = 780, Herfindahl–Hirschman Index (HHI): sum of squares of raw materials production (in %) in each country (aICP)</td>
<td>4.5 ↓</td>
</tr>
<tr>
<td>4. Market power Company concentration (HHIc)</td>
<td>HHI mining companies = 442, HHI refineries = 375, Herfindahl–Hirschman Index (HHI): sum of squares of raw materials production (in %) in each country (aICP)</td>
<td>2.000 ↓</td>
</tr>
<tr>
<td>5. Supply and demand trends Future market capacity (McF) in 2010 Future market capacity</td>
<td>McF = −3.2% (at 4% growth of demand), Possible compensation through mine expansions. Ratio of mine production plus additional annual production capacity (MP+APcF) of future projects and necessary future mine production (MPIn) at a forecasted growth in demand for mining products of x%/year.</td>
<td>780 ↓</td>
</tr>
<tr>
<td>Degree of exploration Lt,M = R/MF; Lt = 31 years, IE = 34.4 US$/tonne (last 5 years). Weighted values of static life time (Lt) and investments in exploration (IE). Lt is the ratio of reserves (R) and mine production (MP). IE is the exploration budget (ExB) for each tonne of mine production.</td>
<td>45 ↓</td>
<td>25</td>
</tr>
</tbody>
</table>

For example, taking the main indicator (1) (supply and demand, Fig. 2), the factors production (P), changes in reported stock-keeping (ΔSk) and consumption (C) are used to calculate the indicator “market balance” (Step 1, see Fig. 4). The “market balance” indicator (Mb) of the raw material (i) is calculated over a specific time period (Δt). Using the time period 1960–2004, the benchmarks for copper ± 100,000 tonnes are labeled moderate. Due to the sharp reduction of stocks on the metal exchanges and at producer’s warehouses, the market coverage for copper in 2004 was +80,000 tonnes including the movement in reported stocks (moderate; problematic excluding movement in reported stocks). Due to the low stocks of copper and continued high demand, the trend for the future market balance is problematic. This is clearly underlined by a second indicator, “stock-keeping” (Sk, blue line), which in comparison to 1975, shows a much lower ratio of copper stocks to annual refinery production (1975: 21.4%, “relaxed”; 2004: 3.3%, “problematic”, benchmark for relaxed/problematic is defined at 10%). A further indicator evaluates the utilisation of mines and refineries. Together, the three indicators “market balance”, “stock-keeping”, and “refinery/mine utilisation” define the main indicator (1). The additional main indicators
production costs (2), geostrategic risks (3), and market power (4) further characterise the supply side.

**Forecasts**

The forecast for future supply and demand presented as main indicator (5) is based on the analysis of: (i) the production capacity of mines currently under construction, expansion and production forecasts for exploration projects in grassroots, pre-feasibility and feasibility status; and (ii) the growth in demand based on published market sector and economic data. According to the supply and demand forecast, the balance may lead to the conclusion whether supply may sufficiently meet demand in five or fifteen years (Step 3).

In order to better estimate the extend of future exploration and mining activities, the development of the companies’ exploration budgets and capital expenditure for mining projects are also considered. Estimating the demand comprises an extensive literature review of the global economic outlook including GDP and industrial production as well as growth foresight studies of industrial sectors and future technologies.

Simplified forecasts of this kind are always fraught with uncertainty. For this reason, the analysis should be adjusted at intervals of two to four years by continually checking the data at hand.

Once the main indicators are calculated, rated and presented in a characteristic spider chart, the market situation can quickly be assessed (Fig. 2). The spider chart may be used for better visualisation of the results. The chart shows, whether and which indicator (1–5) point to a “relaxed”, “moderate” or “problematic” market situation. The numbers on the chart correspond to the tabled indicators in Fig. 2.

As a result, suitable actions for companies may be recommended to ensure supplies of raw materials, for example by signing long-term contracts, by hedging or by diversifying sources of supply.

**Analysis for copper**

**Data situation**

The statistical database for analysing the copper market is generally very good. This analysis used the following data sources, as of 2004–2005:

- International Copper Study Group (ICSG, 1960–2006; production, consumption, recycling, mine/refinery capacities)
- World Bureau of Metal Statistics (WBMS, 1960–2006; production, consumption, stocks, prices)
- World Bank (country risk, economic data)
- BGR database (combined statistical database on production and consumption, annual production capacity from new mining and exploration projects, prices)
- Raw Materials Group (2005, mines and projects: annual production capacity, production, mergers and acquisitions, reserves, resources, ore content)
- United States Geological Survey (USG, 1960–2005; reserves, reserve base)
- Business reports from mining companies, market analyses, for example from Citigroup (2005), Morgan Stanley (2004) (cash costs, capital costs, growth forecasts, demand development)

The statistical data on global supply and demand for the period from 1960 to 2005 is largely complete. However, worldwide data in exploration and capital expenditures as well as cash costs were only available since the early 1990s and are partially incomplete.

**Price trends**

Copper prices more than doubled between 2002 and 2005. The annual average price rose from 1560 to 3680 USD/tonne, and...
reached record levels of over 8000 USD/tonne in 2006. Unexpectedly high demand and the inability of supply to meet this demand in the short run led to both high prices and low stocks. Continued low stocks between 2004 and 2005 combined with expectations for high demand from Asia kept the market nervous and thus prices up. In addition, low total capital and exploration spending relative to the average between 1990 and 2002 as well as high mine utilisation and the effects of labour strikes to price are an indication that production levels are limited and cannot be raised quickly. Low elasticity of demand is another effect pushing up prices since mid-2005.

Supply and demand

Market balance (rating: 4, moderate; trend: problematic)

Worldwide mine production for copper increased by 243% from 4.24 million tonnes in 1960 to 14.56 million tonnes in 2004 at an average annual growth rate of 2.9%. Since 1995, the annual growth in global mine production has been significantly higher at 4.3%. The two biggest producers – Chile and the USA – had shares of global production of 37% and 8%, respectively in 2004 (Fig. 3A). Refinery production increased between 1960 and 2004 by 2.7% annually, accelerating to 3.5% after 1995, reaching a record level of 15.58 million tonnes in 2004.

Throughout the period under consideration, the average growth in consumption of refined copper was 3.0%. In China and South Korea, the growth rates were 8.3% and 17.6%, but in the industrialised countries, USA, Japan and Germany, they were only between 2.1% and 4.1% (Fig. 3B). In the past ten years, the average global annual growth in refined copper consumption was 3.6%, with China in first place with an average annual growth rate of 12.8%. In industrialised countries, on the other hand, growth in refined copper consumption was stagnant or – as in the case of the USA and Japan – even fell slightly (Fig. 3C).

The calculated difference between refined copper production and consumption shows that there were supply deficits at the end of the 1970s, 1980s and 1990s which – combined with strong demand – resulted in price increases of more than 100% (e.g. at the end of the 1980s) (Fig. 4). Some of this shortfall was compensated using stock held by producers, suppliers and exchanges. As a result, these global stocks continued to shrink. From the mid 1990s a supply surplus accumulated again, causing the price of copper to fall to almost the levels of the 1970s and early 1980s and stocks to rise. Since 2003, due to increasing demand, particularly from China, accumulated stocks have fallen dramatically and at 517,000 tonnes in 2004, they were even lower than the level of 1987 (521,000 tonnes).

Overall, the market balance in 2004 was moderate. It was possible to cover the large supply deficit of 612,000 by utilising stocks, which meant that the market balance including movements in documented stocks was +83,000. In the meantime, the situation has become much worse. Looking at the market balance (including movements in stocks) over time, we have set
Refined consumption [million tonnes] % Growth
Korea Rep. (South) Germany Japan USA PR China Others


Fig. 3. (Continued)

Refinery utilisation
Mine utilisation


Stocks / refinery production
Surplus/ deficit
Surplus/ deficit incl. Δstocks
Ratio of stock to refinery production


Fig. 4. Development of supply and demand for copper: market coverage for refined copper, stock-keeping and price (Data Source: World Bureau of Metal Statistics, International Copper Study Group).
benchmarks between +100,000 and −100,000 tonnes. In that range, the market situation is considered as moderate. Levels above +100,000 tonnes are considered relaxed, levels below −100,000 tonnes are considered problematic.

Stock-keeping (rating: 9, problematic)

Due to the development described above, the stock-keeping situation is evaluated as a serious cause for concern. In 1975 stocks amounted to around 21.4% of refinery production, and by 1985 this value declined to around 10%. Between 1986 and 2003 the value ranged between 5% and 10%. Since then it has fallen to a problematic 3.3% (Fig. 4). In order to quantify the supply risk, the stock-keeping is considered here as moderate when stocks amount to around 10–15% of refinery production. If stocks are below 10% of refinery production for a period of more than one year, there seem to be serious problems to keep up supply. Although this indicator is more appropriate for understanding the current situation and to describe short-term risks, strategic stock planning by governments such as in the USA and more recently in China may influence the market in the longer run. Selling of national stocks may act as a buffer in tight markets, buying may masquerade demand and may support prices in a falling market.

Mine/refinery capacity utilisation (rating: 7, problematic; trend: problematic)

In comparison with the relatively low refinery capacity utilisation (2004: 85%), mine capacity utilisation in the past ten years has been relatively high, between around 90% and 94% (Fig. 3D). Mines were not able to increase production according to the increasing demand. Minor production losses, such as strikes in Asarco or Codelco mines or through missing deliveries of spare parts (truck tyres) additionally destabilised the market. Looking at the historic development, a capacity utilisation of > 90% may thus be defined as problematic.

Production costs

Cash costs (rating: 3, relaxed)

Between 1994 and 2005, cash costs for planned copper production from projects in feasibility status or under construction lay between 0.37 and 0.50 USD/lb. In 2005, with a value of 0.46 USD/lb, they were just above the average 0.45 USD/lb (Fig. 5). This information is based on an analysis of project data from over 177 flotation and SX-EW (Solvent Extraction, SX-EW) operations since 1994 (Metals Economics Group).

Between 1994 and 2005 there was no clear trend regarding rising or falling average cash costs, so the situation is currently evaluated as relaxed. If the average cash costs increase to a level above about 0.6 USD/lb over some period, the situation may be termed problematic with respect to possible long term price escalations. In real terms, cash costs have fallen at an almost constant rate since 1980. However, between 2005 and 2007 costs also in real terms have increased significantly. Some companies have registered rises in costs, which means that cash costs should be monitored in the long term. Phelps Dodge reported rises in costs of around 25% for maintenance and service, 23% for energy, 18% for processing and freight, 17% for equipment and 15% for personnel (International Mining, 2006; see also Tulpule, 2008). Codelco also announced a total increase in operating costs of 20% for 2005 (Codelco, 2006).

Continuing rationalisation and increased efficiency in copper mining, for example through increasing the amount of in situ and heap leaching (solvent extraction methods), increased automation in open-cast mines and the use of more efficient, energy-saving mills (high pressure grinding rolls), makes it foreseeable that despite certain cost increases, worldwide operating real costs per tonne of ore mined may tend to fall or remain the same.

Geostrategic risks

Country concentration and country risks (rating: 4, relaxed; trend: relaxed)

In order to quantify the country concentrations with the Herfindahl–Hirschman Index (HHI), this study defines scores between 1000 and 2000 as benchmarks for moderate

![Fig. 5. Development of cash costs for copper mining projects (Data Source: Metals Economics Group).](image)

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</tr>
</thead>
<tbody>
<tr>
<td>Chile</td>
<td>2219.9</td>
<td>23.4</td>
<td>545.85</td>
<td>5412.5</td>
<td>37.2</td>
<td>1381.50</td>
<td>7.32</td>
<td>2.72</td>
</tr>
<tr>
<td>USA</td>
<td>1813.0</td>
<td>19.1</td>
<td>364.09</td>
<td>1174.0</td>
<td>8.1</td>
<td>65.00</td>
<td>8.22</td>
<td>0.66</td>
</tr>
<tr>
<td>Peru</td>
<td>395.9</td>
<td>4.2</td>
<td>17.36</td>
<td>1035.6</td>
<td>7.1</td>
<td>50.57</td>
<td>4.46</td>
<td>0.32</td>
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<td>Australia</td>
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<td>4.4</td>
<td>19.35</td>
<td>854.1</td>
<td>5.9</td>
<td>34.40</td>
<td>8.34</td>
<td>0.49</td>
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<td>Indonesia</td>
<td>309.7</td>
<td>3.3</td>
<td>10.63</td>
<td>843.2</td>
<td>5.8</td>
<td>33.53</td>
<td>4.34</td>
<td>0.25</td>
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<td>Russia</td>
<td>573.3</td>
<td>6.0</td>
<td>36.41</td>
<td>745.0</td>
<td>5.1</td>
<td>26.17</td>
<td>3.74</td>
<td>0.19</td>
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<td>PR China</td>
<td>395.6</td>
<td>4.2</td>
<td>17.34</td>
<td>607.5</td>
<td>4.2</td>
<td>17.41</td>
<td>4.50</td>
<td>0.19</td>
</tr>
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<td>Canada</td>
<td>590.8</td>
<td>6.2</td>
<td>38.66</td>
<td>563.4</td>
<td>3.9</td>
<td>14.97</td>
<td>8.25</td>
<td>0.32</td>
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<td>Poland</td>
<td>378.2</td>
<td>4.0</td>
<td>15.84</td>
<td>530.5</td>
<td>3.6</td>
<td>13.27</td>
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<td>Kazakhstan</td>
<td>218.8</td>
<td>2.3</td>
<td>5.30</td>
<td>461.8</td>
<td>3.2</td>
<td>10.06</td>
<td>3.76</td>
<td>0.12</td>
</tr>
<tr>
<td>Others</td>
<td>2188.3</td>
<td>23.0</td>
<td>44.24</td>
<td>2334.4</td>
<td>16.0</td>
<td>23.66</td>
<td>–</td>
<td>0.02</td>
</tr>
<tr>
<td>Total</td>
<td>9501.6</td>
<td></td>
<td>1115.1</td>
<td>14562.0</td>
<td></td>
<td>1670.5</td>
<td>5.6</td>
<td></td>
</tr>
</tbody>
</table>

Data Sources: World Bank (2005), World Bureau of Metal Statistics (1960–2006). WB = World Bank, the WB scale of country risk rating from −2.5 to +2.5 has been converted to a scale of 1–10; % values = percent of world mine production; Herfindahl–Hirschman Index (HHI) = country concentration; weighted country risk = sum of share of production \times country related risk.
supply risk (the US Department of Justice and Federal Trade Commission (1997) uses values between 1000 and 1800), scores above 2000 as problematic, and scores below 1000 as relaxed. In relation to the standardised World Bank scale for country risks (World Bank, 2005, values of $\pm 2.5$ converted to a scale from 1 to 10), countries with a country risk between 4.5 and 5.5 are evaluated as benchmarks for moderate supply risk. Values below 4.5 are classified as problematic, and values above 5.5 as relaxed.

With a Herfindahl–Hirschman Index (HHI) of 1670 for copper, the country concentration for mine production has significantly increased compared to 1994 (Table 2, rating: 6). Since the increased country concentration for mine production is largely caused by the share accounted for by Chile, which has a low country risk (5.6, rating: 3), the geostrategic risk for mine production is evaluated at 4.5 (moderate). Because, according to this principle, the geostrategic risk for refinery production is evaluated at 2.0 (relaxed, not shown), the overall result is a moderate geostrategic risk for copper mine and refinery production worldwide.

**Market power/company concentration**

**Company concentration (rating: 2, relaxed)**

The exertion of market power through global company concentration for mine and refinery production is evaluated overall as relaxed, since in each case the HHI lies well below 1000 (Fig. 6A and B). Thus, with regard to competition, the supplier base can be classified as diversified. In order to quantify the company concentration using the HHI, the scale applies similarly to the country concentration.

![Fig. 6. Company concentration in copper mining (A) and copper refineries (B), comparison between 1994 and 2004 (HHI = Herfindahl–Hirschman Index, Data Sources: Raw Materials Group, World Bureau of Metal Statistics).](image-url)
Supply and demand trends/forecast

Static life time of reserves and resources (rating: 5, relaxed)

From a purely geological view, the long-term situation regarding reserves and reserve base for copper can be termed as relaxed (see USGS, 1980 for definition). The largest reserve base in the world, amounting to 39%, lies in Chile (Fig. 7A). Due to successful exploration activities in the last 40 years, the static life time for global copper reserves and resources was maintained for between 40 and 60 years, respectively (Fig. 7B). However, since the early nineties, the reserve range has fallen from around 40 to 20 years. Since 2002, with the beginning of the bull market and resurgent international exploration activities. In 2004 it lay between around 31 years for reserves (408 million tonnes) and 64 years for the reserve base (940 million tonnes; Table 2). Values between 25 and 45 years may be used as a benchmark for a moderate situation. If the static life time of reserves falls below 25 years, exploration activities should thus be monitored regularly. The static life time of reserve and resource is a function of exploration activities, and are therefore not an absolute measure of the shortage of a raw material (see Wellmer, 1998). For this reason, the degree of exploration needs to be estimated.

Degree of exploration (for 2000–2004, rating: 6.5, moderate; for 2004 rating: 2, relaxed, trend relaxed)

Because the life time of reserves and resources is not a measure of shortage, it is necessary to consider annual exploration costs and budgets in the mining sector. The indicator “degree of exploration” weights the life time (for copper, rating: 5) and the total amount of the exploration expenditures or budgets of mining and exploration companies in relation to global mine production (for copper, rating: 8). For the time period 2000–2004, the total rating of 6.5 for copper indicates that the market situation is moderate to problematic. The exploration budget for copper is significantly below the average of the last ten years (Fig. 8A). Between 1997 and 2002, exploration expenditures per tonne of copper extracted worldwide fell from over 65 USD/tonne to just over 20 USD/tonne which is significantly below the average value of 42 USD/tonne for the period 1994–2005. Because companies’ exploration expenditures were rising again since 2004, a positive trend is emerging regarding the possible discovery of new mine locations, which – supposed to be successful – in the long-term will lead to an increase or stabilisation of the life time of reserves and resources.

Investments (for 1998–2002, rating: 6, moderate)

Between 1990 and 2002 the trend for capital expenditures for new copper mines was similar to the development of the exploration costs (Fig. 8B). Per tonne of copper extracted worldwide, investments fell from 491 USD/tonne in 1997 to the problematic level of 128 USD/tonne in 2002. In 2002 they were significantly below the average of 250 USD/tonne. Data for the period after 2002 were not available, but it can be assumed that capital expenditure for new copper mines since 2003

Fig. 7. Distribution of worldwide reserves and reserve base (A) (reserve base = reserves plus part of resources, USGS, 2005) as well as static life time (B) for copper (Data Sources: World Bureau of Metal Statistics, USGS).
has increased significantly. In the next few years they presumably will be well above 250 USD/tonne of copper extracted worldwide.

**Market balance in 5 years (rating: 7, problematic)**

The total expected additional annual production capacity from mines under construction, projects in pre-feasibility and feasibility status reveal an additional estimated copper supply of 3.2 million tonnes for the period 2005–2010 (Table 3). This assumes that all 40 recorded projects starting within that period will actually come into production at the level of announced annual production capacity (see Tables 4 and 5). With an annual growth of 4% in worldwide demand for mined copper (average demand in the past 10 years: 3.9%), and taking the expected production for new projects into account, a worldwide copper deficit of 3.2% would remain in 2010 (Fig. 9A). However, since these estimates do not include mine expansions, it is not clear how well this potential deficit will be met. According to cautious estimates, current operating expansions lie at 1.175 million tonnes annual production capacity (Table 3). Roughly half of this would be sufficient to cover this deficit.

Assuming a time period of 6–15 years (including all projects with a published start of annual production capacity after 6 years or undefined date), annual growth in refined copper consumption and mine production of around 3% (average demand over the past 44 years for both: 3.0% and 2.9%, respectively), and taking the expected production for new projects into account (6.5 million tonnes), a speculative worldwide copper deficit of 9.8% would persist until 2020 (Fig. 9B). Here again, mine expansions are not considered. On top of that, the possible start of production of 222 recorded projects at an early exploration stage is not included in this estimate. These projects plus today’s still undiscovered deposits could entirely offset the calculated deficit.

Developments in the demand are difficult to predict. It is unclear whether the growth curve will take a similar path to that of the past 44 years. In the long run, copper demand will continue to be dominated by the building sector, mechanical and electrical engineering, the automotive industry and precision engineering. There will be significant demand for copper...
from the expansion of infrastructure in ambitious emerging countries as well as sectors of engine development (e.g. hybrid engines), smart house technology (e.g. building construction) and the introduction of energy-efficient technologies. In the telecommunications sector, the possibility of substitution still exists due to wireless data transfer, pipes and panels made from plastic, or from the use of aluminium or superconductors in electrical wires.

According to the past trends, an annual growth in copper demand of 4% seems to be a realistic estimate. However, in the long term, global recycling of copper could improve thus leading to a much lower demand of primary copper production of rather 2% (see Frondel et al., 2007 for comparison).

### Overall rating

Due to strained market coverage, low stock-keeping and high mine utilisation, the overall supply conditions for 2004–2005 are evaluated as problematic (rating: 7). The development of production costs, geostategic risks and the possibility of mining companies and refinery operators exerting their market power to control prices are evaluated as moderate to relaxed. In contrast, supply and demand trends indicate that the market situation for copper is problematic until 2010. Exploration and mining projects should therefore carefully be monitored.

### Discussion and conclusions

Due to their limited accuracy, statistical data for mineral raw materials, which largely base on worldwide surveys, must be treated with caution. However, they may provide valuable information on future market developments and trends, especially when data series exist for a long period of time and current events can be compared with past developments.

Despite those statistical uncertainties, there are further limitations. For example, in order to estimate the country risks, the World Bank Group’s Governance index was used as a basis (World Bank, 2005). As for most country risk classifications developed by banks and investment companies (e.g. Aon Political Risk Services, 2006), the main focus is on the overall investment and not on supply security. This means that the Governance index can, at best, only approximate the supply risk for raw materials from a particular country. Here again, as for all other data, experience becomes part of the valuation process.

Estimating supply trends is full of uncertainty. The data for annual production capacity from new projects and the date of commencement are only target figures published by exploration and mining companies. By their very nature, planned mining projects may be postponed or do not go further. Information on reserves and resources also change during the course of exploration. This means the status of projects must be updated regularly. Data on annual production capacity from mine expansions in the copper sector is always difficult to evaluate. It is unclear to what extent they will replace deceasing production from current mine sites or – in absolute terms – add to new supply. Production information for mine extensions therefore is initially not included in the supply/demand balance, but looked at for final evaluation of the market situation.

For all these reasons, supply/demand forecasts are of limited value in absolute terms but may be very useful to identify market trends and possible market failures. They are essentially based on approximated scenarios over a period of 5 to 15 years, accompanied by monitoring the degree of exploration, investment in mining projects, trends in production costs, geostategic risks or changes in market powers.

At present, the overall balance for supply and demand trends does not take into account either future changes in the worldwide copper recycling rate, or a detailed demand growth forecast. The demand growth scenarios are based on the assessment of existing market analyses for individual raw material sectors. The method is thus open to further development and extension. Indicators for estimating the future demand of mineral raw materials have recently been published (Frondel et al., 2007).

In spite of the uncertainties mentioned, the method described has some main advantages: a systematic market evaluation and

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**Table 5**

Summary of the 25 largest copper projects in pre-feasibility and feasibility status with a planned annual capacity over 80,000 tonnes, project costs and expected start of production.

<table>
<thead>
<tr>
<th>Project</th>
<th>Company</th>
<th>Country</th>
<th>Status</th>
<th>OP/UG</th>
<th>Expected annual capacity 1000t</th>
<th>Project costs Million US$</th>
<th>Expected start of production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toromocho</td>
<td>Peru copper</td>
<td>Peru</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>300</td>
<td>980</td>
<td>After 2010</td>
</tr>
<tr>
<td>Petaquilla</td>
<td>Petaquilla miner, inmet</td>
<td>Panama</td>
<td>Feasibility</td>
<td>OP</td>
<td>230</td>
<td>1124</td>
<td>After 2010</td>
</tr>
<tr>
<td>Rio Blanco</td>
<td>Monterrico</td>
<td>Peru</td>
<td>Feasibility</td>
<td>OP</td>
<td>220</td>
<td>915</td>
<td>2009</td>
</tr>
<tr>
<td>Frieda River</td>
<td>Highland pacific</td>
<td>Papua New Guinea</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>220</td>
<td>1124</td>
<td>After 2010</td>
</tr>
<tr>
<td>El Fachon</td>
<td>Falconbridge</td>
<td>Argentina</td>
<td>Feasibility</td>
<td>OP</td>
<td>200</td>
<td>1150</td>
<td>After 2010</td>
</tr>
<tr>
<td>Quellaveco</td>
<td>Anglo American</td>
<td>Peru</td>
<td>Feasibility</td>
<td>OP</td>
<td>200</td>
<td>840</td>
<td>2006</td>
</tr>
<tr>
<td>Salobo</td>
<td>CVRD</td>
<td>Brazil</td>
<td>Feasibility</td>
<td>OP</td>
<td>200</td>
<td>1055</td>
<td>2006</td>
</tr>
<tr>
<td>Hales</td>
<td>Codelco</td>
<td>Chile</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>190</td>
<td>900</td>
<td>2007</td>
</tr>
<tr>
<td>Mansa (MM)</td>
<td>Codelco</td>
<td>Chile</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>188</td>
<td>900</td>
<td>2008</td>
</tr>
<tr>
<td>Letpadaug</td>
<td>Ivanhoe, State of Myanmar</td>
<td>Myanmar</td>
<td>Feasibility</td>
<td>OP</td>
<td>188</td>
<td>389</td>
<td>2007</td>
</tr>
<tr>
<td>Lumwana</td>
<td>Equinox, Phelps Dodge</td>
<td>Zambia</td>
<td>Feasibility</td>
<td>OP</td>
<td>150</td>
<td>387</td>
<td>2007</td>
</tr>
<tr>
<td>Alemao</td>
<td>CVRD, State of Brazil</td>
<td>Brazil</td>
<td>Pre-feasibility</td>
<td>UC</td>
<td>150</td>
<td>550</td>
<td>2006</td>
</tr>
<tr>
<td>Gaby Sur</td>
<td>Codelco</td>
<td>Chile</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>150</td>
<td>550</td>
<td>2008</td>
</tr>
<tr>
<td>Agua Rica</td>
<td>Northern Orion</td>
<td>Argentina</td>
<td>Feasibility</td>
<td>OP</td>
<td>149</td>
<td>996</td>
<td>2009</td>
</tr>
<tr>
<td>Tampakan</td>
<td>Indophil</td>
<td>Philippines</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>140</td>
<td>700</td>
<td>2009</td>
</tr>
<tr>
<td>Udokan</td>
<td>Summerset Hold, Chita</td>
<td>Russia</td>
<td>Feasibility</td>
<td>OP</td>
<td>130</td>
<td>700</td>
<td>2008</td>
</tr>
<tr>
<td>Antapacay</td>
<td>BHIF Billiton Gr</td>
<td>Peru</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>120</td>
<td>230</td>
<td>2005</td>
</tr>
<tr>
<td>Haib Mine</td>
<td>Namibia Copper</td>
<td>Namibia</td>
<td>Feasibility</td>
<td>OP</td>
<td>115</td>
<td>500</td>
<td>After 2010</td>
</tr>
<tr>
<td>Esperanza</td>
<td>Antofagasta, Equatorial</td>
<td>Chile</td>
<td>Feasibility</td>
<td>OP</td>
<td>110</td>
<td>550</td>
<td>2009</td>
</tr>
<tr>
<td>Safford</td>
<td>Phelps Dodge</td>
<td>USA</td>
<td>Feasibility</td>
<td>OP</td>
<td>110</td>
<td>450</td>
<td>2008</td>
</tr>
<tr>
<td>Cristalino</td>
<td>CVRD</td>
<td>Brazil</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>108</td>
<td>420</td>
<td>2005</td>
</tr>
<tr>
<td>Fortuna de Cobre</td>
<td>Falconbridge</td>
<td>Chile</td>
<td>Feasibility</td>
<td>OP</td>
<td>90</td>
<td>300</td>
<td>After 2010</td>
</tr>
<tr>
<td>Prominent Hill</td>
<td>Oxiana</td>
<td>Australia</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>90</td>
<td>407</td>
<td>2008</td>
</tr>
<tr>
<td>Golpu</td>
<td>Harmony</td>
<td>Papua New Guinea</td>
<td>Pre-feasibility</td>
<td>OP</td>
<td>80</td>
<td>230</td>
<td>2007</td>
</tr>
</tbody>
</table>

assessment of supply risks using time series analysis ideally for a long period of time, which allows comparison of the current market situation with past market cycles; a clear scaling of many different risk factors, which helps to quantify the supply risk; comparability of results even among different mineral raw material sectors; and estimates of future market trends. The method thus provides valuable information for identifying changes on the mineral raw materials markets at an early stage. The method can be used to help companies to make better informed decisions whether to take action to ensure the supply of raw materials.

This method – among others – is used by Volkswagen AG to assess long-term trends in the mineral raw materials market. The automotive industry is particularly strongly affected by the availability and price of raw materials in its pre-production value-added chains. By carefully selecting materials and increasing the efficiency of material use, as well as by the targeted use of hedging or long-term contracts, negative market trends can be financially counteracted at an early stage. This is especially a sensitive field, given the context of new technological developments and indications of risky raw material compositions.

**Acknowledgements**

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The BGR is the central geoscientific authority providing georelated advice to the German Federal Government and the
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Appendix 1. Selection of basic data for assessing long-term supply risks for mineral raw materials. The list is open to further additions

See Table A1.

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Sohn, I., 2006. Long-term projections of non-fuel minerals: we were wrong, but why?. Resources Policy 30, 259–284.


