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China and Global Markets: Copper Supply Chain Sustainable Development

A Life Cycle Assessment Study

Martin Streicher-Porte, Empa
Hans Jörg Althaus, Empa

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China and Global Markets: Copper Supply Chain Sustainable Development: A Life Cycle Assessment Study

Martin Streicher-Porte
Hans-Jörg Althaus
Empa—Materials Science and Technology
Technology and Society Laboratory
Lerchenfeldstrasse 5
CH-9014 St. Gallen, Switzerland
Phone +41 (0)71 274 74 74
Fax +41 (0)71 274 74 62
Martin.Streicher@empa.ch
Hans-Joerg.Althaus@empa.ch

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International Institute for Sustainable Development
161 Portage Avenue East, 6th Floor
Winnipeg, Manitoba
Canada R3B 0Y4
Tel: +1 (204) 958–7700
Fax: +1 (204) 958–7710
Email: info@iisd.ca
Website: www.iisd.org

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Abstract

Chinese production of copper cathodes depends largely on imports of copper concentrates, copper scrap or other intermediate copper products, because the natural occurrence of copper in China can not satisfy the demand. In this study, the environmental impacts of the global copper supply chain of copper cathodes produced in China were assessed. A Life Cycle Assessment of copper cathodes produced in China from primary resources (22.9 per cent), cathodes produced globally from primary resources and imported to China (12.7 per cent), cathodes produced in China from secondary resources (18.6 per cent), and cathodes produced in China with imported concentrates (45.8 per cent) was conducted. The percentages given in brackets represent the share of the production mix that was assumed for this assessment. A sample of 15 mines, 15 smelters and 15 refineries was collected and grouped according to the technology applied. The sample covers more than 30 per cent, 80 per cent and 70 per cent of each category, respectively, of the Chinese production. Data for copper-cathode production in other global regions and the global average were used to compare the impacts.

The results show that the environmental impacts of the Chinese production mix for copper cathodes are lower than the world average and lower than production in Indonesia, Latin America and other Asian and Pacific regions. The results are in the range of North American impacts, but are higher than those surrounding European production. The reasons for this are mainly (1) usage of a lower grade copper ore in China than in Europe, (2) prevalence of a Chinese electricity mix of an almost 100 per cent fossil fuel footprint, and (3) a relatively low share of secondary copper in the entire copper mix.

Mining can be improved by focusing on higher grade material, environmental abatement techniques and environmental restoration of processing sites. The smelter and refinery standards are relatively good and can be improved by consequent phase-out of old fashioned technologies. A comprehensive collection and pre-treatment of copper-containing products could increase the share and quality of copper-cathode production from secondary resources.

The results were tested with five different Life Cycle Impact Assessment methods, which showed relatively large variations in the impact results. The chosen default evaluation method was Eco-indicator 99 in the Hierarchist perspective, which lies in the middle of all Life Cycle Impact Assessment results.

List of Acronyms

CSCSD	Copper Supply Chain Sustainable Development
EI99	Eco-indicator 99
EMPA	Swiss Federal Institute for Materials Testing and Research
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCIA	Life Cycle Inventory Assessment
LCI	Life Cycle Inventory
LME	London Metal Exchange
SX-EW	solvent extraction/electrowinning process

Table of Contents

Acknowledgements ii

Abstract iii

List of Acronyms iv

1.0 Introduction 1

- 1.1 Goals of the Commodity Chain Sustainability Analysis 1
- 1.2 Chinese Copper Market 2

2.0 General Approach / Life Cycle Assessment Method 6

- 2.1 General Approach 6
- 2.2 LCA Method 7
  - *2.2.1 ISO 14040 and Chinese LCA Standards 7*
  - *2.2.2 Supporting Modelling Tools 9*
  - *2.2.3 Inventory Analysis 9*
  - *2.2.4 Impact Assessment Method 9*

3.0 Life Cycle Assessment of Chinese Copper Production 12

- 3.1 Goal and Scope Definition 12
  - *3.1.1 Functional Unit 12*
  - *3.1.2 System Characterization 12*
  - *3.1.3 System Borders 14*
  - *3.1.4 Allocation 15*
- 3.2 Inventory Analysis 15
  - *3.2.1 Chinese Mines, Smelters and Refineries 16*
    - *3.2.1.1 Chinese Copper Mines 16*
    - *3.2.1.2 Chinese Copper Smelters 18*
    - *3.2.1.3 Chinese Copper Refineries 20*
  - *3.2.2 Copper Scrap Recycling in China 21*
  - *3.2.3 Technology Mix 23*
  - *3.2.4 Transport 25*
- 3.3 Impact Assessment 26
  - *3.3.1 Environmental Impacts of Production Technologies in China 26*

3.3.1.1 Primary Production *26*

3.3.1.2 Primary and Secondary Production *28*

3.3.1.3 Detailed Impacts of Mining Processes *30*

3.3.2 Comparison of Environmental Impacts with Different LCIA Methods *32*

4.0 Conclusions and Implications for Policy Recommendations 36

5.0 References 38

6.0 Appendix 43

6.1 List of Chinese Mines, Smelters and Refineries 43

6.2 Schematic Representation of the Consumer Mix of Copper in Europe 45

6.3 Detailed Environmental Impacts, Cu-Cathode Primary Production 46

6.4 Contribution Analysis of Mining and Beneficiation 47

6.5 Short Descriptions of Common Life Cycle Impact Assessment Methodologies 47

6.5.1 Eco-Indicator 99 .... *47*

6.5.2 CML 2001 .... *48*

6.5.3 Ecological Scarcity 1997 .... *48*

6.5.4 IPCC 2001 (Climate Change) *49*

6.5.5 Cumulative Energy Demand *50*

List of Tables

Table 3.1 Overview of Cu-cathode consumption and production in China from 2000–2009. Assumed production shares of five production routes used in this study shown in last column. 13

Table 3.2 Coverage of mines, smelters and refineries investigated in this study as percentage of the entire Chinese production. Reported industry data in ktons of copper content in the output of each process (mines->concentrate; smelter->anodes, refineries ->cathodes). 17

Table 3.3 Chinese mines included in this study. 17

Table 3.4 Average ore grade and content of co-produced metals........ 18

Table 3.5 Chinese smelters. 19

Table 3.6 Worldwide use of particular smelting technologies and the corresponding use in China in 2008 (of this sample). 20

Table 3.7 Chinese refineries. 21

Table 3.8 Primary and secondary Cu-cathode production in China between 2000 and 2014 (unit: Cu-kt/%). 22

Table 3.9 Analysis of old scrap generation in China from 2010 to 2015 (unit: kt-Cu). 23

Table 3.10 Share of each process contributing to the functional unit 1kg Cu-cathode. 24

Table 3.11 Origin of Cu-concentrate, secondary copper and Cu-cathodes, average transport distances and the ton-kilometres used in this assessment. 26

Table 3.12 Main contribution to the environmental impact of mining and beneficiation (global mix) of individual substances or processes; results are shown ranked (biggest above) in Eco-indicator 99 points. 32

Table 6.1 List of mines included in the calculation. 43

Table 6.2 List of smelters included in the calculation. 44

Table 6.3 List of refineries included in the calculation. 44

List of Figures

Figure 1.1 Global copper mine production, smelter production and refinery production in 2005. Values are given in million tons of copper in output material. Share of the refinery production of different countries in percentiles (pie chart). 3

Figure 1.2 Chinese capacities of copper mines, smelters and refineries. 4

Figure 1.3 Chinese Copper consumption (historical data and forecast) and Chinese copper production. 5

Figure 2.1 Overview of processes considered in this study. The colour code highlights which data were collected specifically for this study, which were collected from literature sources, and which were available at the ecoinvent database. 7

Figure 2.2 The different steps of a Life Cycle Assessment study according to the ISO technical standard 14040. 8

Figure 2.3 General representation of the methodology. The white boxes refer to intermediate results; the coloured boxes refer to procedures (for more, see http://www.pre.nl/eco-indicator99/eco-indicator_99_introduction.htm). 11

Figure 3.1 Schematic representation of the production routes of one kilogram of Cu-cathode investigated in this study. CN = China; GLO = global. 14

Figure 3.2 Copper prices. LME = London Metal Exchange. 15

Figure 3.3 Generic input-output chart for primary and secondary copper smelting. 25

Figure 3.4 Environmental impacts in Eco-indicator 99 points for all primary producing technologies and averaged for different global regions. The results show the impacts of each technology producing 1kg Cu-cathode with primary production............................27

Figure 3.5 Impacts of each of the five process steps for each technology, primary and secondary production. 29

Figure 3.6 Relative impacts of each of the five process steps for each technology, primary and secondary production. 29

Figure 3.7 Environmental impacts in Eco-indicator 99 points for mining processes including beneficiation. The results are shown in details and, at the same time, grouped according to the impact categories Human Health (orange), Ecosystem Quality (blue) and Resource Depletion (grey)..31

Figure 3.8 Comparison of Chinese and European LCIA results with the four different impact evaluation methods. From the CLM evaluation methods, the two indicators "Abiotic depletion" and "Acidification potential" were used. Impacts from both primary and secondary production are included..33

Figure 3.9 Comparison of the LCIA results for each technology or process contribution to the production of 1kg Cu-cathode in China. Transports, secondary and primary production are shown, both in China and Europe. The sum of the production/process mix for China is compared to the European average. For comparability, all results are normalized on the European average. 35

Figure 6.1 Schematic representation of the consumer mix of copper in Europe in ecoinvent. As a proxy for Europe, the consumption pattern for Germany in 1994 is chosen. 45

Figure 6.2 Environmental impacts in detailed impact categories in Eco-indicator 99 points. The results show the impacts of each technology producing 1kg Cu-cathode with primary production. 46

Figure 6.3 Contribution analysis of mining and beneficiation processes in the Asia and Pacific regions...47

1.0 Introduction

Within the project "China and Global Markets: Copper Supply Chain Sustainable Development" (CSCSD), the environmental impacts of Chinese copper production are evaluated by a Life Cycle Impact Assessment (LCIA). This report summarizes the methodology, documents the data collection and compilation of a Life Cycle Inventory (LCI), and presents the results of the Life Cycle Assessment (LCA). The overall goal of the CSCSD is to produce a set of recommendations to ensure long-term sustainability of the global copper supply chains.

China suffers from a lack of natural deposits of copper, despite its richness in other base or special metals. For some years, the growing demand of copper in China has not been met by Chinese primary production. Both the national consumption of copper and the demand of copper in the manufacturing industries have shown strong increases over the last decades.

In 2006 China was the worldwide second biggest importer of copper ores and concentrates (after Japan), and the third biggest importer of refined copper (after the United States and Germany). Half products or semis (sheets, strips, bars, tubes, rods, coils, foils and so forth) or finished products (sectors such as power infrastructure, consumer appliances, building and construction materials, and automotive and transport materials) are produced, to a large extent, in China. Also in 2006, China ranked number one worldwide as importer of semi-fabricated copper products and number two worldwide as exporter of such products, after Germany (Atherton, 2009).

Due to the above mentioned reasons, China is a net importer of copper. Imported are an entire range of materials (ore, concentrates), substances (refined copper), half products and, increasingly, copper-containing waste material (copper scrap, automotive scrap or waste electrical and electronic equipment). China is today an important part of the global value chain of copper-containing products. At the same time, it depends strongly on the supply of copper ore, concentrates or refined copper from abroad.

In order to strategically plan and improve the copper supply, the environmental impacts of each production step are analyzed. Particularly, the use of energy, emission of greenhouse gases, and water use are considered.

1.1 Goals of the Commodity Chain Sustainability Analysis

The goal of the entire project was formulated in the International Institute for Sustainable Development's document, "China and Global Copper Markets: A Framework for Global Commodity Chain Sustainability Analysis":

> The research project seeks to produce a set of recommendations on ways in which [Ministry of Commerce and Trade] MOFCOM and other branches of the Chinese government can work to ensure the long-term sustainability of its global copper supply chains. Given the strong role of global markets in determining the sustainability of supply chains, the project places significant emphasis on trade and market relationships in determining the most effective means to attaining the desired outcomes—hence the application of the Global Commodity Chain Sustainability Analysis. The purpose of the research is to provide a robust and practical set of recommendations for building global supply chain and trade sustainability. A key objective of the China and Global Markets project is its emphasis on seeking shared solutions—namely, solutions that involve coordination and cooperation with foreign governments and international supply chain actors—as a reflection of the shared responsibility that exists for global trade and supply chains.

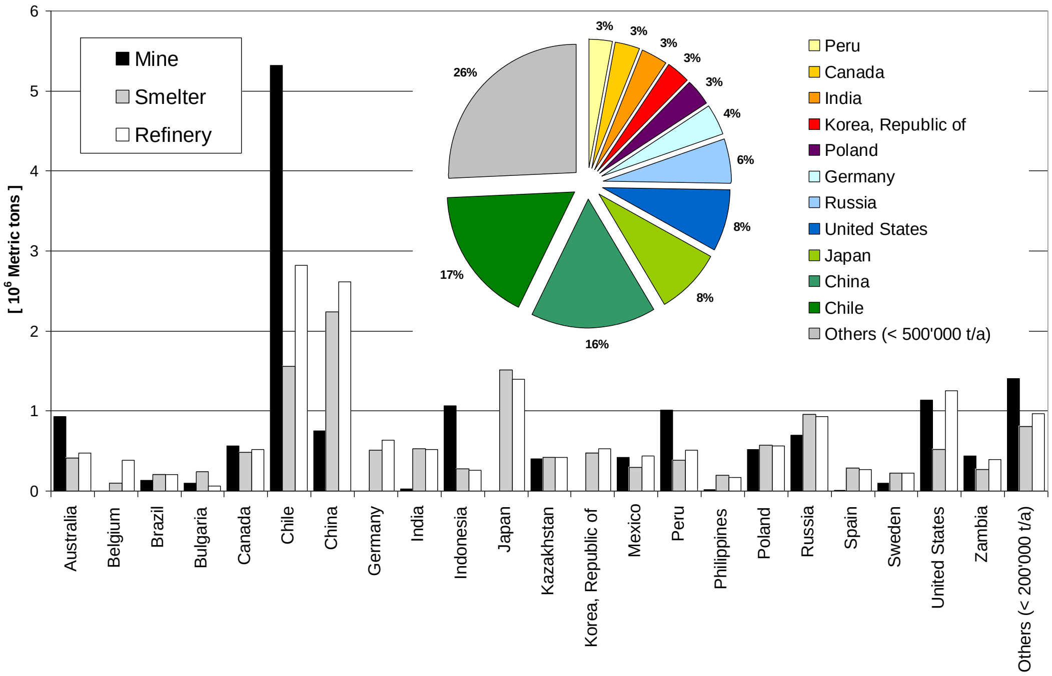
In Section 2.0 of this paper, the general approach and the LCA methodology is introduced. Section 3.0 consists of the detailed results of the LCA, including the definitions of goal and scope, inventory analysis, impact assessment and interpretation, along with key environmental impacts. This is followed by interpretation and discussion of the results in Section 4.0. The consequences of the LCA, with respect to the formulation of policy recommendations, are included in Section 4.0.

1.2 Chinese Copper Market

China does not play as much of an important role when it comes to mining copper ores as, for example, Chile—by far the world leader in mining—and countries such as the United States, Indonesia, Peru and Australia. In contrast, for copper refineries and even more so for smelters, China is one of the leading nations in terms of annual production (see Figure 1.1).

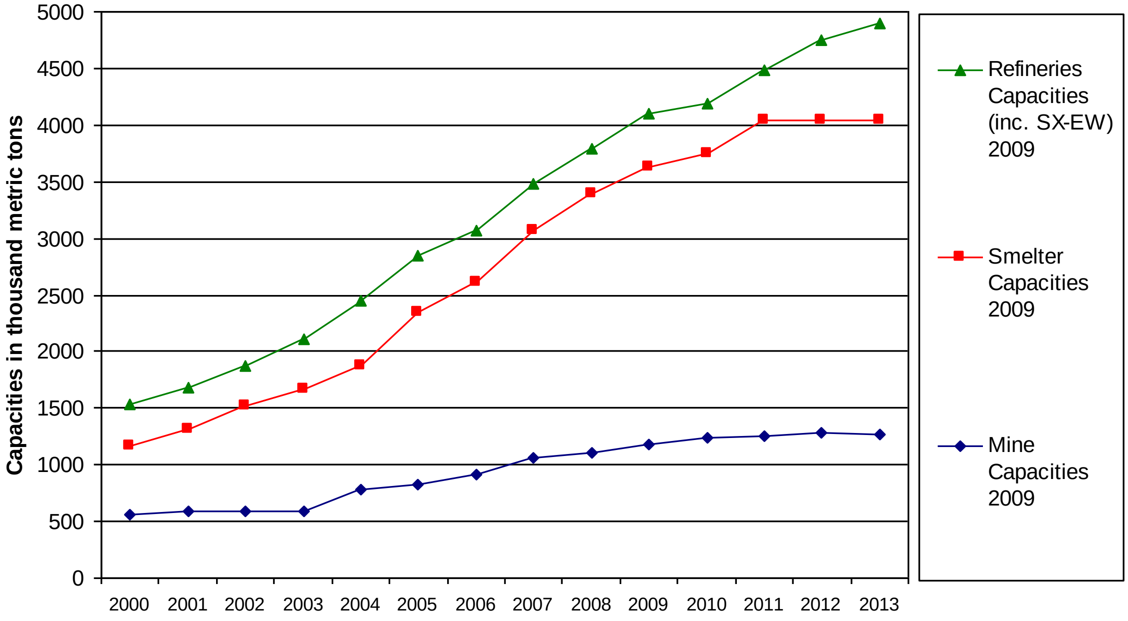
This situation has to do with recent developments in the Chinese copper market. Since 2000 the capacities for smelters and refineries have increased substantially. At the same time, the mine capacities increased, albeit not at the same rate as smelters and refineries (see Figure 1.2). The large gap between the capacities and the actual extraction of copper ore in China is compensated by large trade volumes (net imports) of copper concentrates, copper matte, refined copper or half products.

Figure 1.1 Global copper mine production, smelter production and refinery production in 2005. Values are given in million tons of copper in output material. Share of the refinery production of different countries in percentiles (pie chart).



Source of data: United States Geological Survey (USGS), 2005; source of illustration: Eugster, 2008.

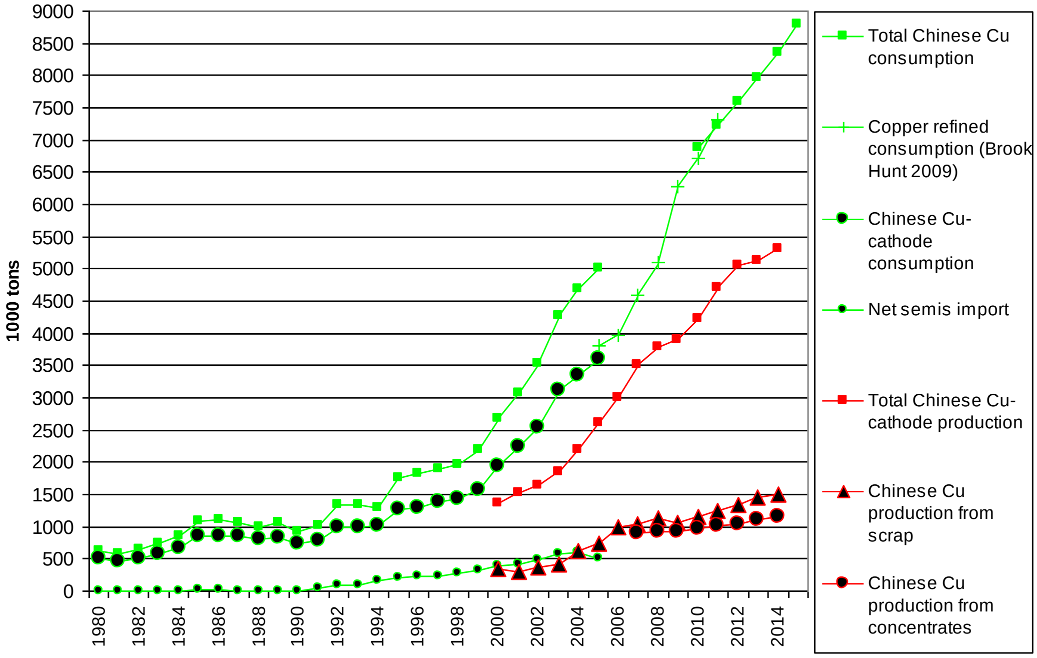
Figure 1.2 Chinese capacities of copper mines, smelters and refineries.



Source: International Copper Study Group (ICSG), 2009.

Copper is imported into China in all different forms. This can be seen by comparing the Chinese copper consumption and the Chinese copper production shown in Figure 1.3. The national production does not meet the national demand. Therefore, large imports of semis and half products (e.g., for the building sector) and components (e.g., for the electronic sector) occur. It is forecasted that until 2014, this tendency will be accentuated (see Figure 1.3). The re-export of copper, contained in finished products, is represented by the annual gap between national production and consumption.

Figure 1.3 Chinese Copper consumption (historical data and forecast) and Chinese copper production.



Source: Beijing General Research Institute of Mining & Metallurgy (BGRIMM), 2009a; BGRIMM, 2009b; Brook Hunt, 2009.

2.0 General Approach / Life Cycle Assessment Method

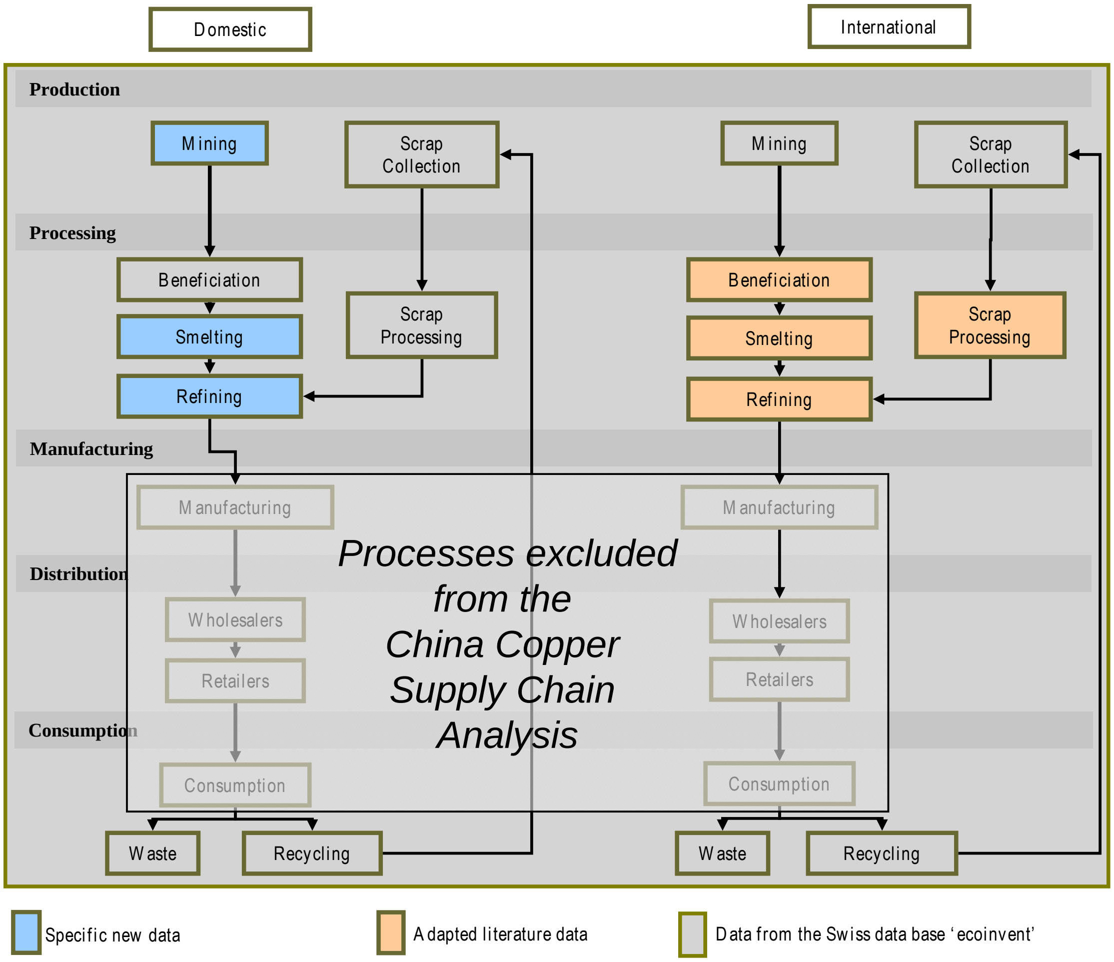
2.1 General Approach

The key objective of the environmental assessment of Chinese copper production is to assess the global environmental impacts of copper production, as well as the relative importance of specific stages over the supply chain. Therefore, the key question is: What are the main environmental impacts from the production chain of copper in China?

In order to assess the environmental impacts, a compilation of an LCI of Chinese copper production had to be established. Combining these specific LCI datasets with existing datasets of the ecoinvent database, Version 2.01 (ecoinvent, 2007), allowed an LCIA of a specific functional unit.

Because Chinese copper production is highly connected to a world market of ores, concentrates, scrap, electrolyte copper or half products, international and national production paths had to be considered. Figure 2.1 gives an overview of the processes that were decided upon by a first expert group meeting, to be included in this study. The colours highlight the origin of their data. Blue processes were assessed specifically for this study; data of orange processes were taken from literature sources. The grey area indicates all processes represented in the ecoinvent database.

Figure 2.1 Overview of processes considered in this study. The colour code highlights which data were collected specifically for this study, which were collected from literature sources, and which were available at the ecoinvent database.



2.2 LCA Method

2.2.1 *ISO 14040 and Chinese LCA Standards*

The environmental impacts of the product chain of copper production in China are quantified and interpreted using LCA methodology; according to the international standard ISO 14040 (ISO 14040, 1997; ISO 14040, 2006), the basic principle of this method, the following steps can be distinguished:

1. Defining the goal and scope of the study (step "A" in Figure 2.2);
2. Making a model of the product life cycle with all environmentally relevant inflows and

outflows. This data collection effort is usually referred to as the LCI phase (step "B" in Figure 2.2);

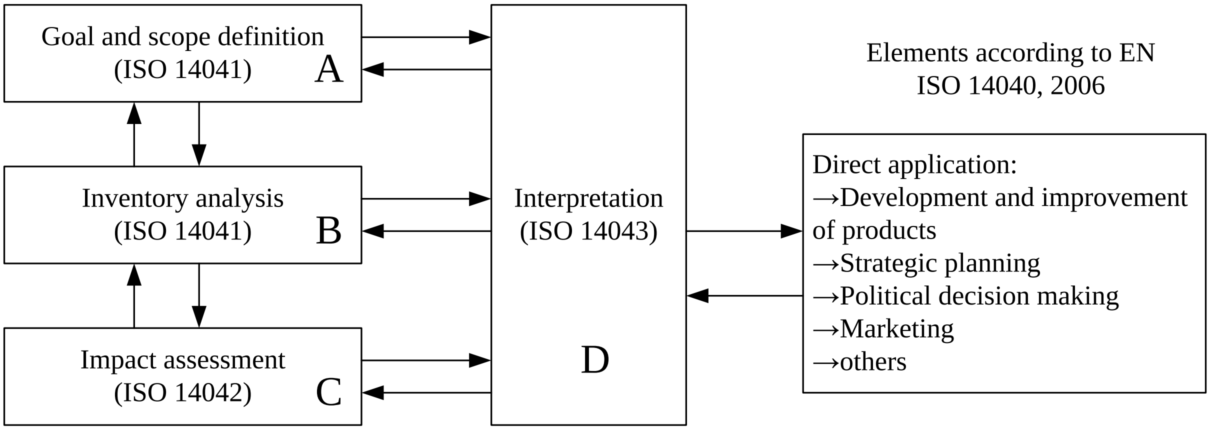
3. Understanding the environmental relevance of all inflows and outflows; this is referred to as the LCIA phase (step "C" in Figure 2.2); and
4. Interpreting the results of the study (step "D" in Figure 2.2).

The priority and logical relation among the stages are showed in the following chart. Figure 2.2 shows how these different steps are linked together and emphasizes the iterative characteristic of the LCA approach.

In China, the State Environmental Protection Administration (SEPA) drafted and issued national standards for LCA in line with the ISO standard system, ISO/EN 14042 (2000):

- GB/T 24040-1999, identical to ISO 14040 (1997): Environmental Management—Life Cycle Assessment—Principles and Framework (SEPA, 1999);
- GB/T 24041-2000, identical to ISO 14040 (1997) (ISO 14040, 1997): Environmental Management—Life Cycle Assessment—Goal and Scope Definition and Inventory Analysis (SEPA, 2000);
- GB/T 24042-2002, identical to ISO 14042 (2006): Environmental Management—Life Cycle Assessment—Life Cycle Impact Assessment (SEPA, 2002); and
- GB/T 24042-2003, identical to ISO 14043 (2006): Environmental Management—Life Cycle Assessment—Interpretation (SEPA, 2003).

Figure 2.2 The different steps of a Life Cycle Assessment study according to the ISO technical standard 14040.



2.2.2 *Supporting Modelling Tools*

Within this study, the LCI and the LCIA analyses are carried out using the LCA software system SIMAPRO, Version 7.1, with the ecoinvent data, Version 2.01 (PRé Consultants, 1999).

2.2.3 *Inventory Analysis*

In the inventory phase, a model is made of the complex technical system that is used to mine and concentrate copper ore, reduce copper concentrate in a smelting process and refine copper in an electrolytic process. In addition, the processes of smelting and refining copper from scrap material are investigated. Thereby, for each process, all the relevant inflows and outflows are collected. New data are partly gathered in China within the scope of this project, or existing datasets from an inventory database are adapted or used directly. Details of the procedure can be found in Section 3.1, "Goal and Scope Definition."

2.2.4 *Impact Assessment Method*

An impact assessment method, the Eco-indicator 99, Hierarchist version (Goedkoop and Spriensma, 2000) is used here. In this method, the impact analysis categories analyzed are climate change (or global warming), resource consumption (including minerals and fossil fuels), respiratory effects, acidification and eutrophication, land use, carcinogens and ecotoxicity. Within this methodology, these categories are associated with three types of environmental damages:

1. *Human Health* (unit: DALY= Disability Adjusted Life Years; this means different disabilities caused by diseases are weighted);
2. *Ecosystem Quality* (unit: PDF*m^2*a; PDF= Potentially Disappeared Fraction of plant species); and
3. *Resources* (unit: MJ surplus energy; additional energy requirement to compensate lower future ore grade).

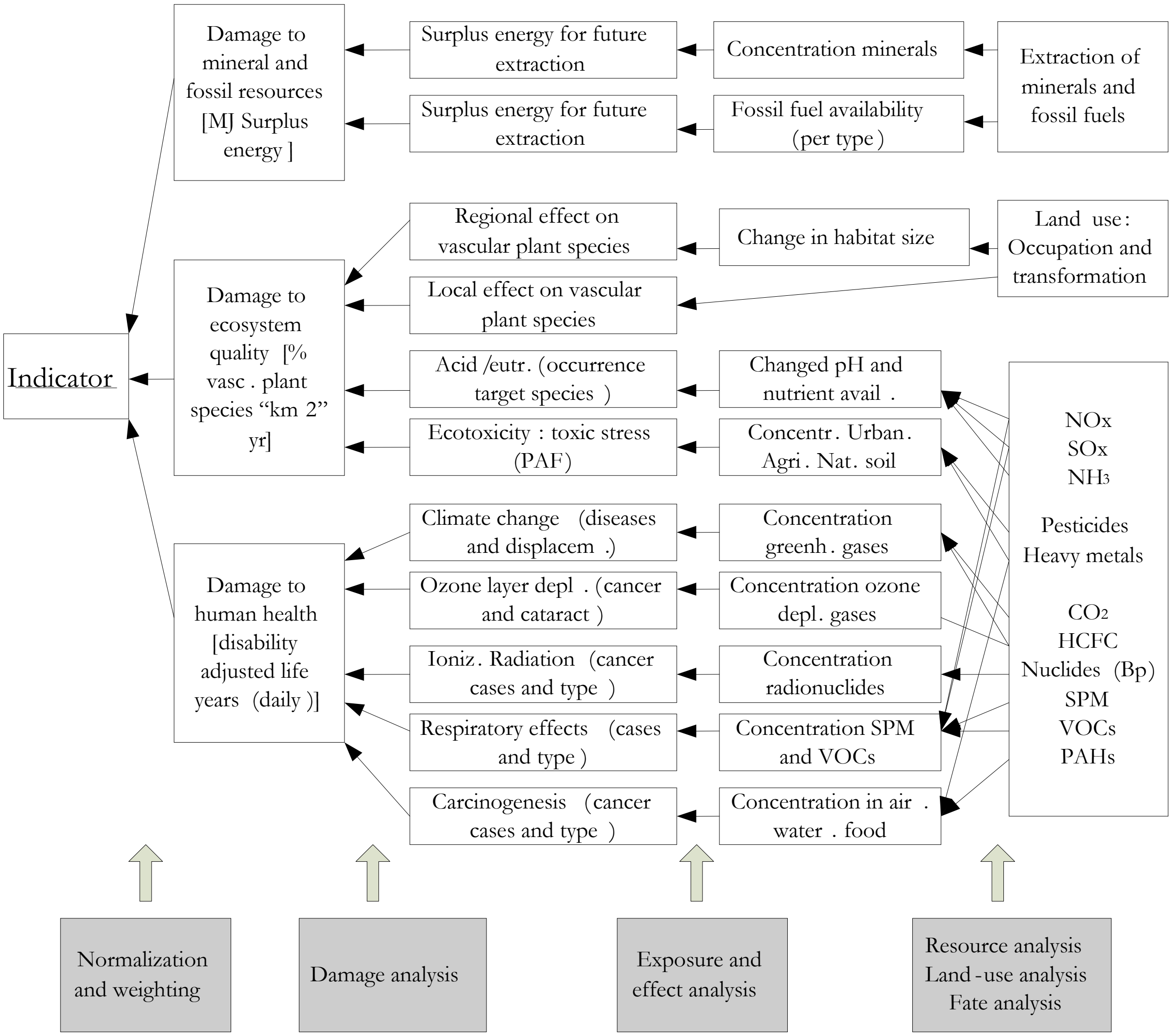
Normalization and weighting are performed at this damage category level (end-point level in ISO terminology). Figure 2.3 shows an overview of these various steps within the Eco-indicator 99 method.

The whole method is an example for the damage-oriented approach, referring to European conditions. But the proceedings that were introduced above allow for establishment of a technology mix that is tailor-made for the present Chinese copper production. Nonetheless, there is no specific LCIA method for China available; this method is used in this study.

In the sense of a sensitivity analysis of this chosen method, the main calculations also have been made with further, commonly used methods (i.e., CML'01; UBP'97; Cumulative Energy Demand, or CED; and Global Warming Potential, according to the Intergovernmental Panel on Climate Change, or IPCC). Brief descriptions of each evaluation method can be found in Section 6.5, "Short Descriptions of Common Life Cycle Impact Assessment Methodologies." Because these further methods don't end up in significantly different results, the report here shows, for the majority of the examined aspects, the results only with the Eco-indicator 99. The sensitivity of the other calculations is discussed in Section 3.3.2, "Comparison of Environmental Impacts with Different LCIA Methods."

The methodological procedure follows the pattern of a similar study on key environmental impacts of the Chinese electronic industry, conducted in 2007. Therefore, parts of Section 2.0 on the LCA methodology were taken from Hischier et al., 2007). Where it became necessary, the text was updated and adapted.

Figure 2.3 General representation of the methodology. The white boxes refer to intermediate results; the coloured boxes refer to procedures (for more, see http://www.pre.nl/eco-indicator99/eco-indicator_99_introduction.htm).



3.0 Life Cycle Assessment of Chinese Copper Production

3.1 Goal and Scope Definition

The overall goal of the study is to evaluate the environmental impacts of mining, concentrating, smelting and refining of copper from primary sources and collecting, smelting and refining of copper from secondary sources in China. Methodologically, this is done by conducting an LCA of Chinese copper production. More specifically, the method allows analysis of the main causes of the environmental impacts and, hence, allows policy-makers to deduce measures for improving the Chinese copper supply chain. The study is not an LCA in its strict sense, as some of the consumption processes of copper bearing products are excluded from this study. Therefore, this LCA is a "cradle to gate" rather than a "cradle to grave" study (see also Figure 2.1).

3.1.1 Functional Unit

The functional unit is one kilogram of copper cathode ("Cu-cathode") at regional storage in China. This Cu-cathode is electro-refined copper, at least equal or higher than the "grade A" quality standard of the London Metal Exchange. "Grade A" means copper of 99.99 per cent purity. Each step of the production chain has correspondingly one kilogram of output product as a functional unit (e.g., "Cu-concentrate" or "Cu-anode").

3.1.2 System Characterization

In the used Version 2.01 of the ecoinvent database, the coupled production of copper concentrate and molybdenite concentrate are inventoried for the regions Europe, Asia and Pacific, Latin America and the Caribbean, North America, and Indonesia, as well as globally. The region-specific data mainly acknowledges differences in ore quality or electricity supply mix but do not differentiate in differences of the technologies used in specific regions.

For China, no specific datasets for mines, smelters and refineries in China are yet available. In contrast to the existing datasets in ecoinvent, this study particularly focused on the existing technology park as well as the potential for technological improvement. Therefore, it became necessary to focus on the specific mix of technology for copper mining, smelting, refining and recycling processes prevailing in China. The following approach was chosen:

1. Samples of mining, smelting, refining and recycling enterprises were collected. A specific "Chinese copper producing technology mix" was established.

2. A “generic life cycle dataset” of copper mining, smelting, refining and recycling processes was created.
3. A generic flow chart of one kilogram of Cu-cathode produced in China was created. A sketch of this can be seen in Figure 3.1, highlighting the individual inputs from following production routes:
    - Cu-cathode produced in China from primary resources;
    - Cu-cathode produced globally from primary resources, imported to China;
    - Cu-cathode produced in China from secondary resources; and
    - Cu-cathode produced in China with imported concentrates.
4. By combining the “Chinese copper producing technology mix” with the “generic life cycle dataset,” the specific resource consumption and environmental emissions of the functional unit were calculated.
5. Lastly, the environmental impacts were evaluated and interpreted.

The share of each production route to one kilogram of Cu-cathode produced in China can be found in Table 3.1. These numbers were used to calculate the environmental impacts of the functional unit. Because the production of Chinese Cu-concentrates over the last four years (see Table 3.8, lines 3 and 4) was not higher than 30 per cent of the entire Chinese Cu-cathode production in the same years (see Table 3.1), it was assumed that one-third of the Chinese Cu-cathode production originates from Chinese concentrates and two-thirds from imported concentrates. This explains the numbers of 22.9 per cent for concentrates from China and 45.8 per cent for concentrates from imports in Figure 3.1.

The specific technology mix for primary produced Cu-cathodes in China, the mix of secondary resources in China and the allocation values are explained below in Section 3.2, “Inventory Analysis.”

Table 3.1 Overview of Cu-cathode consumption and production in China from 2000–2009. Assumed production shares of five production routes used in this study shown in last column.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average	Average used in this study
Chinese Cu-cathode consumption	1944	2242	2544	3109	3350	*3815*	*3967*	*4600*	*5100*	*6273*		
Chinese Cu-cathode production	1371	1523	1633	1836	2199	2600	3003	3499	3795	4110		
% of entire Chinese Cu-cathode consumption	71%	68%	64%	59%	66%	68%	76%	76%	74%	66%	68.7%	
% of Cu-cathode production from Chinese ore												**22.9%**
% of Cu-cathode production from 'global' ore												**45.8%**
China’s Secondary refinery production	348	307	380	426	620	744	999	1050	1139	1060		
% of entire Chinese Cu-cathode consumption	18%	14%	15%	14%	19%	20%	25%	23%	22%	17%	18.55%	
% of Cu-cathode from promt scrap												**9.3%**
% of Cu-cathode from promt scrap												**9.3%**
Imports of Cu-cathodes	225	412	531	847	531	471	-35	51	166	1104		
% of entire Chinese Cu-cathode consumption	12%	18%	21%	27%	16%	12%	-1%	1%	3%	18%	12.73%	**12.7%**

Source: BGRIMM, 2009a; BGRIMM, 2009b; Brook Hunt, 2009.

Figure 3.1 Schematic representation of the production routes of one kilogram of Cu-cathode investigated in this study. CN = China; GLO = global.

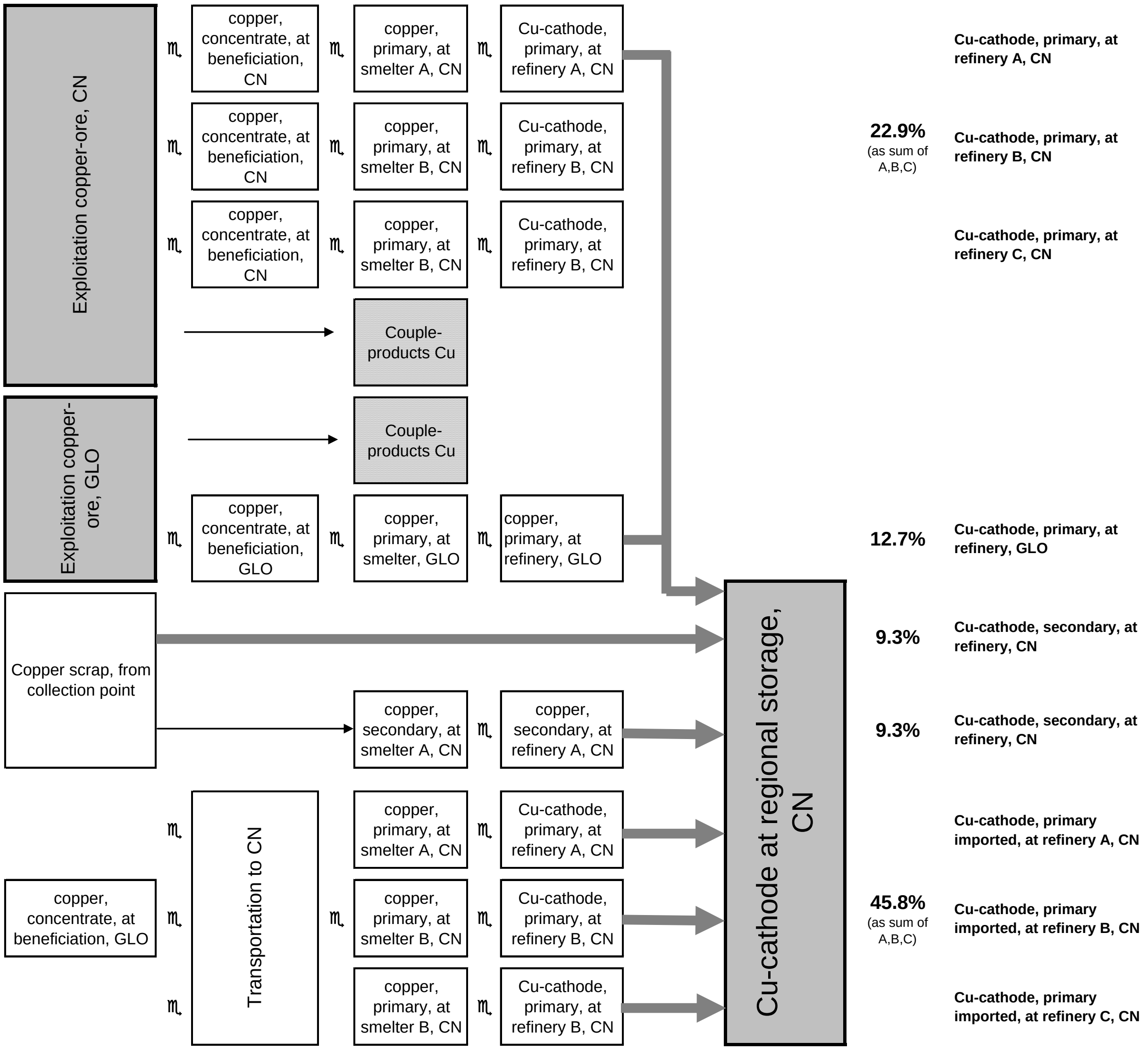


Figure 6.1 in the Appendix shows the schematic representation of the copper datasets in the ecoinvent database, in comparison to Figure 3.1 (Classen et al., 2009). It can be seen that this study's emphasis lies upon different technologies within China.

3.1.3 *System Borders*

The geographic system border is the People's Republic of China.

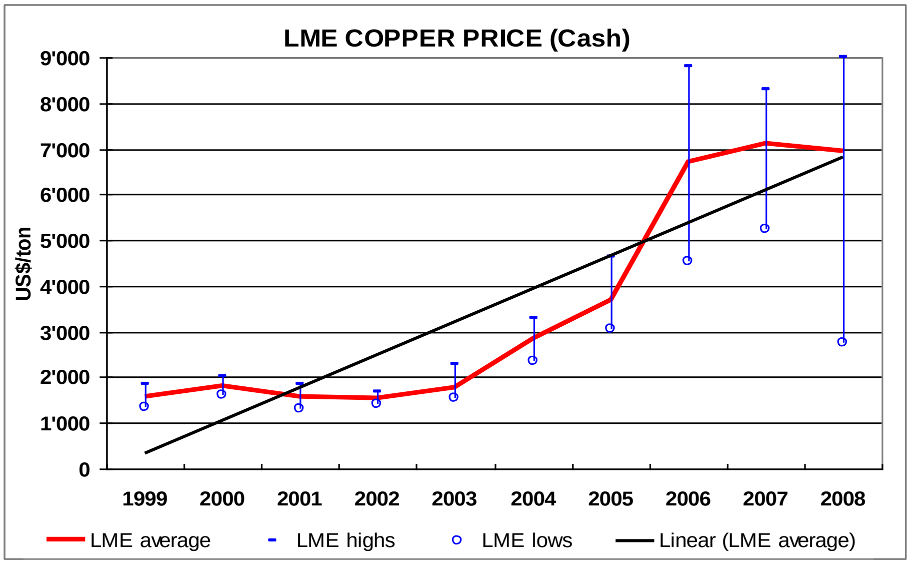
3.1.4 *Allocation*

Because several metals are co-products of copper mining activities, an allocation of the environmental burden is necessary. Due to the large diversity of metals contained in copper ore, the impacts are allocated according to the market value of the metal. In this study, only gold and silver are considered by-products. The details of the allocation values are discussed in Section 0,"Chinese Copper Mines." This procedure is also applied in the ecoinvent Version 2.01. In reverse, copper is also produced as a by-product from mining of other metals. But due to the budgetary and time constraints of this study, this supply path was not accounted for.

3.2 Inventory Analysis

High copper prices between 2006 and 2008 (see Figure 3.3) have boosted the technological renovation of the copper smelting and refining sector. But many of the inventory data have been collected before this time. More specific, up-to-date technology or country data are not yet available. Therefore, some emission data dating before this period should be considered as upper limit.

Figure 3.2 Copper prices. LME = London Metal Exchange.



Source: ICSG, 2007.

When reading the inventory data and the results, one has also to consider that many industry data are reported as "given values" of the manufactures of smelters or other machinery. Actually measured input and output data are "reported industry data," which generally are collected by national metals association or by ministries. Such "reported industry data" can deviate from "given values” considerably, depending on factors such as maintenance, actual processing hours, feed material and others. The data on mines and smelters and refineries are “reported industry data” and have been collected by the Beijing General Research Institute of Mining and Metals (BGRIMM). Data on smelting technologies were provided by the German Copper Institute (Deutsches Kupferinstitut, or DKI) and several literature resources. DKI data are “reported industry data” from the year 2000. They are only net input–output data and do not account for reverse flows of slag, filter ashes, dusts, sludge, sweepings and other production waste of individual processing steps.

3.2.1 *Chinese Mines, Smelters and Refineries*

The samples of mines, smelters and refineries investigated in this study cover different shares of the total Chinese production. Table 3.2 lists the actual production volumes for each production cluster (mining, smelting, refining) over four consecutive years. The share is calculated as a percentage of entire Chinese production and ranges, for mines, between 32 and 36 per cent; for smelters, between 80 and 82 per cent; and for refineries, between 67 and 70 per cent.

3.2.1.1 Chinese Copper Mines

In China, most copper mines employ underground mining, accounting for 70–80 per cent of copper minerals mined. Only seven mines operate open-pit mining, accounting for 10–20 per cent of mined minerals, and about 2 per cent of minerals are processed with in-situ leaching (solvent extraction/electrowinning process, or SX–EW) (BGRIMM, 2010). Dexing copper mine is the biggest mine and, at the same time, also the biggest open-pit mine in China (see Table 3.3).

In contrast, worldwide 65 per cent of the copper minerals are mined open-pit, whereas the smaller portion is mined underground. The world average of 10 per cent in-situ leaching (SX–EW) is higher than the corresponding usage of this technology in China (Krauss, 1999).

Table 3.3 lists the mines included in this analysis. They account for 32–36 per cent of the total Chinese copper mineral production. The capacities are shown for 2008, the actual production for four consecutive years (2006–2009). Also, the specification of type of mine, quality of ore and average copper content in dry ore is given.

The average ore grade of the investigated mines is slightly higher than the range published for all of China (average for 2006–2008: 0.85 per cent of copper in dry ore; source: China Non-Ferrous Metal Industry statistics). For this study, an average ore grade of the sampled mines with 0.90 per cent of copper in dry ore was used.

Table 3.2 Coverage of mines, smelters and refineries investigated in this study as percentage of the entire Chinese production. Reported industry data in ktons of copper content in the output of each process (mines ->concentrate; smelter->anodes, refineries->cathodes).

	2006	2007	2008	2009 (estimates)
Mines production (this study)*	305	330	348	346
Mines production (entire China)**	873	928	1076	961
% entire China	**35%**	**36%**	**32%**	**36%**
Smelter production (this study)*	1563	1684	1966	2250
Smelters production (entire China)**	1918	2112	2453	2739
% entire China	**82%**	**80%**	**80%**	**82%**
Refinery production (this study)*	2022	2386	2660	2860
Refinery production (entire China)**	3003	3499	3795	4110
% entire China	**67%**	**68%**	**70%**	**70%**

Source for this study: BGRIMM, 2010; source for entire China: ICSG, 2009; BGRIMM, 2010.

Table 3.3 Chinese mines included in this study.

Mine capacities and actual production	**Main output material**	**Mining capacities**	**Actual production Production in kt-Cu metal/year**				**Type of mine operation**			**Quality of ore**		**Average copper content in ore**	
		2008	2006	2007	2008	2009 (e)	Under-ground	Open-cut mining	SX-EW In-situ leaching	Sulfidic	Non sulfidic	Minimal value	Maximal value
Dexing	Concentrates	100ktpd	107	113	116	125		x		x		0.38	0.51
Yongping	Concentrates	10ktpd	19	19	20	20	x	x		x		0.69	0.71
Huogeqi	Concentrates	7kpd	21	20	22	19	x			x		1.20	1.61
Dongguashan	Concentrates	10kpd	15	22	28	32	x			x		1.09	1.20
Tongkuangyu Copper mine	Concentrates	20kpd	20	20	20		x			x		0.49	0.58
Ashele	Concentrates	4ktd	30	28	29	30	x			x		0.24	0.26
Dahongshan	Concentrates	15ktpd	21	27	33	35	x			x			
Lala Copper	Concentrates	15ktpd	20	27	26	30		x		x		0.66	0.76
Chengmenshan	Concentrates	2ktpd	6	6	6	6		x		x		0.74	0.82
Wunuketushan Mine	Concentrates	30ktpd (started production end of 2009						x		x		0.42	0.56
Daye Tonglushan Copper mine	Concentrates	4ktpd	9	10	10	10	x			x		1.41	1.78
Dexing SX-EW plants	Cathode	2ktpa	2	2	2	2			x	x			
Anqing Copper Mine	Concentrates	3.5ktpd	8	9	9	10				x		1.05	1.05
Dongchuan	Concentrates	7.5ktpd	20	20	20	20	x			x		0.81	1.29
Hongtoushan Copper Mine	Concentrates	2ktpd	8	8	8	8	x			x		1.5	1.7
Sum			**305**	**330**	**348**	**346**						0.82	0.99
% of entire China			**35%**	**36%**	**32%**	**36%**							
			2006	2007	2008	2009							
Entire China		**107300 ktpa**	**873**	**928**	**1076**	**961**	70~80%						
		SX-EW production kt	16.1	18.1	16.6	18.9							

Source: BGRIMM, 2010.

All mines investigated in this study recover reagents, process water and have dammed lakes for tailings and slag. But only 27 per cent (in terms of number) or 53 per cent (in terms of production volume) of the mines have invested in the ecological rehabilitation of the land transformed during their mining activities. Details of the mine survey data can be found in the Appendix (Table 6.1).

Gold and silver were considered as co-produced metals with the average concentrations given in

Table 3.4. Both co-produced metals are separated in the anode slime of the final processing step—the electrowinning process. The environmental impacts of all production steps until the electrowinning process are therefore allocated according to the factors given in Table 3.4. The market values are average prices for the pure metals for the years 2004–2006 according to the London Metal Exchange. This period was taken as reference years, in order to be consistent with data used in ecoinvent 2.01 for the global average of mining products. In other words, only 38 per cent of the environmental impacts of winning copper from Chinese mines are allocated to copper itself; 41 per cent of the impacts are burdened onto gold and 21 per cent onto silver.

3.2.1.2 Chinese Copper Smelters

Chinese smelters focus either on primary or on secondary input materials; mixing of inputs is not very common (BGRIMM, 2010). Table 3.5 lists the 15 major smelters (in production volume) in China that were investigated in this study. Because this sample covers more than 80 per cent (of production volume) of all copper smelters in China, the smelter mix of the sample was taken as an approximation of the average Chinese smelters mix.

Table 3.4 Average ore grade and content of co-produced metals.

	Average (% Cu) min	Average (% Cu) max	Average assumed for allocation (gram/ton)	Average value ($/kilogram)	Average value in ore	Allocation factor
Cooper	0.82	0.99	900.00	4.475	4028	38%
Gold			0.286	15624	4461	41%
Silver			8.074	273.6	2209	21%

Source: BGRIMM, 2010; China Non-Ferrous Metal Industry statistics.

Table 3.5 Chinese smelters.

Smelter capacities and actual production	Process applied	Capacities	Actual productionin ktons/year			
		2008	2006	2007	2008	2009 (e)
Guixi (smelter)	Old flash smelting-converter-andoe refining	300	300	300	300	300
	New Flash smelting-converter-andoe refining (since 2007)	200		29	177	146
Jinchuan (smelter)	Composite smelting-converter-anode	350	258	314	290	380
Yunnan Copper	Isasmelting-converter-anode furnace	200	186	208	192	210
Jinlong (Tongdu)	Flash Smelting-converter-anode	350	209	250	280	330
Daye/ Hubei	Noranda smelting- converter-anode refining	120	120	120	120	120
	Reverberatory-converter-anode, to be phased out in 2010	50	30	52	44	62
Shandong Fengxiang (smelter)	Outokumpu Flash smelting-flash convertering-anode furance	200			110	178
Jinchang (Tongling II)	Ausmelt smelting-converter-anode	180	150	150	150	180
Huludao	Blast smelting-converter-anode, stopped in 2009, Ausmelt smelter under construction	120	49	34	15	0
Baiyin (smelter)	Baiyin furnace (similar to Noranda)-converter-anode refining	100	78	78	81	82
Jinfeng	Jinfeng furnace (similar to Vanukov furnace)-converter-anode refining	100	26	0	36	75
Kangxi (Liangshan)	Blast Furnace, might stop production soon	35	20	27	22	25
Yantai Penghui	Side blowing bath smelting-converter-anode refininig	60	49	30	33	35
Fuchunjiang	Blast Furnace-converter-anode refining, might stop production in 2010/2011	80	36	34	35	35
Zhongtiaoshan (Houma)	Ausmelt smelting-Ausmelt converting -anode refining	70	53	56	56	62
Feishang	SKS smelting (bottom blowing)-converter-anode refining	60			25	30
Sum		**2'575**	**1563**	**1684**	**1966**	**2250**
% of entire China		**93%**	**82%**	**80%**	**80%**	**82%**
Entire China		**2778.5**	**1918**	**2112**	**2453**	**2739**

Source: BGRIMM, 2010.

The smelters covered in this study are all equipped with environmental technology, which is up to date. For air emissions coolers, fabric filters, hot electrostatic precipitators and cyclones are installed. Sulphuric acid plants recover emission of sulphur dioxide (SO_2) from smelting but as well from the conversion process, which is often linked to a smelter. Only older installations are lacking wet or semi-dry scrubbers of the off gases. Details of the survey data can be found in the Appendix (Table 6.2).

When comparing the Chinese smelter mix used in this study with the world average, one can see that China has advanced considerably in the renovation of its smelter park. The world average use of smelter installed and the corresponding Cu-blister production are listed in Table 3.6. The Chinese average use of a particular technology in 2008 is shown in the last column. The low percentage of Reverberatory furnaces used in China compared to their use in the world shows that the phase-out of this technology is successful. Both the composite smelter technology and the SKS process can be considered as "state-of-the-art" technologies, the latter being an invention from China utilizing oxidizing processes in the bottom blowing furnace and reducing smelting in the blast furnace.

Table 3.6 Worldwide use of particular smelting technologies and the corresponding use in China in 2008 (of this sample).

	Number of smelters using that technology (World)	Number of furnaces (World)	Blister production 1998 '000 t/yr (World)	**% of total blister production (World)**	**Average use of technology in 2008 (China, this sample)**
Outokumpu flash smelting	26	26	3801	**35%**	**36%**
Outokumpu flash smelting, direct blister	2	2	238	**2%**	
Reverberatory	27	37	1604	**15%**	**2%**
El Teniente reactor	7	12	1344	**12%**	
Ausmelt / ISA Smelt	11	13	1000	**9%**	**28%**
Elelctric furnance	6	8	560	**5%**	
Blast furnance	14	29	548	**5%**	**3%**
Mitsubishi process	4	4	497	**5%**	
INCO flash smelting	3	3	448	**4%**	
Vanuykov process	3	5	448	**4%**	**1%**
Noranda reactor & other bath smelters	2	2	197	**2%**	**10%**
Controp	1	1	116	**1%**	
Bayin process	1	1	57	**1%**	
Kivcet	1	1	15	**0%**	

Source: IPPC, 2009; BGRIMM, 2010.

To compare these techniques to the categories given, the composite smelter technology of the Jinchuan Corporation was categorized as an Ausmelt smelter, and the SKS smelter of Feishang Corporation was categorized as an Outocumpu flash smelter (Jiang, 2009).

3.2.1.3 Chinese Copper Refineries

In addition, Chinese refineries are focusing either on primary or on secondary input materials. Mixing of inputs is not common (BGRIMM, 2010). The 15 refineries covered in this study mainly apply startsheet refining with stainless steel cathodes (Table 3.7). They are equipped with wet or semi-dry scrubbers to prevent acid mist emissions. No information could be obtained on the use of renewable energy, such as electricity produced with hydropower. Details of the survey data can be found in the Appendix (Table 6.3).

Table 3.7 Chinese refineries.

Refinery capacities and actual production	Process applied	Capacities	Actual productionin ktons/year			
		2008	**2006**	**2007**	**2008**	**2009 (e)**
Guixi	Two ISA refineries with total capacity of 600kt/a. One startsheet refinery with capacity of 300kt/a	900	444	554	702	800
Jinchuan	Startsheet refinery	400	200	250	284	389
Yunnan Copper	ISA refinery	600	378	406	385	345
Jinlong (Tongdu) (refinery)	Outokumpu stainless steel refinery	400	209	250	300	350
Daye/ Hubei (refinery)	One ISA refinery with the capacity of 120kt/a, and the rest capacity is from conventional startsheet refinery	300	205	252	264	256
Shandong Fengxiang	Outokumpu stainless steel refinery	200			110	178
Jinchang (Tongling II) (refinery)	Startsheet refinery	150	150	150	150	180
Zhangjiagang	Startsheet refinery	150				
Huludao (refinery)	Startsheet refinery	120	58	34	15	8
Jintian	Startsheet refinery	120	122	135	104	60
Baiyin	Startsheet refinery	100	76	71	77	85
Chifeng	Startsheet refinery	100				
Yantai Penghui (refinery)	Startsheet refinery	120	72	103	87	85
Zhongtiaoshan (Houma) (refinery)	Startsheet refinery	100	55	90	91	62
Fuchunjiang (refinery)	Startsheet refinery	100	55	90	91	62
Sum		**3860**	**2022**	**2386**	**2660**	**2860**
% of entire China		**78%**	**67%**	**68%**	**70%**	**70%**
Entire China		**4967**	**3003**	**3499**	**3795**	**4110**

Source: BGRIMM, 2010.

3.2.2 *Copper Scrap Recycling in China*

The percentage of secondary copper, contributing to the total Cu-cathode production volume in China between the years 2000 and 2008, ranged between 20 and 33 per cent. According to the forecast of BGRIMM, this situation will not change considerably in the near future (BGRIMM, 2009a; BGRIMM, 2009b; see Table 3.8). Therefore, an average contribution of 25 per cent of the total Cu-cathode production from secondary copper sources was assumed. In other words, 250 grams of the functional unit of one kilogram of Cu-cathode originates from secondary copper smelters.

Table 3.8 Primary and secondary Cu-cathode production in China between 2000 and 2014 (unit: Cu-kt/%).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
										estimates	forecast	forecast	forecast	forecast	forecast
Chinese production of Cu-concentrate								910	930	930	980	1020	1045	1100	1145
% of total cathode production								26.0%	24.6%	23.9%	23.3%	21.7%	20.7%	21.4%	21.6%
China's Secondary refinery production	348	307	380	426	620	744	999	1050	1139	1060	1148	1250	1350	1450	1500
% of total cathode production	25.4%	20.2%	23.3%	23.2%	28.2%	28.6%	33.3%	30.0%	30.1%	27.2%	27.2%	26.6%	26.7%	28.3%	28.2%
Rest (net-imports of copper)								1539	1710	1902	2087	2429	2663	2579	2667
% of total cathode production								44.0%	45.3%	48.9%	49.5%	51.7%	52.6%	50.3%	50.2%
Total Chinese cathode copper	**1371**	**1523**	**1633**	**1836**	**2199**	**2600**	**3003**	**3499**	**3779**	**3892**	**4215**	**4699**	**5058**	**5129**	**5312**

Source: BGRIMM, 2009a; BGRIMM, 2009b.

According to BGRIMM (2010), primary and secondary smelters in China are almost entirely separated businesses. For the latter, an overcapacity of facilities was built up in the past years, which could lead to a fierce competition over secondary copper sources in the years to come. For the LCA study, it was assumed that secondary smelters resemble the Ausmelt/IsaSmelt technology. The submerged lance furnace of this technology is frequently used to process secondary raw material. Input-output of the Ausmelt/IsaSmelt technology were taken from Davenport et al., 2002 and DKI, 2010.

Based on the consumption patterns of the past, the generation of copper scrap in the future was calculated (BGRIMM, 2009b; see Table 3.9). BGRIMM distinguishes between "old copper scrap" and "new copper scrap"; where the former originates from sources listed as in Table 3.9, the latter is production waste of primary copper facilities.

Old copper scrap can be of highest quality, particularly if it originates from the building, transport and power cable infrastructure. Only by collection or physical removal of coatings, without a refining process, can Cu-cathode qualities be achieved. Other copper scrap is of lower quality (such as electronic scrap or scrap form primary production with lower purity) and needs to be treated in secondary smelters or refineries. According to Rentz *"…the copper content varies within a range between 94% (granulate from cable assembly) and 1.5% (shredded iron from household appliances, electronic scrap)"* (Rentz et al., 1999). As can be seen in Table 3.9, 53 per cent of the Chinese old copper scrap will be coming from the electric power sector, infrastructure and transport, and 47 per cent from scrap electronics and other sources. In this study it was therefore assumed that 50 per cent is copper scrap having Cu-cathode quality; this is called prompt scrap and is provided directly to the "Cu-cathode at regional storage" process. Another 50 per cent is copper scrap that needs to be treated in secondary smelters and refineries. The contribution of copper scrap to the functional unit is therefore 9.3 per cent from each secondary copper source, as shown in Figure 3.1.

Table 3.9 Analysis of old scrap generation in China from 2010 to 2015 (unit: kt-Cu).

	2010 forecast	2011 forecast	2012 forecast	2013 forecast	2014 forecast	2015 forecast	**Average**
Electric power & construction	272	239	268	311	354	446	
% Electric power & construction of total	48%	44%	42%	42%	41%	43%	**43%**
Transport	44	50	60	83	95	115	
% Transport of total	8%	9%	9%	11%	11%	11%	**10%**
Home electrical applinaces	94	116	143	184	227	257	
% Home electrical applinaces of total	17%	21%	22%	25%	27%	25%	**23%**
Others	153	143	171	167	180	228	
% Others of total	27%	26%	27%	22%	21%	22%	**24%**
Total	563	548	642	745	856	1046	
	100%	100%	100%	100%	100%	100%	

Source: BGRIMM, 2009b.

3.2.3 *Technology Mix*

Worldwide, the technology of primary copper smelters is dominated by three smelter types: Outocumpu, Reverberatory furnaces and El Teniente Reactors. These account for more than 62 per cent of the world copper production. In recent years the Ausmelt/IsaSmelt—being a flash smelting technology—has shown a strong increase (Table 3.6). Outocumpu can be considered a "state-of-the-art" technology, whereas Reverberatory furnaces and Blast furnaces represent old-fashioned technologies.

In China the main technologies used are Flash smelting (such as Outocumpu), Ausmelt/IsaSmelt and Bath smelters (such as Noranda) (see Table 3.6). The smelters investigated in the sample were grouped according to the type of furnace technology, as shown in Table 3.10. For each type of furnace technology listed, specific input-output data were used to depict the resource consumption and emissions of the individual smelting process.

Input-output data of Outocumpu, Noranda, Blast furnace, Reverberatory furnace and Vanuykov smelters were retrieved from DKI (2010). For the Ausmelt/IsaSmelt technology, data were taken from Davenport et al., 2002 and DKI, 2010.

For the conversion of copper matte into blister copper, average data on a standard Peirce–Smith converter were taken as an approximation (DKI, 2010). Average data of an electric furnace for casting the anodes and average data on an electro-refining processing plant were used to depict the final processing steps. Conversion, anode casting and electro-refining were used uniformly for all smelters (DKI, 2010).

The actual mix, the functional unit "1kg Cu-cathode," can be seen in Table 3.10. The share of each technology given in Table 3.6 had to be scaled up, as only 80 per cent of the Chinese smelting production is covered by the 15 smelters investigated in this study.

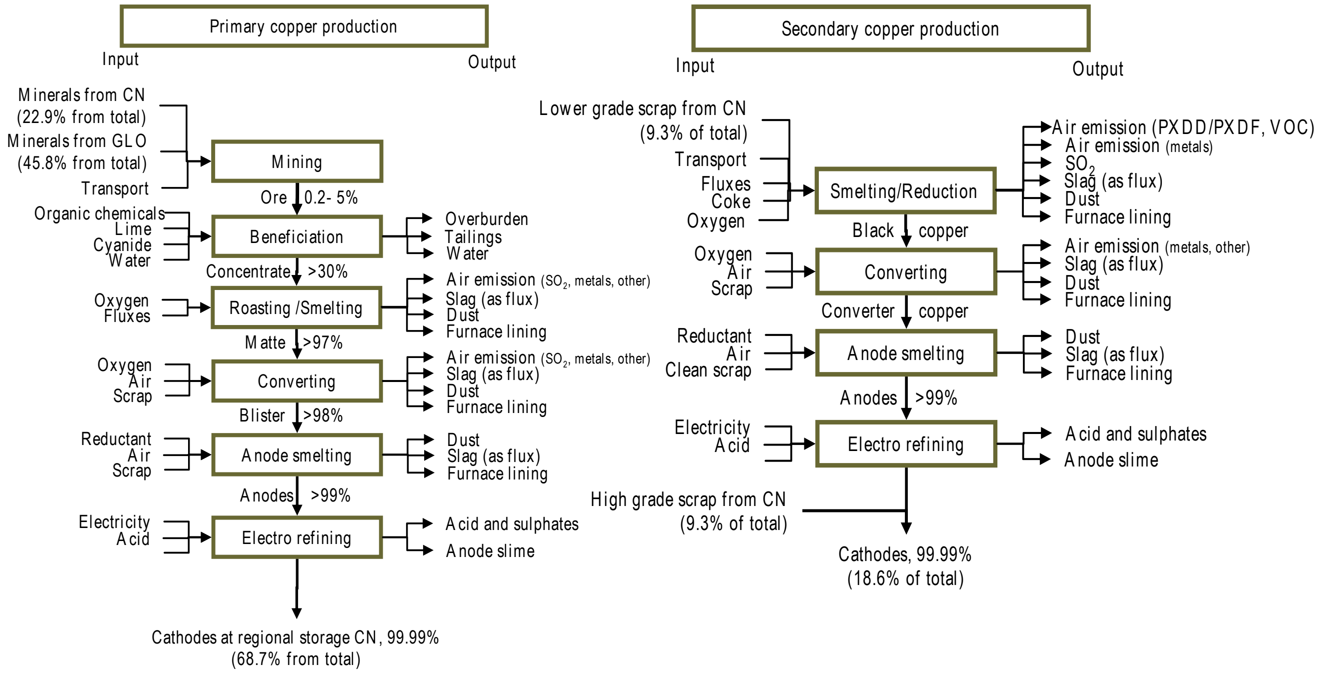
The other key numbers in Table 3.10 have been introduced in Section 3.2.2, "Copper Scrap Recycling in China" (for scrap collection and treatment) and in Table 3.1 of Section 3.1.2, "System Characterization" (for imports of Cu-cathodes).

In Figure 3.3, the generic process steps (inputs and outputs of primary and secondary copper production) are shown. The list of inputs and outputs are reduced to the most relevant; also, many internal flows, such as slag and dust recycling, are not shown.

Table 3.10 Share of each process contributing to the functional unit 1kg Cu-cathode.

Process or Origin	Share of process to functional unit	Origin
Outokumpu flash smelting	10.39%	Chinese ore
Ausmelt / IsaSmelt	8.01%	Chinese ore
Noranda reactor & other bath smelters	2.73%	Chinese ore
Reverberatory	0.51%	Chinese ore
Blast furnance	0.83%	Chinese ore
Vanuykov process	0.42%	Chinese ore
Cu-scrap smelted and refined	9.30%	Chinese collection
Cu-scrap direct use	9.30%	Chinese collection
Cu-Cathode imported	12.70%	Global production and import
Outokumpu flash smelting	20.78%	Global production of Cu-concentrate / Chinese smelting and refining
Ausmelt / ISA Smelt	16.03%	Global production of Cu-concentrate / Chinese smelting and refining
Noranda reactor & other bath smelters	5.46%	Global production of Cu-concentrate / Chinese smelting and refining
Reverberatory	1.03%	Global production of Cu-concentrate / Chinese smelting and refining
Blast furnance	1.67%	Global production of Cu-concentrate / Chinese smelting and refining
Vanuykov process	0.84%	Global production of Cu-concentrate / Chinese smelting and refining
Sum	**100% or 1kg**	

Figure 3.3 Generic input-output chart for primary and secondary copper smelting.



Adapted from Classen et al., 2009 and IPPC, 2009.

3.2.4 *Transport*

To include the transport of Cu-concentrates, secondary copper and Cu-cathodes in the LCA, a rough estimation of distances was conducted. The biggest producing countries of copper ore in 2006 (USGS, 2008) were taken as approximation to estimate the share of Cu-concentrate imports to China (the shares are given in brackets after the countries' names). It was assumed that over-water transport is occurring with a large ocean vessel and over-land transport with a lorry (>32 tons). The resulting "ton-kilometres per kg of Cu-cathode produced" can be seen in the last two columns of Table 3.11. These values were used in the LCA calculation. Their meaning is, for instance: in order to produce 1kg Cu-cathode in China, each ton of material used (mainly ore) was transported on average 60.8 km by vessel. The analysis of transport distances and modes was not looked at more specifically. Earlier LCA studies have shown that transport does not play a major role when it comes to the environmental impacts of the metal producing sector.

Table 3.11 Origin of Cu-concentrate, secondary copper and Cu-cathodes, average transport distances and the ton-kilometres used in this assessment.

		Amount in 2008 (kt/year)	Average transport distance (km)		tkm		tkm per kg of Cu-cathode produced	
			Vessel	Lorry	Vessel	Lorry	Vessel	Lorry
China	Cu-Concentrate	4304		1000		4.30E+09	0.00E+00	3.68E+00
China	Secondary Cu	1139	1000	500	1.14E+09	5.70E+08	2.41E+00	1.20E+00
China	Cu-Cathode	869	1000	500	8.69E+08	4.35E+08	1.70E-01	8.52E-02
Imports	Cu-Concentrate (Chile, 48%)	4132	20000	500	8.26E+10	2.07E+09	5.57E+01	1.84E+00
Imports	Cu-Concentrate (USA, 11%)	947	10000	500	9.47E+09	4.73E+08		
Imports	Cu-Concentrate (Peru, 9%)	775	20000	500	1.55E+10	3.87E+08		
Imports	Cu-Concentrate (Austrailia, 8%)	689	7000	500	4.82E+09	3.44E+08		
Imports	Cu-Concentrate (Indonesia, 7%)	603	5000	500	3.01E+09	3.01E+08		
Imports	Cu-Concentrate (Other, 17%)	1463	10000	500	1.46E+10	7.32E+08		
Imports	Cu-Cathode	166	10000	1000	1.66E+09	1.66E+08	2.56E+00	2.56E-01
Sum							**6.08E+01**	**7.07E+00**

3.3 Impact Assessment

3.3.1 Environmental Impacts of Production Technologies in China

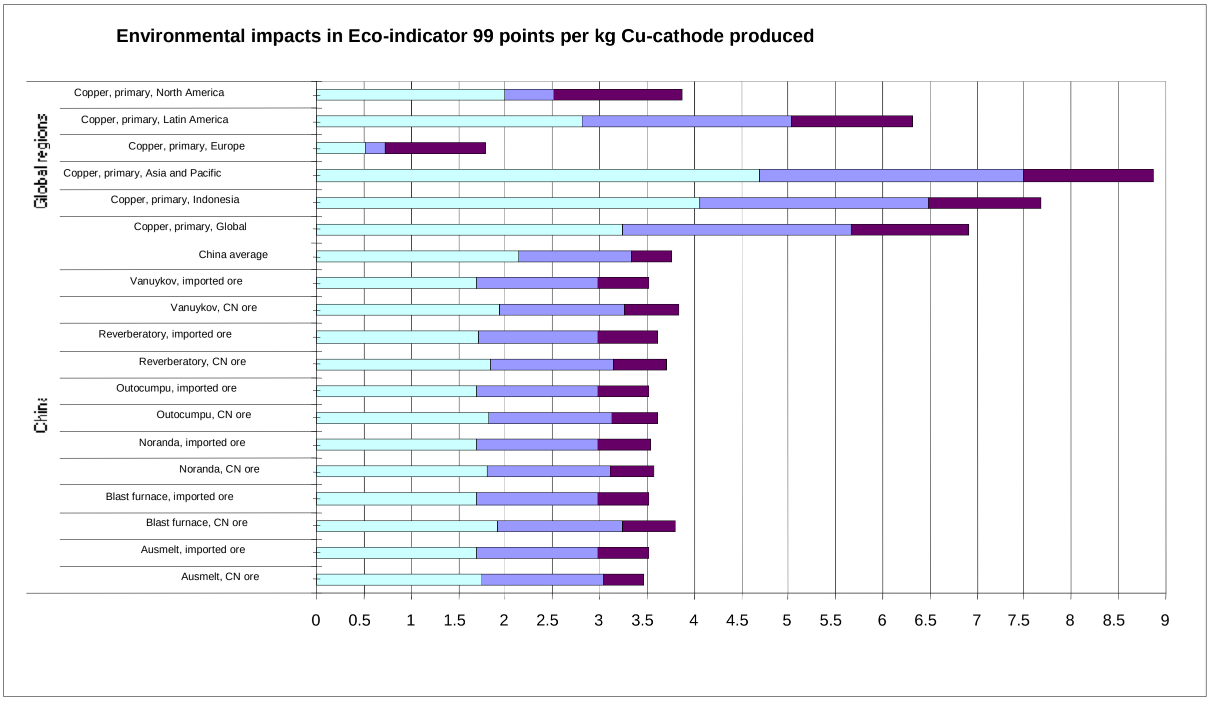
3.3.1.1 Primary Production

In Figure 3.4, the environmental impacts of the production of 1kg Cu-cathode from individual processing technologies as well as the average for the production mix in China can be seen. The results are shown in Eco-indicator 99 (EI99) points, which are aggregated values for the three impact categories: Human Health, Ecosystem Quality and Resource Depletion. Eco-indicator 99/Hierarchist was the version chosen for the calculation. It weights Human Health with 40 per cent, Ecosystem Quality with 40 per cent and Resource Depletion with 20 per cent.

Only the primary production is shown in Figure 3.4, in order to compare the Chinese results to already existing LCIA results of other global regions. For those regions, only data for primary production are available in ecoinvent.

It can be seen that the environmental impacts of processes applied in China do not show too much variation. Generally, the environmental impacts of production with Chinese ore are slightly higher than the ones with imported ore. This is due to the fact that the Chinese ore has a lower grade than imported global ore. Also the Chinese electricity mix, consisting of only conventional production by fossil fuel power stations and no hydropower, increases the EI99 scores.

Figure 3.4 Environmental impacts in Eco-indicator 99 points for all primary producing technologies and averaged for different global regions. The results show the impacts of each technology producing 1kg Cu-cathode with primary production.



Comparing the average of the environmental impacts of the Chinese primary production to those of primary production in global regions, it can be seen that:

- Chinese primary production has fewer environmental impacts than the global average;
- Chinese primary production has fewer environmental impacts than those in Latin America, Asia and Pacific, and Indonesia;
- Chinese primary production has higher environmental impacts than primary production in Europe; and
- Chinese primary production shows roughly the same or slightly fewer environmental impacts than primary production in North America.

However, it should be noted that the values for countries and regions other than China are based on Inventory data from 1994. Consideration of technological development in the last 15 years would probably lead to significantly lower impacts in these countries and regions too.

The share of Ecosystem Quality category is higher in China than in Europe and in North America, whereas comparable to the global average and other global regions. The detailed environmental impacts of each production path are shown in Figure 6.2 in the Appendix.

3.3.1.2 Primary and Secondary Production

Figure 3.5 and Figure 3.6 show the environmental impacts of five processing steps of primary and secondary production technologies used in China, the former in absolute and the latter in relative EI99 points.

It can be seen that secondary production has much less impact than the primary production. Because secondary copper does not carry the burden of mineral extraction, which is accounted only to the first use of copper, reuse of copper is naturally more environmentally friendly than primary production.

Looking at the relative results (Figure 3.6) it becomes more evident that the impacts of primary production, caused by the mineral extraction of Cu-ore, contribute the most to the overall impacts. More than 70 per cent of the impacts for all primary processes are caused by mining or mineral extraction, whereas less than 25 per cent come from the reduction or smelting processes (except for the two technologies of Blast furnace, GLO ore, and Vanuykov, CN ore, which score slightly higher than 25 per cent). Conversion, electro-refining and transport contribute very little (<5 per cent) to the overall impacts of primary production. This picture would actually be more accentuated if emissions from sulfidic tailing deposition were included in the mining step.

The relative results (Figure 3.6) of secondary Cu-cathode production look very different, as the mining or mineral extraction does not occur. It can be seen that the conversion processes contribute between 7 per cent and 8 per cent, whereas less than 3 per cent of the environmental impacts come from electro-refining and transport processes. The relative results for converting, electro-refining and transport processes of the primary production technologies are all less than 1 per cent.

Figure 3.5 Impacts of each of the five process steps for each technology, primary and secondary production.

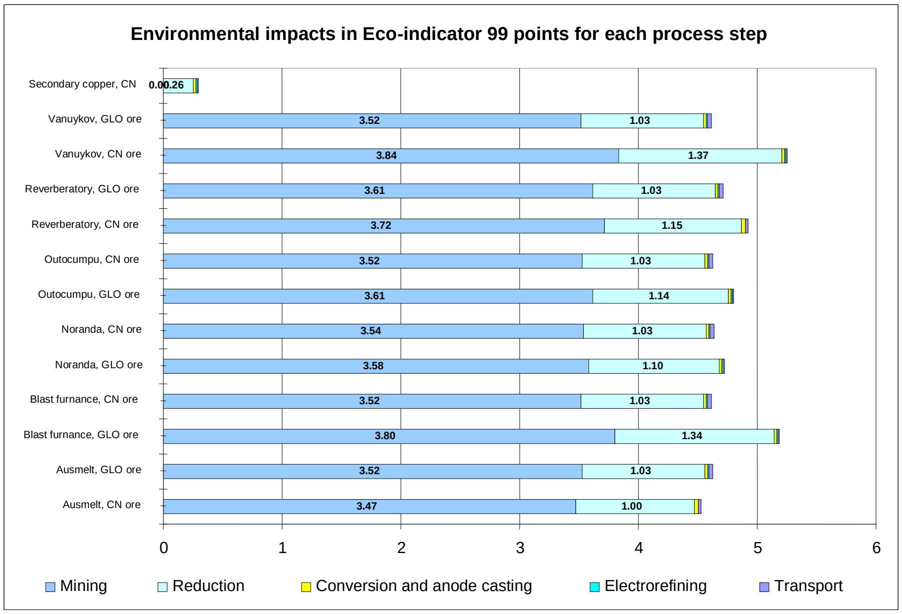
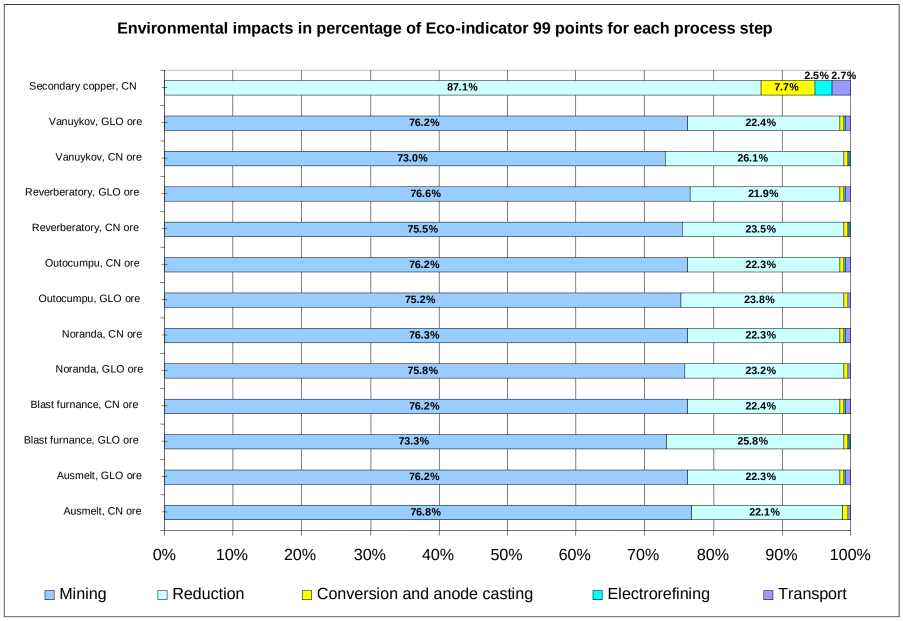


Figure 3.6 Relative impacts of each of the five process steps for each technology, primary and secondary production.



3.3.1.3 Detailed Impacts of Mining Processes

As seen above, the mining and beneficiation processes contribute the most to the overall environmental impacts. Therefore, mining and beneficiation of copper ore were analyzed in detail. Figure 3.7 shows the environmental impacts for mining and beneficiation processes in China, Latin America, Asia and Pacific regions and a global mix. The bar sections represent the intermediate impact categories, whereas the group of colours represent impact the categories Human Health (orange), Ecosystem Quality (blue) and Resource Depletion (grey).

It can be seen that mainly the impact category Respiratory inorganics (for Human Health) and Minerals (for Resource Depletion) have the biggest share. Land use (for Ecosystem Quality) contributes the third most to the overall impacts, but is far smaller than the first two mentioned.

It is not surprising that the depletion of minerals causes environmental impacts in a mining process. More surprising is that Respiratory inorganics create such large impacts for mining and beneficiation processes. It is also astonishing that in comparison, impact categories such as fossil fuels acidification potential and ecotoxicity are almost negligible.

The environmental impacts of mining and beneficiation processes in China, Latin America and the Asia and Pacific regions are all higher than the world average. This could have its reason in a relatively strict environmental legislation and enforcement of the other regions (Europe and North America) but, in the case of China, also in the origin of the ore from mainly underground sources, which most likely causes higher environmental impacts than open-pit mining. Very evident is the highest impact of mining and beneficiation processes in the Asia and Pacific region compared to China and Latin America.

On a lower level one can look at the contribution of each subordinated process to the overall impacts. Figure 6.3 in the Appendix shows the subordinated processes for mining and beneficiation. But even this analysis only shows that the beneficiation process carries the largest burden of both mining and beneficiation. Blasting and disposal of tailings contribute together roughly 15 per cent, which means that the largest part of the impacts are created during the beneficiation process while concentrating the extracted minerals (more than 75 per cent). This process is represented as an individual process in ecoinvent. The consequence of this is that further analysis of the beneficiation process demands an analysis of the subordinated impacts from individual substances.

Figure 3.7 Environmental impacts in Eco-indicator 99 points for mining processes including beneficiation. The results are shown in details and, at the same time, grouped according to the impact categories Human Health (orange), Ecosystem Quality (blue) and Resource Depletion (grey).

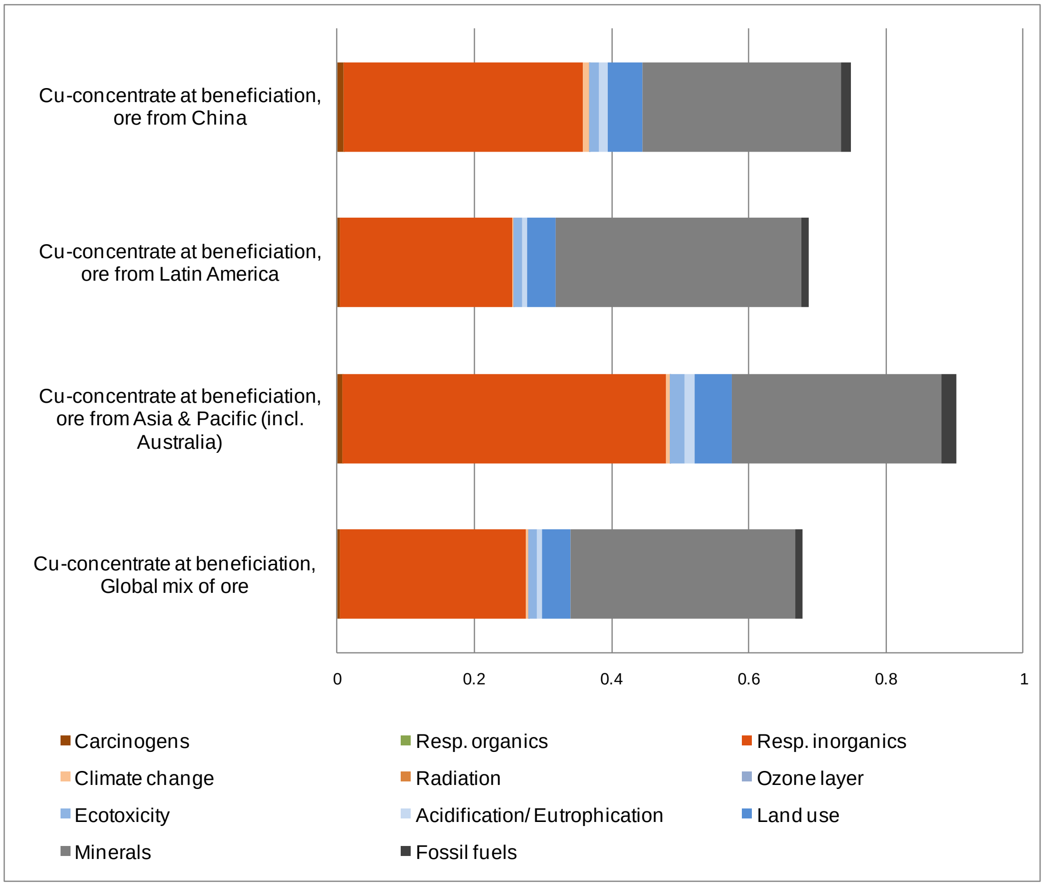


Table 3.12 lists the main contribution of individual substances to the overall impacts of mining and beneficiation for the global average. This mix was chosen because the results for individual regions (Latin America, Asia and Pacific, and China) do not differ considerably. This has partly to do with worldwide similarly applied techniques for mining and beneficiation but also with the lack of specific mining and beneficiation data of individual countries or regions.

It can be seen that, particularly, emissions to air and extraction of raw materials cause the biggest environmental burden. The reason behind this must be large dust emissions during mining as well as the consumption and extraction of raw material and the disposal of large volumes of tailings and overburdens. These emissions also explain why Respiratory inorganics and Minerals cause the largest shares of environmental impacts in Figure 3.7. (The list in Table 3.12 was cut off at a certain point.)

Table 3.12 Main contribution to the environmental impact of mining and beneficiation (global mix) of individual substances or processes; results are shown ranked (biggest above) in Eco-indicator 99 points.

Substance	Compartment	Copper concentrate, at beneficiation, Global mix
Total of all compartments		**0.67914208**
Particulates, < 2.5 um	Air	0.16237087
Particulates, > 2.5 um, and < 10um	Air	0.073432362
Occupation, dump site	Raw	0.041325148
Nitrogen oxides	Air	0.035028468
Transformation, to dump site	Raw	0.009517485
Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	0.008743084
Chromium	Air	0.007855056
Ammonia	Air	0.007346653
Gas, natural, in ground	Raw	0.007215445
Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore, in ground	Raw	0.004914178
Oil, crude, in ground	Raw	0.004512195
Carbon dioxide, fossil	Air	0.002607518
Sulfur dioxide	Air	0.002582826
Transformation, to arable, non-irrigated	Raw	0.00218194
Zinc	Air	0.001508275
Nickel	Air	0.001332946
Arsenic, ion	Water	0.001278891
Nickel, ion	Water	0.000945651
Occupation, industrial area, built up	Raw	0.000605127
Coal, hard, unspecified, in ground	Raw	0.000447159
Cadmium	Air	0.000429688
Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in ground	Raw	0.000427658
Lead	Air	0.00038061
Transformation, to industrial area, built up	Raw	0.000363633
Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in ground	Raw	0.00032498
Occupation, forest, intensive, normal	Raw	0.000314269
Copper	Air	0.000299265
Arsenic	Air	0.000297899
Transformation, to mineral extraction site	Raw	0.000277161
Dinitrogen monoxide	Air	0.000276999
Chromium VI	Air	0.000269491
Occupation, industrial area	Raw	0.000269017
Aluminium, 24% in bauxite, 11% in crude ore, in ground	Raw	0.000223227
Occupation, mineral extraction site	Raw	0.000161023
Transformation, to industrial area	Raw	0.000160979
Chromium, 25.5% in chromite, 11.6% in crude ore, in ground	Raw	0.000143862
Cadmium, ion	Water	0.000141778
Gas, mine, off-gas, process, coal mining/m3	Raw	0.000141093
Methane, fossil	Air	0.000128598

3.3.2 Comparison of Environmental Impacts with Different LCIA Methods

In order to test the sensitivity of the LCIA results, four other methods were used to evaluate the environmental impacts:

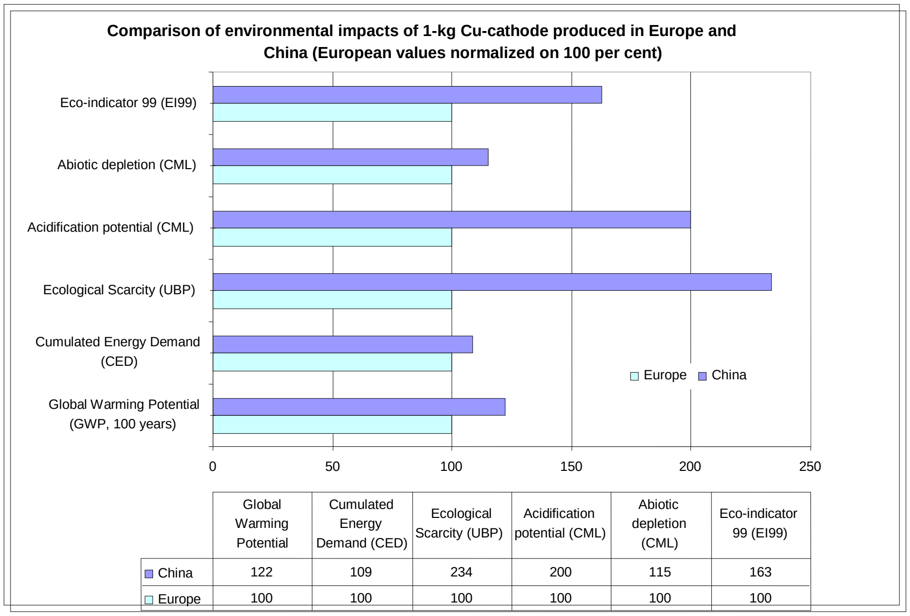
1. CML 2001 (Centre for Environmental Studies, University of Leiden, 2001):
    a. Acidification Potential, and
    b. Abiotic Depletion;
2. Ecological Scarcity 1997;
3. CED (Cumulative Energy Demand); and

4. GWP (Global Warming Potential, IPCC 2001 [climate change]).

For CML 2001, the results can not be aggregated to a single score. Therefore, for this study, two of the most relevant impact categories for metal processing were chosen. A brief description of each evaluation method can be found in the Appendix, Section 6.5, "Short Descriptions of Common Life Cycle Impact Assessment Methodologies."

The production of 1kg Cu-cathode produced in China shows, for all LCIA results, higher impacts than those of the European mix (Figure 3.8). For the Abiotic Depletion according to CML 01 and Cumulative Energy Demand, the Chinese results are only slightly higher than the European average. For the Acidification Potential according to CLM 01 and for the Ecological Scarcity (UBP), they are more than double. The sum of EI99 points for China is 63 per cent higher than for Europe. This can be explained mainly by (1) a higher Cu-concentration in the ore being processed in Europe, (2) a higher share of secondary copper in the European production mix, and (3) a higher percentage of hydropower in the European electricity mix than in China.

Figure 3.8 Comparison of Chinese and European LCIA results with the four different impact evaluation methods. From the CLM evaluation methods, the two indicators "Abiotic depletion" and "Acidification potential" were used. Impacts from both primary and secondary production are included.

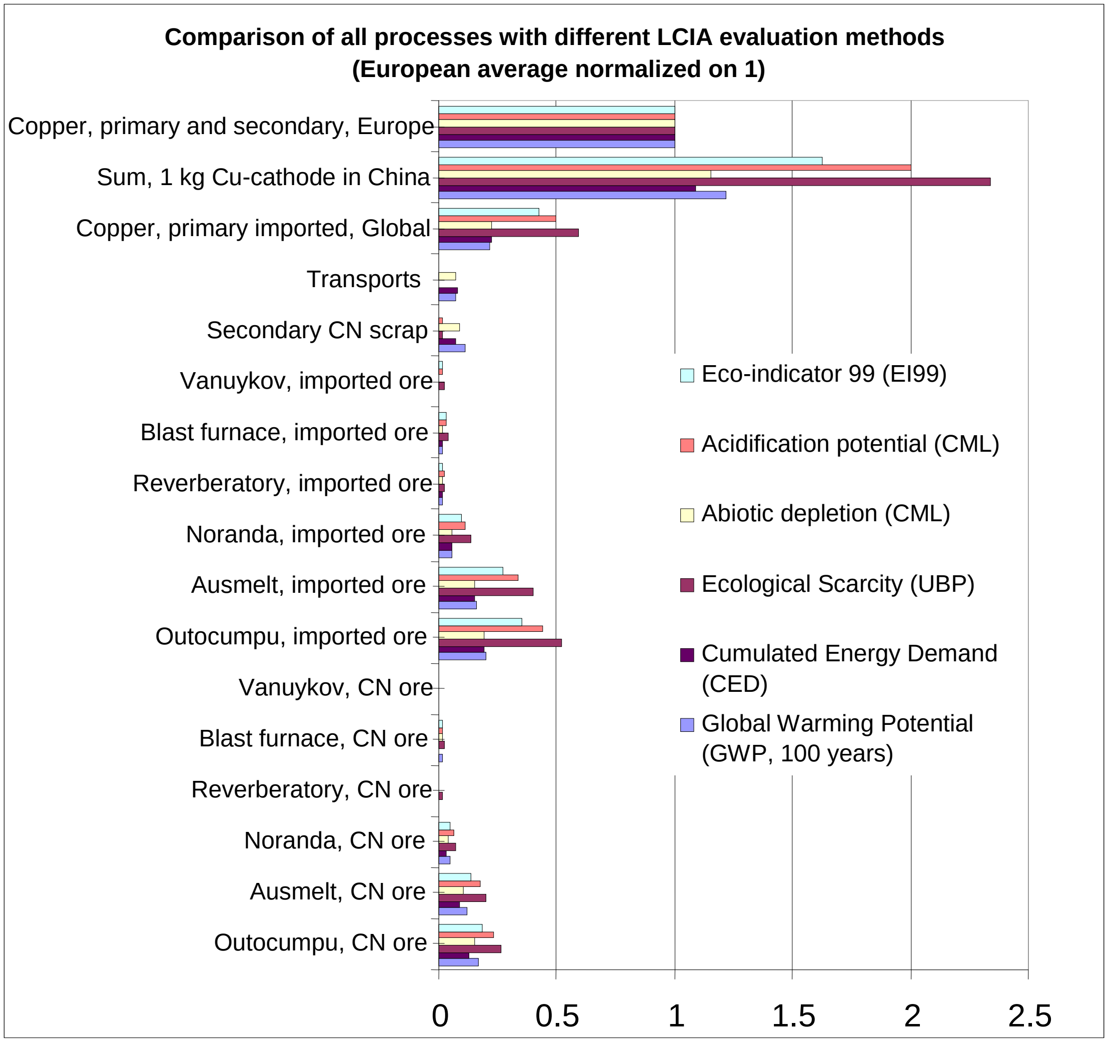


	Global Warming Potential	Cumulated Energy Demand (CED)	Ecological Scarcity (UBP)	Acidification potential (CML)	Abiotic depletion (CML)	Eco-indicator 99 (EI99)
■ China	122	109	234	200	115	163
□ Europe	100	100	100	100	100	100

The detailed comparison of the LCIA results of the evaluation methods is shown in Figure 3.9. In order to allow for this comparison, the European copper production mix is taken as 100 per cent. The first and second bars show the same results as in Figure 3.8. The other bars show the contribution of each production technology, as well as type of raw material used, to the production of 1kg Cu-cathode. Different to Figure 3.4 and Figure 3.5, the individual process impacts represent the share each process contributes to the assumed production mix of the functional unit in China (see Table 3.10). Hence, the highest impacts are from Copper primary imported and Outocumpu, imported ore, as these processes have the highest shares in the production mix.

The Chinese production mix scores for all production techniques are the highest when being evaluated with Ecological Scarcity (UBP) and Acidification Potential (CML). The reason for this is the high value these methods assign to emissions that are relatively high in Chinese electricity production.

Figure 3.9 Comparison of the LCIA results for each technology or process contribution to the production of 1kg Cu-cathode in China. Transports, secondary and primary production are shown, both in China and Europe. The sum of the production/process mix for China is compared to the European average. For comparability, all results are normalized on the European average.



4.0 Conclusions and Implications for Policy Recommendations

The environmental impacts of the copper producing sector are mainly caused by mining and mineral extraction processes. This is not surprising, as copper can only be found at low concentrations in minerals (50 ppm in the earth's crust, and 0.5 per cent to 5.0 per cent in Cu-ore, [Fabian, 1997 in Classen et al., 2009]). The demand on minerals, the caused land transformation, the stripped tailings and overburden, as well as emissions from the ore-beneficiation process, cause environmental impacts that outrange all other processes (see Figure 3.5 and Figure 3.6). Once a Cu-concentrate with a copper content between 25 per cent and 30 per cent is generated, the majority of the environmental impacts have already occurred. It is nevertheless astounding that mining outscores all other processing steps by far. However, it has to be taken into account that very little data on mining technology and mining emissions could actually be found. Thus, the mining Inventory is mainly based on information used in the ecoinvent database for a global situation.

In order to improve the environmental performance of the primary copper production, the main focus should lie on improvement of the mining technologies (e.g., focusing on higher grade wherever possible), environmental abatement techniques (e.g., improved management of waste waters and effluents from beneficiation processes, dammed lakes for tailings) and environmental restoration (e.g., ecological rehabilitation of deposition sites for tailing and overburden). The obvious lack of data implies that an efficient initiative for gathering environmentally relevant data of mining could improve the environmental performance of these processes.

Some general recommendations concerning the international trade patterns of the Chinese copper industry can be deducted. Considering that ore is mainly imported from Chile, Peru, Australia and Mongolia (see Table 3.11 but also oral communication with Jason Potts), it can be concluded that, from an environmental point of view, the distance imports are transported does not matter much. The overall impacts from ore imported from Asian and Pacific regions are higher that those from Latin America. This means that in order to reduce the environmental impacts caused in exporting countries, Chinese importers should scrutinize the mining and beneficiation standards of countries of the Asia and Pacific regions in more detail. For China and also for other countries, improvements of the mining and beneficiation processes can be achieved by improvement of the mining technologies, environmental abatement and environmental restoration.

Improving the smelting technologies can reduce considerably the impacts for the processing steps of Cu-concentrates, particularly as China is largely depending on Cu-concentrate imports. Best available technologies, such as Flash smelters or Submerged-lace smelters, are already widely used in China. The remaining, small scale, old-fashioned smelter types such as Reverberatory furnaces and Blast furnaces are generally not used any more. The consequent phase-out of inappropriate technologies, which is required by law, will therefore improve the standard of primary Chinese copper smelting.

As a consequence of this first main result (the need to improve the mining techniques) but also as a result of comparison of primary and secondary production paths, reuse of copper is the second strategy to prevent negative environmental impacts from producing Cu-cathodes. To set up a comprehensive collection and recycling of all copper-containing products that are waste is environmentally friendly and often also economically profitable. This simple strategy to keep copper in the consumption loop once it is made available from primary resources is a straightforward mean to improve the environmental performance of the Chinese copper producing sector.

As shown in the forecast of the primary and secondary copper production in China in Table 3.11, the need to set up comprehensive collection systems for copper-containing products is a compulsory task for policy-makers. Not only must the collection increase to keep pace, as forecasted, with the growing demand for copper in China, but also the closing of materials loops by enforced collection has the potential to further increase the share of secondary copper of the Chinese production mix. As stated above, once copper is mined and processed from primary resources, the most environmentally friendly way to deal with such a material is to (1) use it as long as possible and (2) collect and reuse it as completely and as often as possible.

The potential for improved collection systems for copper-containing products has been exhibited in several projects and programs such as the e-waste program, "Knowledge Partnerships in e-Waste Recycling" (EMPA, 2010). The experiences made within this program have shown that an e-waste specific manual separation or simple mechanical processing is apt to separate material into very high grade, pure secondary resources (Hagelüken & Kerckhoven, 2006; Gmünder, 2007; Laffely, 2007). Hence the implementations of collection and pre-treatment management systems for e-waste could increase the efficiency of secondary copper smelters, as the Cu-concentration of the secondary feed material can be increased by simple measures. Apart from copper, other metals can also be separated and made available for recovery, which makes the e-waste pre-treatment even more attractive.

The study did not go into details of how secondary copper smelters should be designed, as the data sample did not cover these smelters separately. It was assumed that secondary copper is processed with best available technology, particularly with an advanced off-gas cleaning system and with waste water treatment. Because the capacities for secondary smelters in China is larger than the actual volumes that are available for treatment, policies could focus on favouring environmentally more advanced secondary smelters to those without such technology. A registration, a control and a continuous improvement of the standards (such as the ISO 14000 series) of secondary copper smelters could bring improvement to the environmental performance of secondary copper production, if simply those not having the advanced technology are closed down.

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6.0 Appendix

6.1 List of Chinese Mines, Smelters and Refineries

Table 6.1 List of mines included in the calculation.

Mine capacities and actual production	**Main output material**	**Mining /milling capacities**	**Actual production Production in kt-Cu metal/year**				**Type of mine operation**			**Quality of ore**		**Average copper content in ore**		**Abatement technology**				
		2008	2006	2007	2008	2009 (e)	Under-ground	Open-cut mining	SX-EW In-situ leaching	Sulfidic	Non sulfidic	Minimal value	Maximal value	Recovery of reagent	Recovery of process water from leaching/mineral process	Dammed lake for tailings /slags	ecological rehabilitation	Others
Dexing	Concentrates	100ktpd	107	113	116	125		x		x		0.38	0.51	x	x	x	x	Dexing owned the biggest dam ponds with 835 billion m3 and 110 m height. It is the most adxanced open-pit mine in China
Yongping	Concentrates	10ktpd	19	19	20	20	x	x		x		0.69	0.71	x	x	x	x	
Huogeqi	Concentrates	7kpd	21	20	22	19	x			x		1.20	1.61	x	x	x		
Dongguashan	Concentrates	10kpd	15	22	28	32	x			x		1.09	1.20	x	x	x	x	
Tongkuangyu Copper mine	Concentrates	20kpd	20	20	20		x			x		0.49	0.58	x	x	x	x	
Ashele	Concentrates	4ktd	30	28	29	30	x			x		0.24	0.26	x	x	x		New mime with advanced management
Dahongshan	Concentrates	15ktpd	21	27	33	35	x			x				x	x	x		
Lala Copper	Concentrates	15ktpd	20	27	26	30		x		x		0.66	0.76	x	x	x		
Chengmenshan	Concentrates	2ktpd	6	6	6	6		x		x		0.74	0.82	x	x	x		
Wunuketushan Mine	Concentrates	30ktpd (started production end of 2009						x		x		0.42	0.56	x	x	x		New and advanced mine
Daye Tonglushan Copper mine	Concentrates	4ktpd	9	10	10	10	x			x		1.41	1.78	x	x	x		
Dexing SX-EW plants	Cathode	2ktpa	2	2	2	2			x	x				x	x	x		Recovering copper from the waste stock with bio-leaching process
Anqing Copper Mine	Concentrates	3.5ktpd	8	9	9	10				x		1.05	1.05	x	x	x		
Dongchuan	Concentrates	7.5ktpd	20	20	20	20	x			x		0.81	1.29	x	x	x		
Hongtoushan Copper Mine	Concentrates	2ktpd	8	8	8	8	x			x		1.5	1.7	x	x	x	x	
Sum			**305**	**330**	**348**	**346**						0.82	0.99					
% of entire China			**35%**	**36%**	**32%**	**36%**												
	Mining capacity	Milling capacity	2006	2007	2008	2009												
Entire China	107300 ktpa	126520 ktpa	**873**	**928**	**1076**	**961**	70~80%											
		SX-EW production kt	16.1	18.1	16.6	18.9												

Source: BGRIMM, 2010.

Table 6.2 List of smelters included in the calculation.

Smelter capacities and actual production	Process applied	Capacities	Actual productionin ktons/year				Abatement technology					
		2008	2006	2007	2008	2009 (e)	Fabric filter, hot electrostatic precipitator (ESP) and cyclone	Wet or semi-dry scrubber	Sulfuric acid plant reported as conversion of SO2	Acid waste water treatment by lime neutralization	Cooler, ESP, lime/carbon adsorption and fabric filter	
Guixi (smelter)	Old flash smelting-converter-andoe refining	300	300	300	300	300	x	x	x	x	x	Owned the process for As slag treatment and recover As2O3 as by product, flotating slag for further copper recovering
	New Flash smelting-converter-andoe refining (since 2007)	200		29	177	146	x	x	x	x	x	
Jinchuan (smelter)	Composite smelting-converter-anode	350	258	314	290	380	x	x	x	x	x	
Yunnan Copper	Isasmelting-converter-anode furnace	200	186	208	192	210	x	x	x	x	x	
Jinlong (Tongdu)	Flash Smelting-converter-anode	350	209	250	280	330	x	x	x	x	x	Owned the process for As slag treatment and recover As2O3 as by product
Daye/ Hubei	Noranda smelting- converter-anode refining	120	120	120	120	120	x		x	x	x	
	Reverberatory-converter-anode, to be phased out in 2010	50	30	52	44	62	x		x	x	x	
Shandong Fengxiang (smelter)	Outokumpu Flash smelting-flash convertering-anode furance	200			110	178	x	x	x	x	x	Employ flotation process for reovering Cu of the smelting slag
Jinchang (Tongling II)	Ausmelt smelting-converter-anode	180	150	150	150	180	x	x	x	x	x	
Huludao	Blast smelting-converter-anode, stopped in 2009, Ausmelt smelter under construction	120	49	34	15	0	x		x	x	x	
Baiyin (smelter)	Baiyin furnace (similar to Noranda)-converter-anode refining	100	78	78	81	82	x	x	x	x	x	
Jinfeng	Jinfeng furnace (similar to Vanukov furnace)-converter-anode refining	100	26	0	36	75	x	x	x	x	x	
Kangxi (Liangshan)	Blast Furnace, might stop production soon	35	20	27	22	25	x		x	x	x	
Yantai Penghui	Side blowing bath smelting-converter-anode refininig	60	49	30	33	35	x	x	x	x	x	
Fuchunjiang	Blast Furnace-converter-anode refining, might stop production in 2010/2011	80	36	34	35	35	x	x	x	x	x	
Zhongtiaoshan (Houma)	Ausmelt smelting-Ausmelt converting -anode refining	70	53	56	56	62	x	x	x	x	x	
Feishang	SKS smelting (bottom blowing)-converter-anode refining	60			25	30	x		x	x	x	
Sum		**2'575**	**1563**	**1684**	**1966**	**2250**						
% of entire China		**93%**	**82%**	**80%**	**80%**	**82%**						
Entire China		**2778.5**	**1918**	**2112**	**2453**	**2739**						

Source: BGRIMM, 2010.

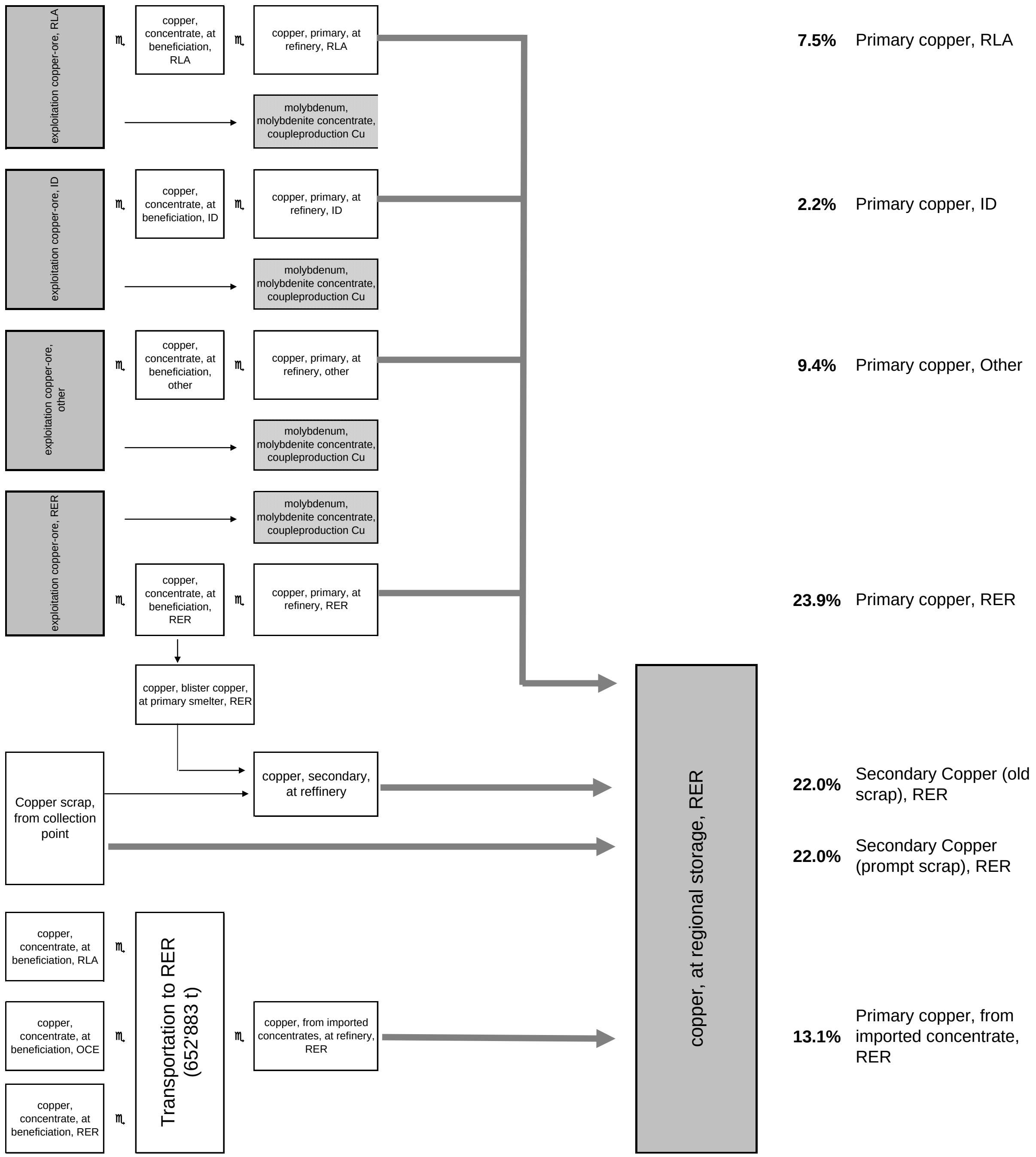
Table 6.3 List of refineries included in the calculation.

Refinery capacities and actual production	Process applied	Capacities	Actual productionin ktons/year				Abatement technology	
		2008	**2006**	**2007**	**2008**	**2009 (estm.)**	**Wet or semi-dry scrubber for acid mist**	**Use of electricity from renewable energy sources (hydropower/wind etc.)**
Guixi	Two ISA refineries with total capacity of 600kt/a. One startsheet refinery with capacity of 300kt/a	900	444	554	702	800	x	n.a.
Jinchuan	Startsheet refinery	400	200	250	284	389	x	n.a.
Yunnan Copper	ISA refinery	600	378	406	385	345	x	n.a.
Jinlong (Tongdu) (refinery)	Outokumpu stainless steel refinery	400	209	250	300	350	x	n.a.
Daye/ Hubei (refinery)	One ISA refinery with the capacity of 120kt/a, and the rest capacity is from conventional startsheet refinery	300	205	252	264	256	x	n.a.
Shandong Fengxiang	Outokumpu stainless steel refinery	200			110	178	x	n.a.
Jinchang (Tongling II) (refinery)	Startsheet refinery	150	150	150	150	180	x	n.a.
Zhangjiagang	Startsheet refinery	150					x	n.a.
Huludao (refinery)	Startsheet refinery	120	58	34	15	8		n.a.
Jintian	Startsheet refinery	120	122	135	104	60		n.a.
Baiyin	Startsheet refinery	100	76	71	77	85	x	n.a.
Chifeng	Startsheet refinery	100					x	n.a.
Yantai Penghui (refinery)	Startsheet refinery	120	72	103	87	85	x	n.a.
Zhongtiaoshan (Houma) (refinery)	Startsheet refinery	100	55	90	91	62	x	n.a.
Fuchunjiang (refinery)	Startsheet refinery	100	55	90	91	62		n.a.
Sum		**3860**	**2022**	**2386**	**2660**	**2860**		
% of entire China		**78%**	**67%**	**68%**	**70%**	**70%**		
Entire China		**4967**	**3003**	**3499**	**3795**	**4110**		

Source: BGRIMM, 2010.

6.2 Schematic Representation of the Consumer Mix of Copper in Europe

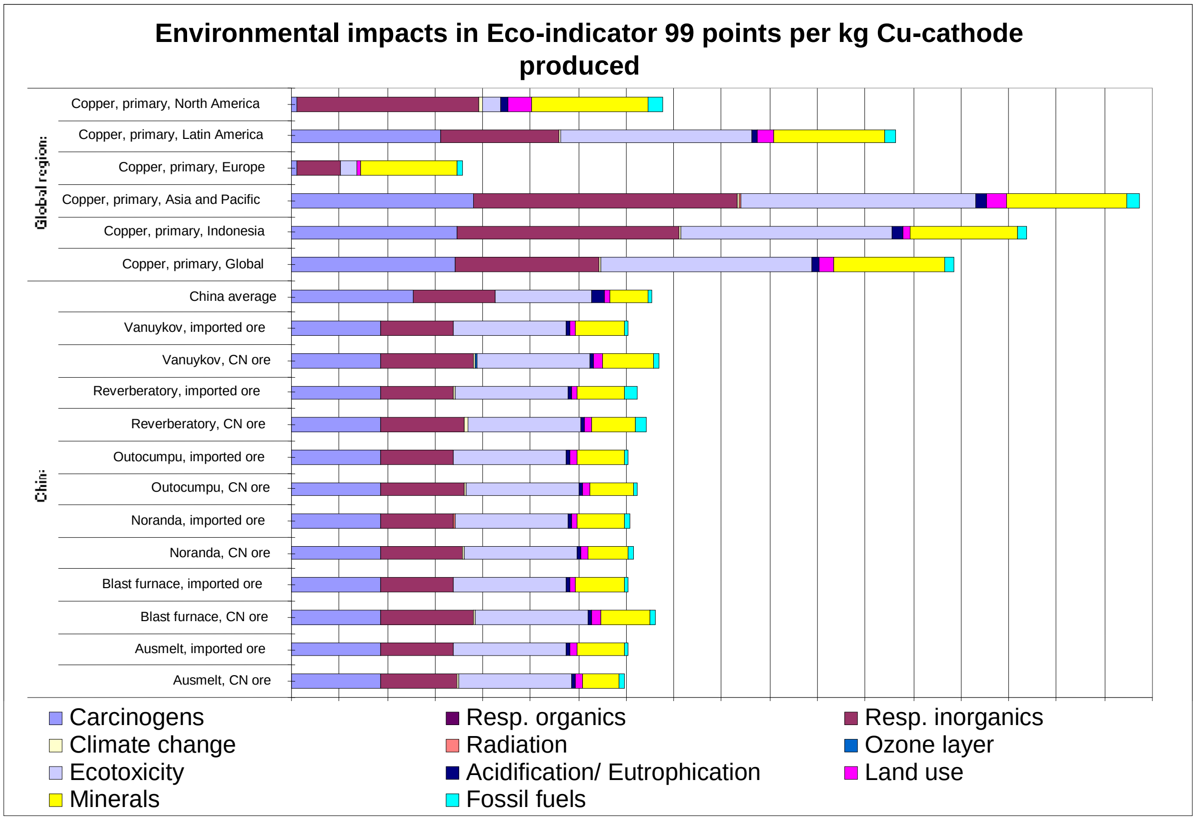
Figure 6.1 Schematic representation of the consumer mix of copper in Europe in ecoinvent. As a proxy for Europe, the consumption pattern for Germany in 1994 is chosen.



Source: Classen et al., 2009.

6.3 Detailed Environmental Impacts, Cu-Cathode Primary Production

Figure 6.2 Environmental impacts in detailed impact categories in Eco-indicator 99 points. The results show the impacts of each technology producing 1kg Cu-cathode with primary production.



The environmental impact category Human Health comprises:

- Carcinogens
- Respiratory organics
- Respiratory inorganics
- Climate change
- Radiation
- Ozone layer

The environmental impact category Ecosystem Quality comprises:

- Ecotoxicity
- Acidification / Eutrophication

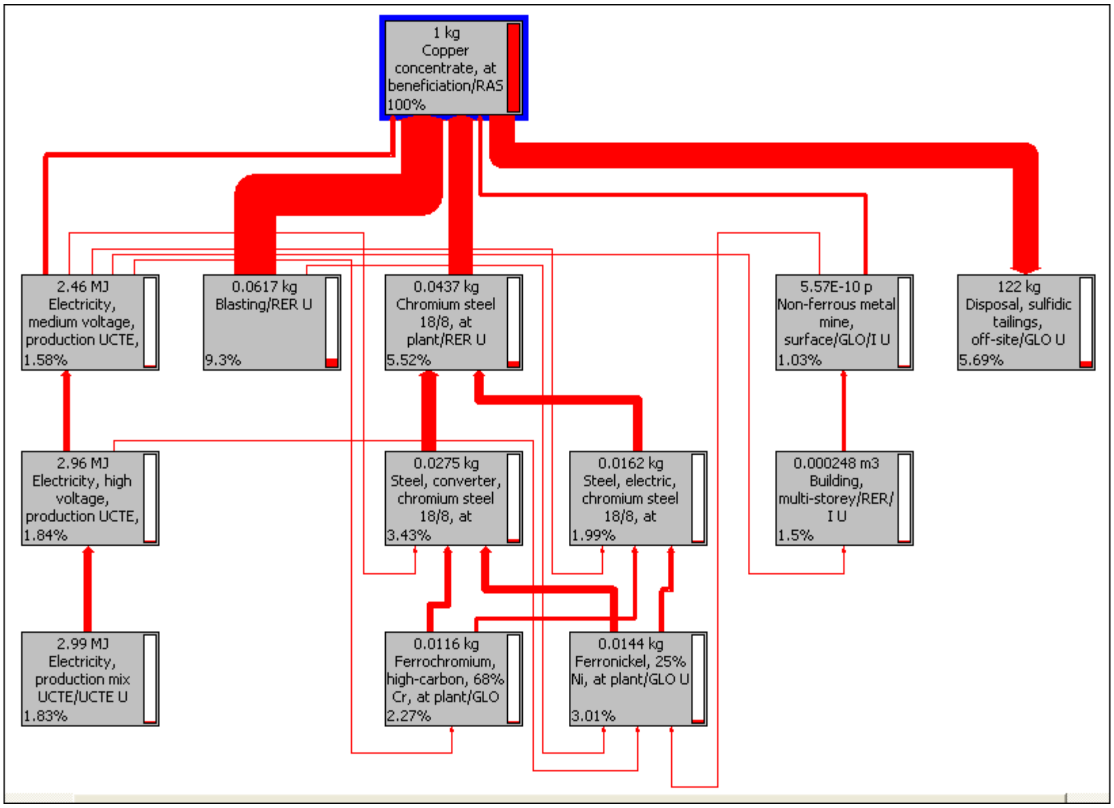
- Land use

The environmental impact category Resource Depletion comprises:

- Minerals
- Fossil fuels

6.4 Contribution Analysis of Mining and Beneficiation

Figure 6.3 Contribution analysis of mining and beneficiation processes in the Asia and Pacific regions.



6.5 Short Descriptions of Common Life Cycle Impact Assessment Methodologies

6.5.1 *Eco-Indicator 99*

Refer to the Eco-indicator 99 (EI99) manual for designers (download from http://www.pre.nl/eco-indicator99/ei99-reports.htm).

Advantages:

Scientifically well-defined method in agreement with ISO/EN 14042 (2000), as long as no single score indicators (Eco-indicator points) are used for external communication of comparative LCA studies. End-point modelling provides safeguard subjects that are easier to rely upon for weighting than environmental problem areas. Different mental models of decision-makers are reflected by the methodology.

Disadvantages:

The method provides a single score and thus could lead to over- or misinterpretation due to seemingly very clear results.

6.5.2 CML 2001

Refer to online textbook CML guide, part 2a, chapter 4.2–4.3.3 (Guinèe et al., 2001); CML guide, part 3, chapter 4.1–4.2 (Guinèe et al., 2001).

Advantages:

Scientifically well-defined method in complete agreement with ISO/EN 14042 (2000).

Disadvantages:

This framework provides a set of many indicators for environmental problems. The results might not be unambiguous. The interpretation (weighting of different environmental problems) has to be done unaided by scientific information.

The results can not be aggregated to a single score. Therefore, for this study, two of the most relevant impact categories for metal processing were chosen and compared to the other LCIA results. These are Acidification Potential and Abiotic Depletion.

6.5.3 Ecological Scarcity 1997

The following description is copied from Frischknecht et al. (2004):

> The method of ecological scarcity—also called eco-scarcity or eco-points method (from the German name of the unit used—“Umweltbelastungspunkte”) allows,

> according to Brand et al. (1997) "a comparative weighting and aggregation of various environmental interventions by use of so-called eco-factors." Brand et al. (1997) is the second report that actually updates and complements the first publication of this method, published in 1990 (Ahbe et al., 1990).
>
> The method contains characterisation factors for different emissions to air, water and top-soil/groundwater as well as for the use of energy resources and some types of waste. All these factors are calculated from the present pollution level (current flows) and on the pollution considered as critical (critical flows). The latter ones are thereby deduced from the scientifically supported goals of the Swiss environmental policy. (Frischknecht et al., 2004, p. 55)

Advantages:

The methodology reflects the political perception of environmental problems in Switzerland (similar concept exists for the Netherlands), suitable for political decisions.

Disadvantages:

Not in agreement with ISO 14042. The methodology has many "blind spots" but nevertheless provides a single score and thus could lead to over- or misinterpretation due to seemingly very clear results.

6.5.4 IPCC 2001 (Climate Change)

The following description is copied from Frischknecht et al., 2004:

> The characterisation of different gaseous emissions according to their global warming potential and the aggregation of different emissions in the impact category climate change is one of the most widely used methods in life cycle impact assessment (LCIA). Characterisation values for greenhouse gas emissions are normally based on global warming potentials published by the IPCC (Intergovernmental Panel on Climate Change) (Houghton et al., 1996; IPCC, 1997; Albritton & Meira-Filho, 2001; IPCC, 2001). The figures given in these publications are used not only for the characterisation of greenhouse gases (Heijungs et al., 1992a; Heijungs et al., 1992b; Guinèe et al., 2001a; Guinèe et al., 2001b) but also within impact assessment methods like Eco-indicator 99 (Goedkoop & Spriensma, 2000) or environmental scarcity 1997 (Brand et al., 1997). All these methods evaluate the

> emissions of greenhouse gases due to anthropogenic activities investigated for the inventory table.
>
> Three time horizons are used to show the effects of atmospheric lifetimes of the different gases. For this study the GWP in 100 years was chosen as time horizon of the calculation.
>
> Use of the method
>
> Direct global warming potentials (GWPs) are relative to the impact of carbon dioxide. GWPs are an index for estimating relative global warming contribution due to atmospheric emission of a kg of a particular greenhouse gas compared to the emission of a kg of carbon dioxide (Albritton & Meira-Filho, 2001). (Frischknecht et al., 2004, p. 97)

Advantages:

Scientifically well-defined method for classification and characterization.

Disadvantages:

No complete impact assessment, but one method usually used among others (e.g., in CML 01, IMPACT 2000+,…).

6.5.5 Cumulative Energy Demand

The following description is copied from Frischknecht et al. (2004):

> Cumulative Energy Requirements Analysis (CERA) aims to investigate the energy use throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. construction materials or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition (Pimentel, 1973; Boustead & Hancock, 1979).
>
> According to VDI (1997), "the data on the cumulative energy demand ... form an important base in order to point out the priorities of energy saving potentials in their complex relationship between design, production, use and disposal". However, the cumulative energy demand (CED) is also widely used as a screening indicator for

> environmental impacts. Furthermore, CED-values can be used to compare the results of a detailed LCA study to others where only primary energy demand is reported. Finally CED-results can be used for plausibility checks because it is quite easy to judge on the basis of the CED whether or not major errors have been made.
>
> Cumulative energy analysis can be a good "entry point" into life cycle thinking. But it does not replace an assessment with the help of comprehensive impact assessment methods such as eco-indicator 99 or ecological scarcity. If more detailed information on the actual environmental burdens and especially on process-specific emissions are available—and the ecoinvent database provides such information—more reliable results are available with such methods. Thus Kasser and Pöll (1999) e.g. write that the CED "makes only sense in combination with other methods".
>
> Different concepts for determining the primary energy requirement exist. For CED calculations one may chose the lower or the upper heating value of primary energy carriers where the latter includes the evaporation energy of the water present in the flue gas. Furthermore one may distinguish between energy requirements of renewable and non-renewable resources. Finally, different ways exist how to handle nuclear and hydro electricity. But so far there is no standardized way for this type of assessment method. (Frischknecht et al., 2004, p. 31)

Advantages:

Only energy demand is needed as inventory data, since no emissions are valuated in this method.

Disadvantages:

Method can lead to wrong conclusions because effects of emissions are not considered, especially when processes have emissions that are not related to energy.