Modelling of the Copper Primary Production – A Scenario Approach to Technique Variation Impacts

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Abstract

The implemented technology for Copper production has a significant influence on the resource requirement. By using the latest technology the environmental burden of products can be reduced. One way to evaluate the impact is using means of life cycle assessment (LCA). Some initiatives working on LCA have been started in the metal industry in recent years.

One of those initiatives is the collaborative research centre (CRC) 525 at University of Technology Aachen, Germany, which is dealing with the identification of options for resource-sensitive supply and use of metallic raw materials considering technical developments and economic, social and ecological aims.

In this paper the simulation of life cycles based on the worldwide primary Copper production from concentrate to cathode production will be presented for different regions (Europe, North America, South America). In order to derive courses of actions, which are influencing metallic raw materials, a scenario was developed until the year 2015 where different technologies were exchanged (e. g. replacing reverberatory furnace by Outokumpu furnace; replacing Peirce-Smith converter by flash converter). Possible consequences of this technology change will be shown for selected parameters (e. g. primary energy, SO_2-emissions, etc.).

1. Introduction

In the report of the World Summit on Sustainable Development in Johannesburg 2002 it is advised to start actions on all levels to improve the contributions of metals towards a sustainable development. For metals the focus is lying especially on transparency and accountability [1]. Certain rules for the use of renewable as well as not renewable natural resources, the capacity of the environment, and the adequate consideration of time are defined by expert groups according to the sustainability. Economic, ecological and social aspects have to be balanced in order to meet the related requirements [2]. Transferring the theoretical rules into practical purposes needs to develop differentiated rules which are considering special aspects of products, production processes and industrial sectors.

Technical progress may be described as a possibility of creating sustainable production systems by efficiency increase. The quantification of technical progress is difficult and its impact on resource use and emissions can only be evaluated for certain conditions for which information is available on the level of different processes and locations. Furthermore, markets progresses need to be integrated. To consider all this aspects, reliable projections of technical progress differentiate between the technical potential of full capacity replacement by newest technology and the smaller potential of reduced replacement. The latter is related to certain timeframe, which can be realistic implemented under consideration of financial and technical market aspects.

In order to reduce the complexity of real systems this paper selects the production of Copper cathodes in Europe, South America and North America. The concept of technical progress in cathode production is introduced, giving detailed description of expected technical progress on the process level until the year 2015. The approach follows the modelling concept of a process chain analysis. Using a scenario approach and differentiating between the maximum and predicted technical potential the impacts of the implementation of modern technical concepts on resource use and emissions are quantified.

2. Development of the process chain model

The complexity of the Copper production process needs to be separated into single unit processes, which can be modelled and for which data can be obtained. The derived process chain is given in Figure 1. For each unit process (framed boxes) data is collected mainly from literature and average unit processes are calculated. Exemplarily some of the unit processes are adjusted with industry. The complexity of the smelting operations makes data collection difficult. Often only data for the main mass flows respectively components can be found in literature and databases. This leads to an unbalanced situation as for some processes actual data and for other processes only older (more than five years) data was accessible. The available data is gathered and analysed. Missing data is calculated partly and estimated partly.

The composition of the input material, material processing, smelting as well as subsequent influencing steps are considered in order to transfer the site-specific data into technique-related average values. The variation of the concentrates is high and depending on the origin mine. Thus the site-specific values are weighted according to the subsequent formula:

$$\boxed{\mathrm{data}_{\mathrm{weighted}} = data_{\mathrm{site}} \cdot \frac{\sum\left(content_{element\ in\ concentrate} \cdot annual\ production_{cathode\ copper}\right)}{\sum\left(annual\ production_{cathode\ copper} \cdot \mathrm{considered\ sites}\right)}}$$

In the process chain model the three parts: pyrometallurgical Copper production, hydrometallurgical Copper production and Copper recycling are integrated (Figure 1). A framed box is representing a process group consisting of up to eight unit processes. For instance the process group "furnace" consists of the unit processes "Outokumpu furnace", "Reverberatory furnace", "Mitsubishi", "Noranda/Teniente" etc.. The most important inputs and outputs also given in Figure 1.

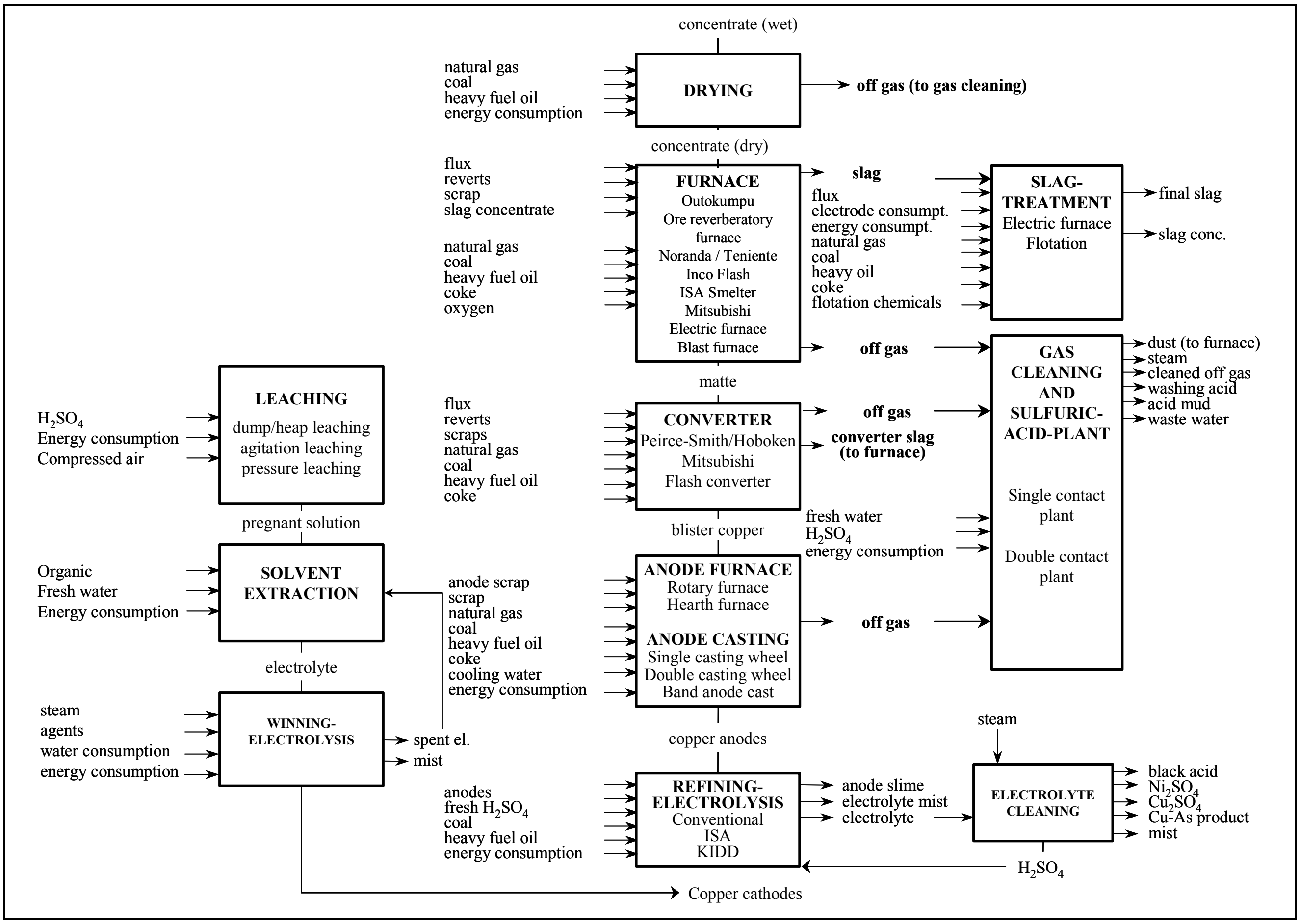

Figure 1: Process chain model of Copper cathode production

Only the most important production routes are considered according to their share on the world production (see Figure 2). In pyrometallurgy the processes are classified according to the furnace type. This is helpful as the different furnaces are representing miscellaneous technologies. In hydrometallurgy a classification is not performed due to missing important differences in the process technology. The difference is covered by the considered parameters.

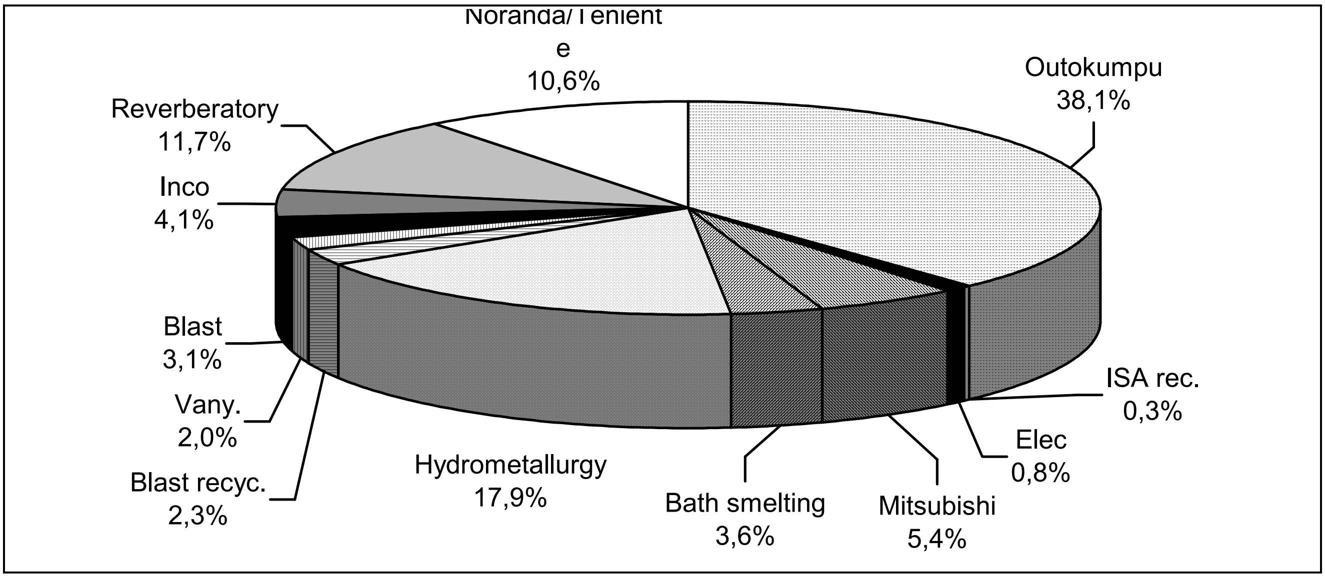

Figure 2: Share of processes on world Copper production 2000

In order to define various technologies for unit processes several adequate indicators were evaluated. (e. g. oxygen enrichment of concentrate burner, energy consumption, concentrate composition). Within pyrometallurgical Copper production the ratio concentrate composition to oxygen enrichment of burner has been investigated (Figure 3)

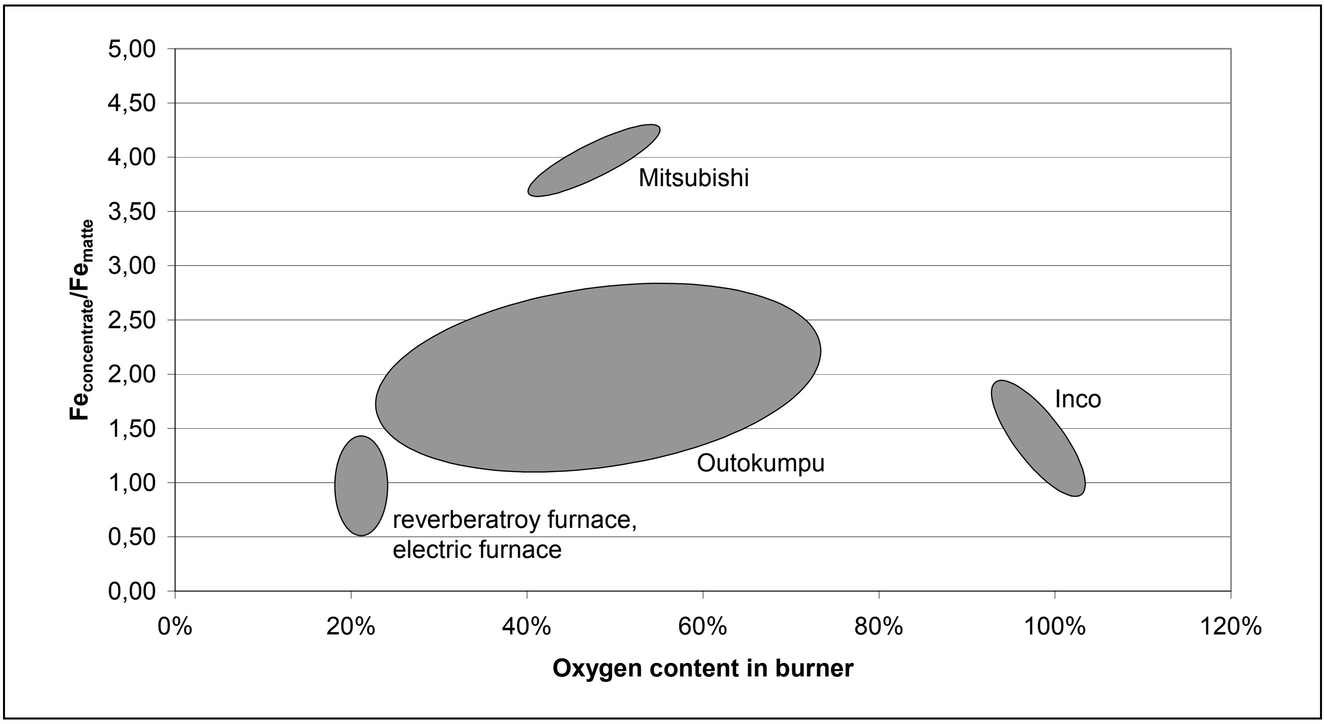

Figure 3: Fe-share of concentrate and matte at ration of oxygen enrichment

An approach for a separation into different technologies is not visible. The miscellaneous working areas of the processes are significant. A description of Teniente-Technology is not possible as white metal (CuS) is produced and thus a statement about the iron ration is difficult. A further example is given in Figure 4. The energy consumption of Copper refining electrolysis in dependency of the current density did hardly deliver an approach for technique variation. Modern tank houses using ISA or KIDD technology need less energy than the conventional electrolysis. This may be explained with the improved current efficiency. PCR electrolysis requires the highest energy due to the dissolution of deposed Copper. In general an increasing current density leads to an increased energy demand.

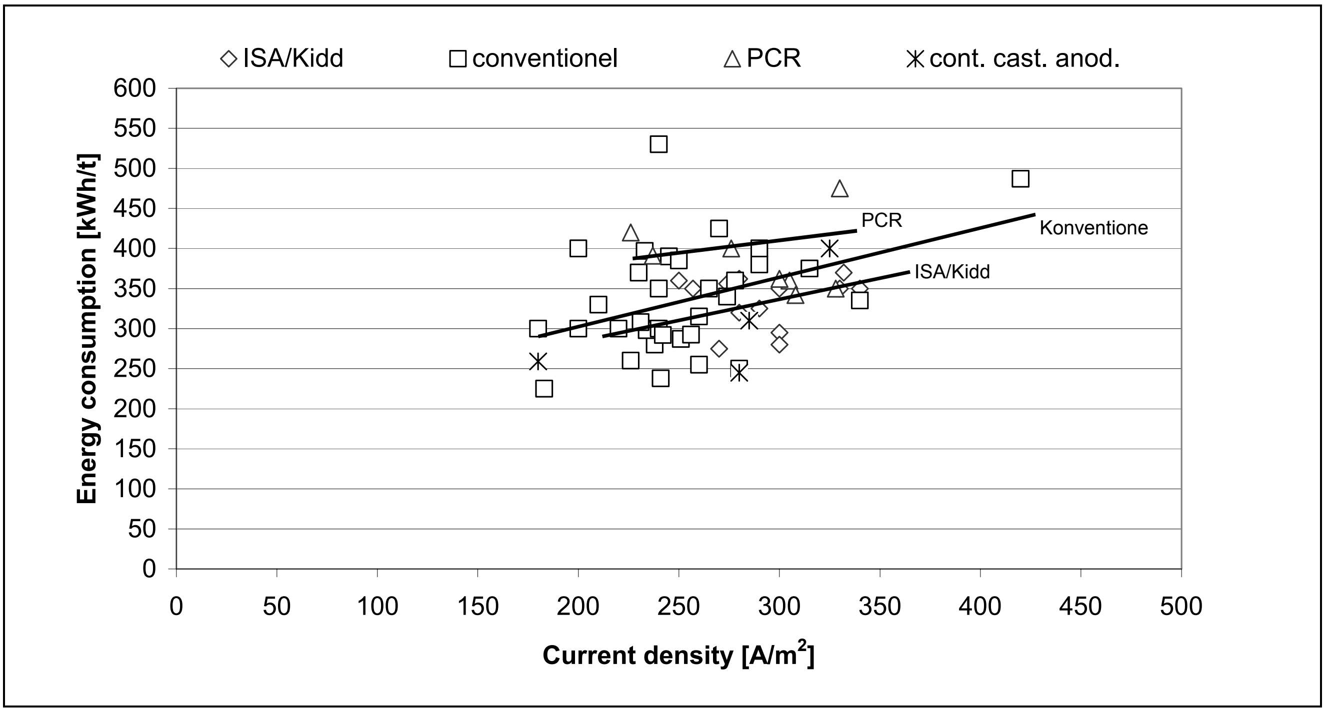

Figure 4: Energy consumption and current density of Copper refining electrolysis

The classification into technologies (old technology, present technology) is performed only between single unit operations within one process group as represented in Table 1.

Table 1: Technique categories example

Furnace	Present technology	Old technology
Outokumpu	x	
Reverbaratory furnace		x
Electric furnace		x
Noranda/Teniente	x	
Bath smelting	x	
Blast furnace		x
Mitsubishi	x	
INCO flash smelting	x	

A general category “new technology” was not defined because relevant technological developments have been performed during the past 30 years. This includes improved oxygen enrichment, higher Copper content in matte, optimisation of processes to higher throughput by intensive cooling of reaction areas or nearly complete collection of SO_2. No major improvement can be foreseen in the next future. Only for the process group "converter" a new technology was defined because the implementation of the flash converter may be seen as a fundamental new technology.

3. Data collection and classification

The major part of the data was collected from different literature sources and commercial databases. Most of the published sources refer to data from 2000. Older data (1995-1999) were assumed still to be valid in the case that no newer data was accessible. Collected data was harmonized with Industrial partners. In table 2 the share of data in the model is given. For all regions over 60 % coverage of the year 2000 producing sites are included in the model. The distribution of the production processes is varying in the regions (Figure 5). In order to give a proper image of the actual situation the production of Copper cathodes was calculated according to this distribution. In other words a cathode produced in Europe consist of 49 % Outokumpu furnace produced cathode, 18 % reverberatory furnace etc.

Table 2: Share of data in model

Technology	Europe Production [kt/a]			North America Production [kt/a]			South America Production [kt/a]		
	2000	in model	[%]	2000	in model	[%]	2000	in model	[%]
Bath smelting	-			188	188	100	-		
Blast f. recyc.	273.8	262	96	-			-		
Blast furnace	354	288	81	-			-		
Electric furnace	114	114	100	17.4	0	0	-		
Inco	-			482	482	100	-		
ISA recyc.	40	0	0	-			-		
Mitsubishi	-			146	146	100	-		
Noranda	-			200	200	100	-		
Other	210	0	0	-			-		
Outokumpu 60	952	927	97	254	254	100	1100	500	45
Outokumpu 90	190	190	100	-			-		
Reverberatory	67	67	100	400	193	48	242	0	0
Teniente	-			-			1025	1025	100
Sum	2200.8	1848	84	1687.4	1275	76	2367	1525	64

The distribution of the electrolytic refining technologies for the single regions is given in figure 6. Except for KIDD-technology sufficient data was gathered in order to calculate reliable modules. Again the share of different produced cathodes was included in the calculation according to the pyrometallurgical approach.

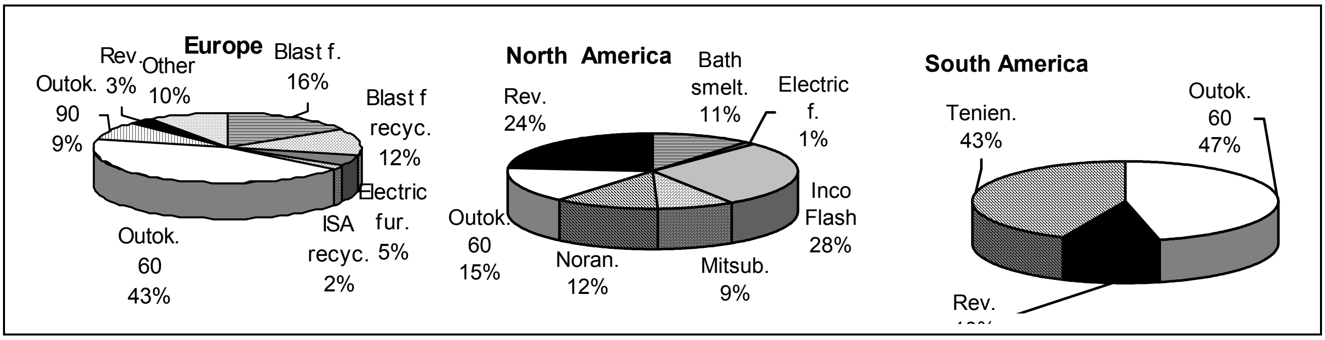

Figure 5: Distribution of furnaces

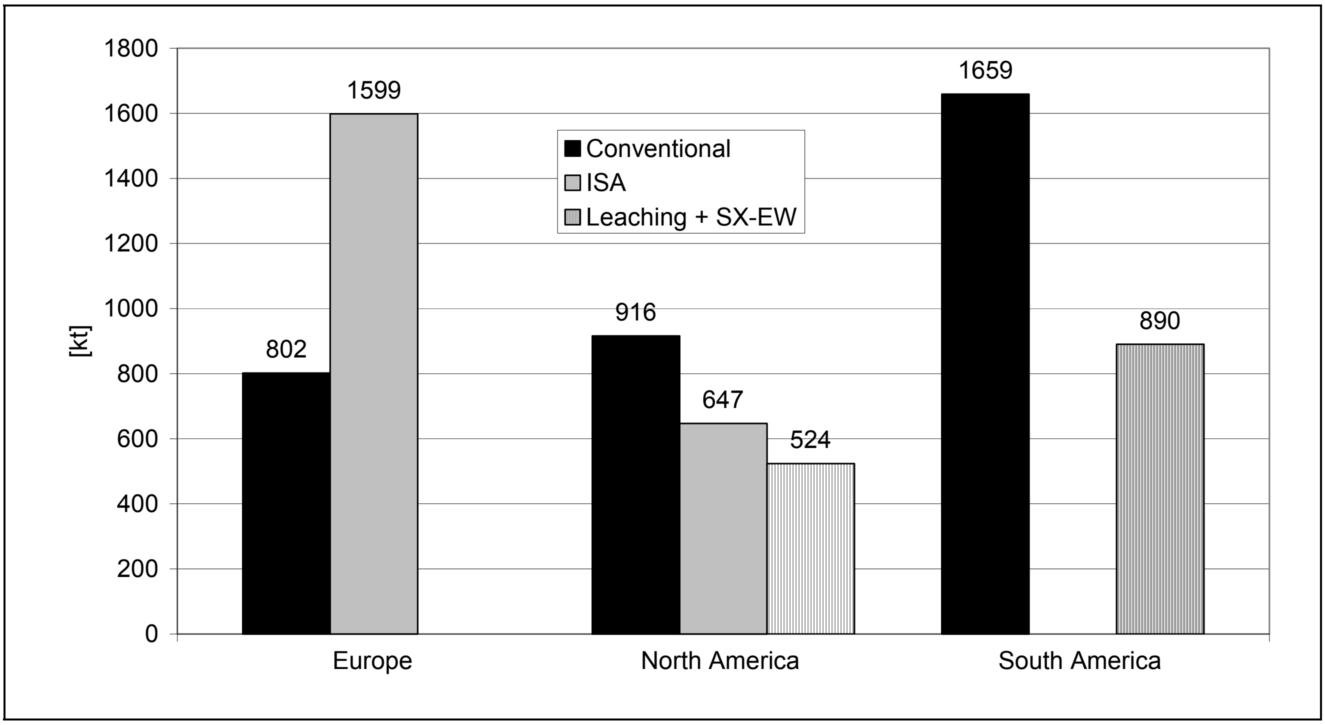

Figure 6: Distribution of electrolytic refining

4. Assumptions for the scenario calculation

For the chosen regions the changes in material and energy flows due to technical progress and innovation and their impact on the environment was investigated. To separate different effects the scenario approach is carried out in three steps:

1. The reference case shows the domestic market supply for Copper cathodes in the three regions for **2000** (including import of blister).

2. In a second case the maximum technical potential through full capacity replacement is calculated considering the exclusive application of newest technology (**2015 NT**) for each process of the 2000 structure.
3. In a third case financial and market aspects are taken into account. Looking at 2015 as the target year only a part of existing plants will be replaced by NT. Some plants will be upgraded and others will not be changed at all (2015 expect.). This differentiation is not a model result but exogenously determined based on expert information.

Following the process chain model several assumptions had to be made for the calculations.

Smelting and refining

Each country of origin is classified into one region. The images of the regions are modelled by connecting the particular modules representing the 2000 reference year. For the different regions the import of blister and Copper cathodes is included.

For the smelting process the share of the different furnace technologies is given in table 3. For several technologies no modules could be calculated due to missing data. This includes ISA recycling furnace, rotary furnace, Kivcet-process and mini-smelter process, which are therefore not considered in the calculations.

Table 3: Share of furnace technologies per country of origin for Europe, North and South America in 2000

	Outo. 60	Outo. 90	Reverb.	Blast	Blast re-cyc.	Bath smelt.	Elec.	El Ten/Nor.	Mitsub.	Inco
Europe	48.8	9.7	3.4	18.2	14.0		5.9			
N. America	42.7		17.5			7.4		7.8	5.7	18.9
S. America	46.5		10.2					43.3		

The conventional converter is taken for all countries considering the particular region. It is assumed that all sites are operating sulphuric acid plants except reverberatory furnaces. The module of the sulphuric acid plant is equal for all regions neglecting the real situation. As consequence, no regional differences of process performances are taken into account.

Due to missing information no credits for steam production are considered. Consequently, the net energy demand for the process could be smaller than assumed. Furthermore credits are not given for the production of sulphuric acid or other by-products.

For the subsequent process unit “fire refining” only the rotary furnace could be modelled for each region. One world average module has been calculated for anode casting (process unit “casting wheel”).

In Europe cathodes are produced to 66 % using ISA technology and to 33 % in conventional tank houses (the remaining 1 % is using KIDD process and neglected in this calculations). Alternatively to the pyrometallurgical route cathodes are produced hydrometallurgical. Hydrometallurgical sites are taken into account for both North and South America. Table 4 summarises the assumptions related to the electrolysis technology and hydrometallurgical route, respectively.

Table 4: Share of electrolysis technologies and electrowinning for Europe, North and South America in 2000

	Conv.	ISA	SX/EW
Europe	36.7	63.6	
North America	42.4	30.0	27.6
South America	67.0		33.0

Energy

The calculation of the energy demand is one of the main objectives of most studies. In the process description of a module specific final energy demands (coal, oil, electric power, etc.) are given. To depict the comparable energy expense of this different final energies they have to be transformed into primary energy. The transformation factor is depending on the technical status of the energy conversion and supply. Investigating a system including different countries, the specific energy supply situation of each region has to be considered. Data for local overall efficiencies of supply for electric energy and thermal energy carriers are taken from CRC 525. These are highly sensitive assumptions as technical efficiency for electric energy supply differ considerably according to the conversion technology. Table 5 indicates the specific overall efficiency for the supply of electric power (g_{el}).

Table 5: Specific overall efficiency for the supply of electric energy for the different countries

Europe	0.349
North America	0.318
South America	0.430

To assess thermal energy carrier to a primary energy basis the following overall efficiency of supply parameters for the different energy carriers are considered (Table 6). No distinctions for different countries are made.

Table 6: Overall efficiency of supply for energy carriers

Natural gas	0.919
Heavy fuel oil	0.908
Diesel	0.905
Hard coal	0.955
Hard coal coke	0.826
Steam	0.735

5. Results

Using the process chain model the changes in the three calculation steps can be quantified. The results allow an analysis in various directions considered to the sustainability discussion. To narrow down the complexity of the overall system selected inputs and outputs are considered. For all three regions the primary energy demand is investigated. Additionally, selected parameters such as CO_2 and SO_2 emissions and the production of sulphuric acid are taken into account.

Primary energy demand

The energy demand is one major parameter to represent technical progress. In table 7 the calculated energy demand for different energy carrier are listed comparing the different scenario cases. It shows the different use of energy carriers in the three regions but also a shift of energy types within the three cases. While most of the demand for energy in Europe declines between 2000 and 2015 in the expected case the demand for heavy fuel oil and electric power increases.

Table 7: Final energy demand for the different regions considering the three scenario cases

	Europe			North America			South America		
[MJ/$t_{cathodes}$]	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.	2000	2015 NT	2015 expect.
Steam	1430	620	600	1180	780	700	730	470	450
Hard coal	310	40	50	500	380	380	330	20	20
Hard coal coke	1590	750	1140	130	190	210	0	0	0
Heavy fuel oil	3330	3020	3700	350	140	140	5600	5210	4830
Natural gas	1670	960	1320	2140	2360	2470	30	0	0
Electric power	1470	1440	1590	3530	3120	3660	4120	4230	4360

To compare the energy consumption of the various regions, each using different forms of energy, the final energy consumption must be converted into a primary energy demand. Figure 7 shows a ranking of the absolute values of primary energy demand of the different scenario calculations. As could be expected, the improvements in the NT case are bigger than for the reduced replacement calculation. Only for South America the realised case has a slightly smaller energy demand due to a higher share of Noranda technology. The reason for the higher electric power demand for North America and South America lies in the application of SX/EW technology.

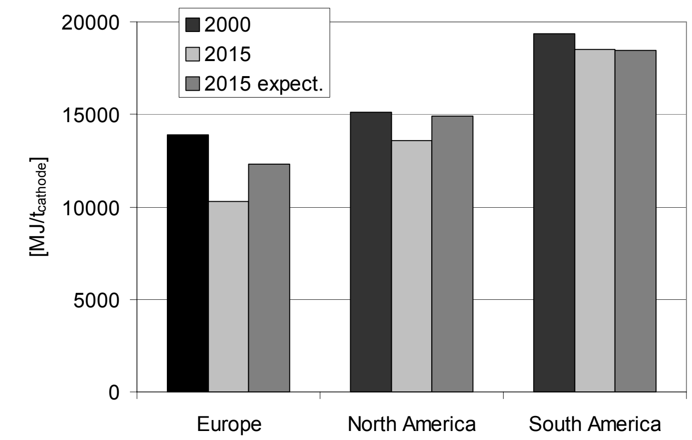

Figure 7: Primary energy demand for the different regions

The European system has the smallest primary energy demand with nearly 14 $GJ/t_{cathodes}$ in 2000. Nevertheless, the reduction potentials to the 2015 cases are the highest. For the NT case the energy demand is assumed to go down by 26% to 10 $GJ/t_{cathodes}$ and for the 2015 expect. case to 12 $GJ/t_{cathodes}$ (11%). This is due to a change in technology but also to an improvement in already existing techniques.

CO_2 Emissions

Close related to the energy demand is the discussion about CO_2 emissions. It must be distinguished between those emissions that are directly related to the processes and those related to the energy supply. Former can be determined by the Copper industry itself, by selection of technology or handling of the processes. Latter can only be determined indirectly by alternation of the energy supplier. Figure 8 depicts the CO_2 emissions connected to the domestic supply with cathodes for the various regions, distinguishing between direct and indirect determined emissions.

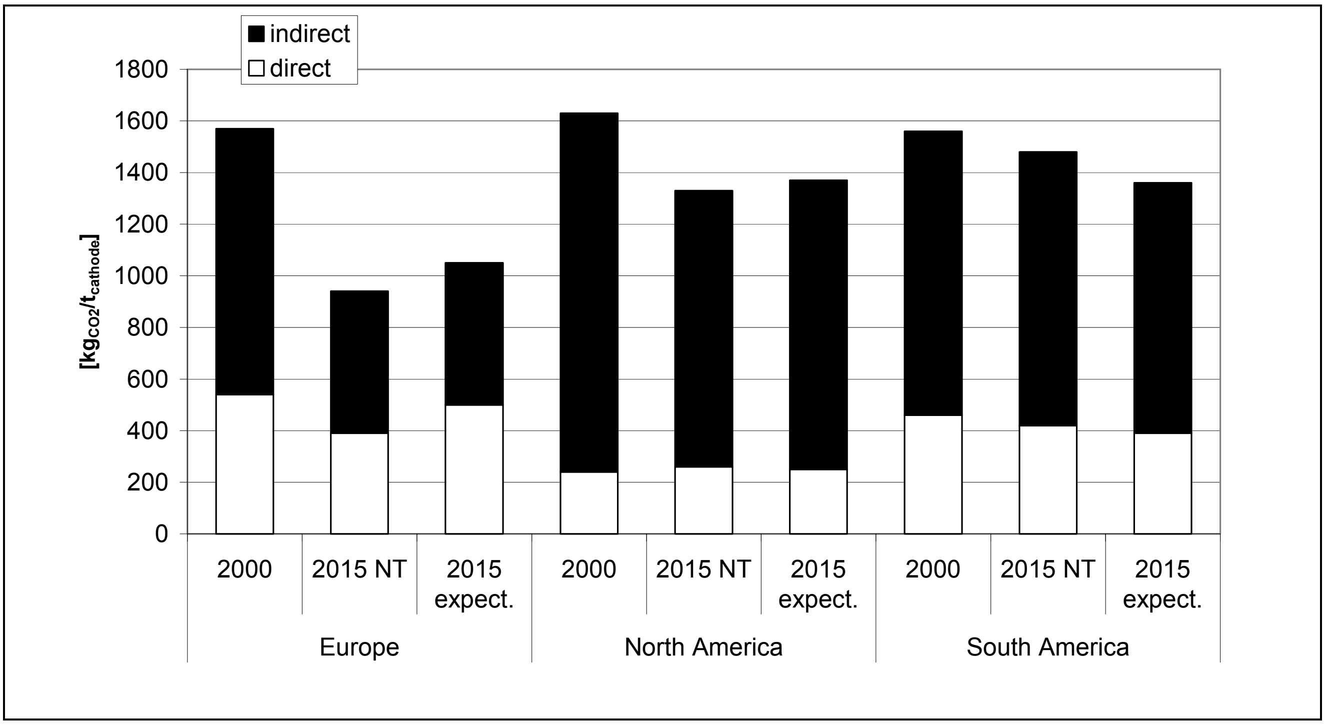

Figure 8: Directly and indirectly determined CO_2 emissions for the different regions

It can be seen that the share of the indirect determined CO_2 emissions is in all three cases dominating. This is especially true for North America. It is strongly connected with the necessary electric energy demand due to hydrometallurgical processes, which is introduced in both American regions. Again, it is expected that in the European system the improvement potential is higher than in the other regions and mostly will be implemented until 2015.

Sulphuric acid and SO_2 emissions

The increasing awareness for environmental protection has lead to a high sensitivity towards the emission of sulphur dioxide. A high share of plants already uses sulphuric acid production. In figure 9 the calculation results for the production of H_2SO_4 and the related emitting of SO_2 are illustrated. The production of sulphuric acid is representing the net production of acid considering the demand of sulphuric acid for the hydrometallurgical route.

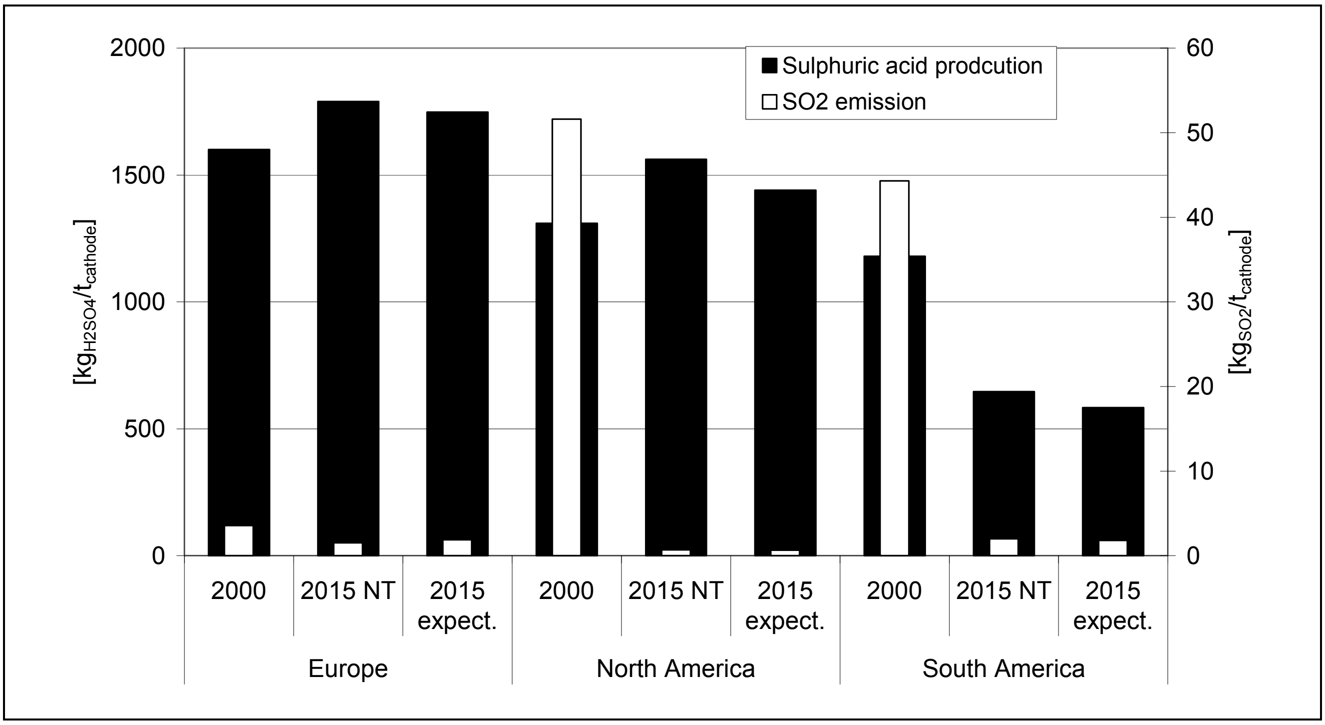

Figure 9: Emitted SO_2 and net sulphuric acid production for the different regions

As can be expected the capture of SO_2 in Europe in 2000 is already quite high. For the year 2015 it is assumed that sulphuric acid plants will be installed in all regions. Therefore, the acid production will increase. The reduction in net H_2SO_4 production is due to an increase of hydrometallurgical cathode production that needs sulphuric acid as an input.

6. Summary and conclusion

In order to reduce the complexity of real Copper production this paper has selected exemplary the production of Copper cathodes in Europe, South America and North America. The method of technical progress for the cathode production has been introduced, giving detailed description of expected technical progress on the process level until the year 2015. The approach followed the modelling concept of a process chain analysis. The process chain for Copper production was developed and modelled using both industrial and literature data. Modelling was performed using the unit processes as smallest process chain part. Three regions Europe, North America and South America were defined. With the collected data 84 % of Copper production in Europe was covered for year 2000 whereas for North America 75 % were reached respectively 64 % for South America. Using a scenario approach and differentiating between the maximum and predicted technical potential the impacts of the implementation of modern technical concepts on resource use and emissions were quantified. Three cases were defined. First case was the reference year 2000 showing the domestic market supply for Copper in the three regions. In a second case the maximum technical potential through full capacity replacement has been calculated considering the exclusive application of newest technology for each process of the 2000 structure. In a third case financial and market aspects were taken into account, which leads to a partial replacement respectively upgrading of the existing plants. Three out of the calculated parameters are presented. For primary energy Europe produced cathodes showed the best results and the highest reduction potential from 14 $GJ/t_{cathodes}$ in the reference year to 10 $GJ/t_{cathodes}$ in the year 2015. However, a reduction down to 12 $GJ/t_{cathodes}$ seems to be realistic. The energy demand for North and South America was significantly higher (16 resp. 17 $GJ/t_{cathodes}$). Accordingly, the reduction potential is lower. Both is related to the applied SX/EW technology. The same trend has been shown for CO_2 emissions as well as for SO_2 emissions.

However the principle functionality of the model has been shown. The calculated results are in the range of comparable studies. The reductions potentials for the three regions have been shown. Thus the model may be used in order to predict possible trends in Copper production as well as to demonstrate applications where the production may be influenced. Nevertheless the results must be treated carefully as several assumptions were made as well as certain data gaps exist, which leads to an uncertainty. Due to stopped financial support of the formerly funding organisation the future research work will be very limited.

7. References

[1] United Nations: Report of the World Summit on Sustainable Development. Johannesburg 2002

[2] Pearce, D.; Turner, R.: Economics of Natural Resources and the Environment. London, 1990

[3] Metal Statistics 1990-2000, 88th edition, 2001

Acknowledgement

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