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Insights to Chinese Environmental Policy

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CHINA'S DEMAND FOR SELECTED MINERAL RESOURCES IN THE IRON AND STEEL SECTOR IN 2025

- IMPACTS OF ECONOMIC GROWTH AND NEEDS FOR CIRCULAR ECONOMY APPROACHES

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The volume and structure of the steelmaking and steel consumption of a country and/or a region is largely depending on the technological and economic level of development as well as on the growth of population (Guo and Fu 2010; McSweeney and Hirosako 1991; Tilton 1989). The world raw steel production increased from 40 million t in the year 1900 to over 1.3 billion t in the year 2009 (World Steel Association 2010). With an annual production of 45.8 million t, Germany ranks seventh in the world. Up to 2002, the European Union (EU25) had been the largest steel producer of the world. Since then by China the position of the largest steel producer in the world is taken (World Steel Association 2010). The growing demand for iron and steel induces increasing activities of China on the international raw material markets. High nominal prices at the raw material stock exchanges were brought in connection to the rising Chinese demand (Guo and Fu 2010).

Aim of this paper is it to analyze China's present and future position in the international value chain in the iron and steel sector until 2025 and to draw conclusions for the international raw material situation.

Against this background, the raw material value chain in the iron and steelmaking is described (Section 1). The two most important procedures for the raw and rolled steel production, the oxygen steel route and/or electric furnace steel route are described and embedded into the raw material value chain. Using an econometric model, the most important steps in the value chain are illustrated and China's present and future position for the international raw material supply offer and the demand is analyzed (Section 2). Section 3 summarizes the results and draws conclusions for the international raw material situation.

[+] This article is based on a paper which has been presented at the 3rd International Wuppertal Colloquium on „Sustainable Growth and Resource Productivity – Harnessing Industry and Policy Towards Eco-Innovation" on 4th September 2010 in Brussels.

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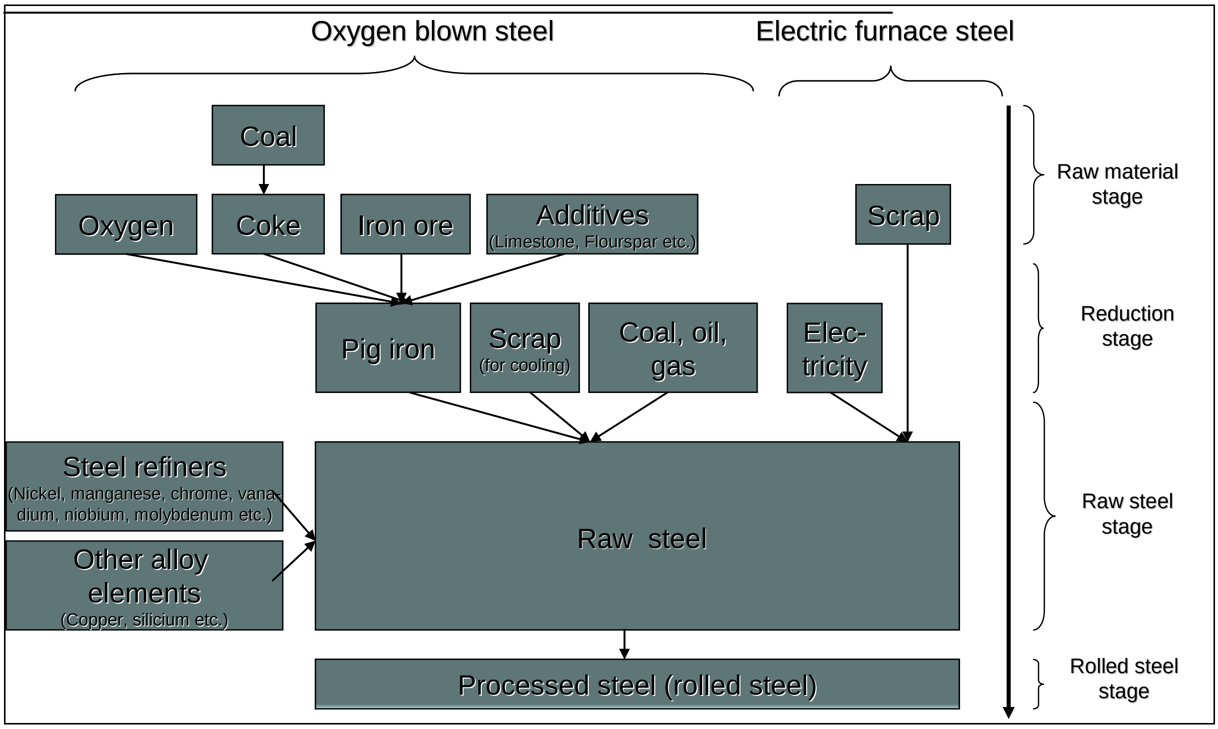
1 Raw material value chain for iron and steel production

Currently, the production of raw steel in China is essentially based on two the paths (Figure 1), the reduction of iron ore, mainly via the blast furnace oxygen blown converter process route, and the melting of steel scrap in electric arc furnaces.

Figure 1:
Raw material value chain in the iron and steel production



Source: According to Wienert (1996).

The old Siemens-Martin process plays only a subordinated role (Wienert 1996). Within these two procedures of the iron and steel production the raw material value chain can be divided into four stages:

- Raw material stage,
- Reduction stage,
- Raw steel stage, and the
- Rolled steel stage

These stages are described in the following with the blast furnace oxygen blown converters as well as the electric furnace steel process

1.1 Raw steel production in oxygen blown converters

Raw material stage

With this process route, iron ores, fluxes and coke as well as other reductants such as coal, oil, gas or processed waste plastics are firstly reduced in blast furnaces into hot metal, which is then converted into crude steel in downstream basic oxygen furnace (BOF) steel plants. Iron ores are charged in the form of lump ores, sinter and pellets. Lump ores are naturally mined ores that are crushed and screened to a certain grain size before their use. However, as a result of preparation and enrichment processes in the iron ore mines to increase the Fe content, very fine-grained ores increasingly accumulate which have to undergo agglomeration. This is done by means of pelletising[1] and sintering[2].

Reduction stage

All the iron ore carriers contain oxygen, which has to be removed through reduction in the blast furnace process. To do this, carbon is used. The most important carbon carrier is blast furnace coke, which nowadays is produced in modern, environmentally friendly coking plants. Understood by coking is the heating of coal in coking chambers, closed off from the outside air, in the course of which the volatile constituents such as coke oven gas, tar, benzol, hydrogen sulphide and ammonia are expelled, collected and recycled for other uses.

For reduction gas production in the lower part of the blast furnace over blast pipes 1200 °C hot air is injected. The coking coal material guest with the oxygen content of air to reduction gas (Carbon monoxide), available within this range, and produces there temperatures of up to 2200 °C. The developing gas rises upward, binds the oxygen and reaches thus the reduction of the ores. The ascending gases warm up the filling. In the iron small quantities carbon separate, whereby the fusing temperature of the pig iron is lowered. The accompanying elements of the materials used form liquid clinkering and can be separated in such a way (Nill 2003).

Pig iron stage

Hot air or "blast" with a temperature of 1200 °C is blown via tuyeres into the lower part of the blast furnace to produce reducing gas. The coke carbon present in this region gasifies with the oxygen contained in the blast to form reducing gas (carbon monoxide), where it generates temperatures as high as 2200 °C. The formed gas rises, binds the oxygen, and thereby brings about the reduction of the ores. The ascending gases heat the burden. Small amounts of carbon become detached in the iron, which lowers the melting temperature of the hot metal. The tramp elements in the charge materials form a molten slag and can thus be separated off. Hot metal and slag collect in the lower region of the blast furnace (hearth) and leave that lower furnace region at a temperature of around 1500 °C via a tap hole, which has to be opened. The hot metal and slag are separated by way of a refractory-lined trough and runner

1 Pelletising involves the forming of ore fines (pellet feed) and concentrates with grain sizes of well under 1 mm into pellets measuring around 10 to 15 mm in diameter. To do this, the ore mix is moistened and a binding agent added. The "green" pellets are then formed in rotating drums or on rotary discs . These green pellets are dried and indurated at temperatures of more than 1000 °C. This can take place in shaft or rotary furnaces or on a travelling grate. Pellet plants are generally located at the iron ore producers.

2 The sintering (= agglomeration) is performed at strand sintering plants, where the strands can measure more than 4 m in width and over 100 m in length. Sintering involves charging a mix of ore fines together with coke breeze, fluxes, in-plant returns and return fines onto a circulating grate, or sinter strand, and igniting the coke breeze contents in the surface by means of gas flames in an ignition furnace. A stream of gas or air is drawn from top to bottom through the mix. A flame front thus passes through the roughly 500 mm thick layer over the strand length and agglomerates the mix into coarse lumps of ore. Sintering plants are located in proximity of the blast furnaces on the works sites of the steel producers. Pelletising and sintering plants can produce around 6 million tonnes of pellets and sinter, respectively, per year.

system and conducted to hot metal torpedo ladles and slag ladles, respectively. To optimise the process and lower the production costs, other carbon carriers such as coal, oil, gas or processed waste plastics are injected as a coke substitute via the tuyeres. Operation of a blast furnace without coke is not possible, however. Coke retains its solid structure in regions of the blast furnace where the ores soften and melt, thereby guaranteeing the gas flow and serving as a supporting structure for the overlying, solid burden column.

Processes have also been developed, though, for reducing ores without the use of coke. These are grouped under the terms 'direct reduction' and 'smelting reduction'.

Direct reduction does not produce any molten hot metal, as it operates at lower temperatures than the blast furnace process. Only the oxygen is extracted from the ores, and the gangue constituents of the ores remain in the sponge iron product (DRI = Direct Reduced Iron). In most direct reduction processes the reducing gas is generated by transforming natural gas into hydrogen and carbon monoxide. DRI is charged mainly in electric arc furnaces.

The smelting reduction process operates in two stages. First of all the ores are reduced to sponge iron, and this is then transformed into hot metal, similar to that from blast furnaces, through the input of coal and oxygen. Of the smelting reduction processes, only the Corex technique has so far been applied industrially.

For reasons of cost efficiency, both processes are restricted to certain regions and plant configurations and are far from attaining the output of a large-capacity blast furnace.

Large-capacity blast furnaces (hearth diameter around 15 m; total volume approx. 6000 m^3) produce some 12000 t hot metal per day or 4 mill. t hot metal per year. This means moving and supplying large quantities of materials on a daily basis, e.g. 19200 t iron ore carriers, 4000 t coke, 1750 t injected coal, and 11 mill. m^3 blast, which is heated in hot blast stoves to over 1200 °C. There is also the accumulation of 3300 t slag daily, which is utilized mainly as a construction material in the cement industry or in road building, as well as of 17 mill. m^3 blast furnace gas which, after cleaning, is used for its energy content. In 2002, some 608 mill. t hot metal were produced in blast furnaces around the world.

The life of a blast furnace, i.e. the duration until its refractory lining needs to be replaced completely, nowadays ranges from 15 to 20 years (Nill 2003).

Rawsteel stage

The hot metal contains spurious tramp elements such as carbon, silicon, sulfur and phosphorus. These constituents are removed in BOF steel plant converters.

From hot metal comes crude steel. The impurities are oxidized in converters by top-blowing oxygen through a water-cooled lance. Certain quantities of scrap, accounting for as much as 25% of the total charge, are added as cooling agents, since the oxidation process generates a strong amount of heat.

A converter holds up to 400 t crude steel. Added along with hot metal and scrap are lime, for slag forming purposes, and alloying agents. The blowing process takes some 20 minutes. Also practiced nowadays besides pure top-blowing with oxygen is combined blowing, in which inert stirring gases or oxygen is additionally injected through the converter bottom (Nill 2003).

1.2 Raw steel production in the electric furnace steel process

Since in the electric furnace steel route instead of iron ore iron scrap is used, there is no reduction stage necessary.

Raw material stage

Increasing importance is being attached to scrap recycling for reasons of optimum raw materials utilization and environmental protection. Steel offers everything needed in this respect, making it a particularly eco-friendly material. Used as the melting unit these days is the electric arc furnace, whose arc makes it possible to transform electrical energy into melting heat with very good efficiency and a high energy density.

The electrical current cannot simply be taken from the public supply system. Using a transformer, it is necessary to turn a current of high voltage into a current of lower voltage (600 to 1000 v) and high amperage (55 to 78 kA). The most important parameter for the performance of an arc furnace is the specific apparent power of the transformer in relation to one ton of charge material, in which respect values of up to 1000 kVA/t are achieved. Graphite electrodes conduct the electrical current and create the arc to the metallic charge (Nill 2003).

Raw steel stage

The main structural elements of an arc furnace are the furnace shell with eccentric bottom tap hole system and working door, the removable roof with graphite electrodes, and the tilting mechanism. The furnace shell has a refractory lining. Arc furnace tap weights nowadays range as high as 200 t, the annual output of such furnaces being around 1.5 mill. t.

To charge the furnace, the roof is lifted and swung aside. The scrap is conveyed in large buckets over the furnace and then charged into the furnace. The roof is moved back into place and the electrodes are lowered, igniting an arc on the cold scrap. During the melt-down process, temperatures in the arc reach as high as 3500 °C, and in the steel bath as high as 1800 °C. The high temperatures also enable the dissolution of difficult-to-melt scrap alloy constituents. Additional injection of oxygen or of other fuel-gas mixtures accelerates the melt-down process. Once the required chemical composition and temperature of the steel have been attained, the furnace is emptied into a ladle by tilting.

An arc furnace can produce any steel grade, completely regardless of the charge (scrap, DRI, hot metal, as well as any combinations). Today, crude steel is produced not only in A.C. electric arc furnaces, which operate with three graphite electrodes, but also in direct-current arc furnaces fitted with only one electrode. This unit, besides offering more favorable conditions for the melt-down of scrap, consumes somewhat less electrical energy and electrode and refractory material (Nill 2003).

1.3 Rolled steel production

The liquid steel, which is produced in large quantities, has to undergo downstream processing. For this purpose it is given certain shapes, dimensions and weights by means of casting. In an integrated iron and steel mill, the capacious casting shop lies, in terms of material flow, downstream of the steel plant and upstream of the rolling mills. Steel is cast according to the ingot or continuous casting method. Ingot casting, which involves pouring the steel portion by portion into permanent (ingot) moulds, is gradually decreasing in importance and used only for high-weight pieces that are to be processed further by forging (Nill 2003).

The liquid steel intended for hot rolling reduction is generally cast by the continuous method nowadays, which in Germany accounts for a share of about 97 %, and world-wide for around 90%.

In the continuous casting process, the liquid steel passes from the casting ladle via a tundish, in closed-stream mode, into a short, water-cooled copper mould. The shape of the mould determines the shape of the strand. Before the start of casting, the bottom of the mould is closed-off by means of a link-type chain or so-called dummy bar. As soon as the required metal level has been reached, the mould is subjected to vertical oscillations so that the strand does not adhere to the mould wall. The incandescent strand, once solidified in its surface zone, is withdrawn from the mould, firstly with the aid of the dummy bar, and then by pinch rolls, while the mould is continuously replenished with liquid steel from the top.

Because of its liquid core, the strand has to be carefully sprayed and cooled with water and supported on all sides by rollers until it has solidified completely, thereby avoiding any breakout through the still thin surface zone.

When it has solidified completely, the strand can be cut to certain lengths by travelling cutting torches or shears. The accelerated cooling produces a uniform solidification structure with favourable technological properties. High casting speeds are achieved these days. Depending on the section and the number of strands to be cast at the same time, speeds range from 0.6 to 6 m/min, the latter for cast sections from 1500 to 2000 mm in width and around 250 mm in thickness.

To be able to cast several heats one after the other without interruption, the follow-on ladle containing the liquid steel has to be brought quickly into casting position. Such sequence casting takes place with the aid of turrets, which can accommodate two ladles.

Continuous casting technology supersedes not only conventional ingot casting but also the blooming-slabbing and billet mills in the downstream rolling stage. The yield of rolled products per tonne of liquid steel can be increased with continuous casting by 10 to 12 % compared with the 85 % for ingot casting, leading to considerable savings in energy and raw materials. The cleanness possible in continuous casting is also better than in ingot casting. The rapid solidification produces a homogeneous structure with less segregation.

The sections continuously cast for long products, such as beams, rails or wire rod, range from 100 x 100 mm to 450 x 650 mm. Slab casters for flat products produce sections measuring 300 x 2000 mm. So-called jumbo casters can achieve sections up to 2700 mm in width.

A currently revolutionary development is near-net-shape casting or casting-rolling, as it saves appreciable rolling work when producing flat steel products (see also: Research & Technology / Production Technology / Shaping & Coating). It is designed to achieve cast thicknesses ranging from 50 to 90 mm for thin slab casting, from 10 to 15 mm for direct strip casting, and from 1 to 5 mm for strip casting. Thin slab technology-based casting rolling has meanwhile become an established process world-wide (Nill 2003).

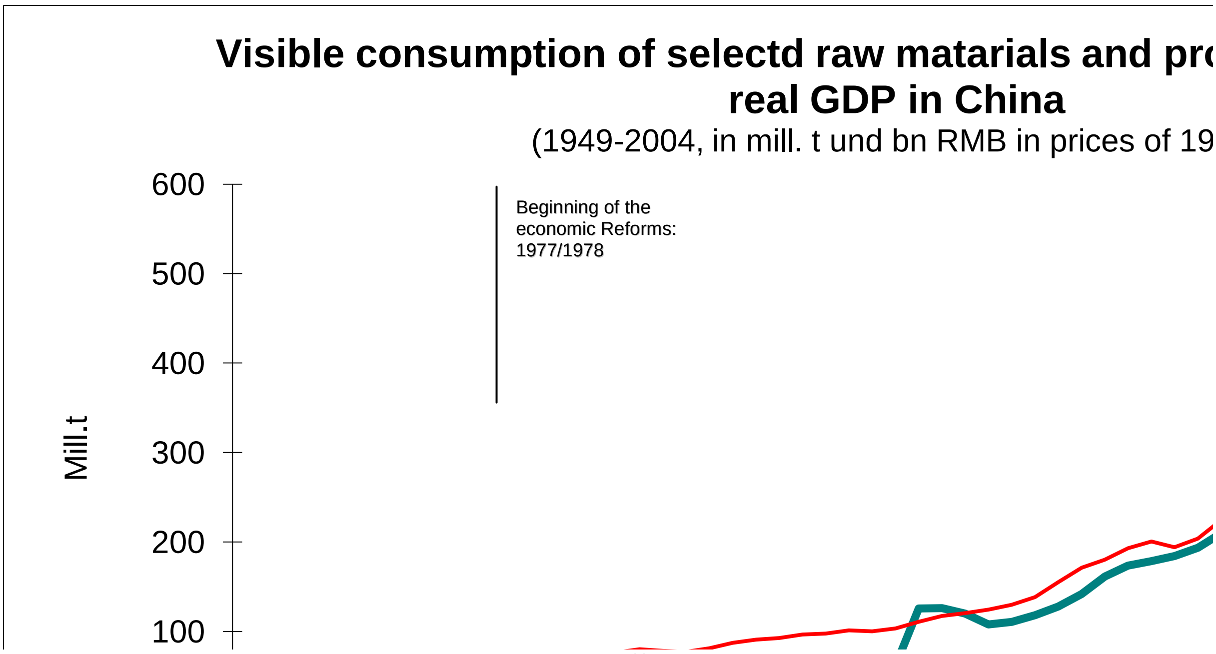
2. China's position in the international value chain

2.1 Present situation

China is a raw material-rich country. According to data of the "White Paper of China's mineral resource policy ", in the country 171 different mineral resources can be found, 158 of them in proven reserves. Substantial reserves are with coal, rare earths, tungsten, zinc, molybdenum, antimony, titanium, gypsum, bentotite, magnesite, barite, fluor-spar, talc and graphite (Xinhua News Agency 2003).

China's importance in the international raw material value chain increased with the growth of iron and steel production in the past years, in particular since the beginning of the economic reforms in 1977/78 and the subsequent fast growing economic development (Figure 2).

Figure 2:
Visible consumption of selected raw materials in China
(1949-2004, in Mill. t)



Source: BGR (2006), State Statistical Bureau China (diff. issues). 1) incl. Stock changes. 2) Rolled steel according to the definition of the Treaty establishing the European Coal and Steel Community.

Investigations in the energy sector showed that with beginning of the economic reforms, a valid correlation can be found between per capita income and resources demand (Oberheitmann and Frondel, 2006).

Between 1977 and 2004 the Gross Domestic Product in China grew by 776%. Except for coke (306%), the visible consumption of other raw materials (iron ore: 744%; iron scrap: 2763%), semi-manufactured (pig iron: 858%; raw steel: 1038%) and manufactured products (rolled steel: 1347%) grew even faster.

With consumption, the domestic production and/or import demand of these raw materials increased. Based on large raw material deposits, China is already the largest producer of coal, coke, pig iron and raw steel in the world (Table 1).

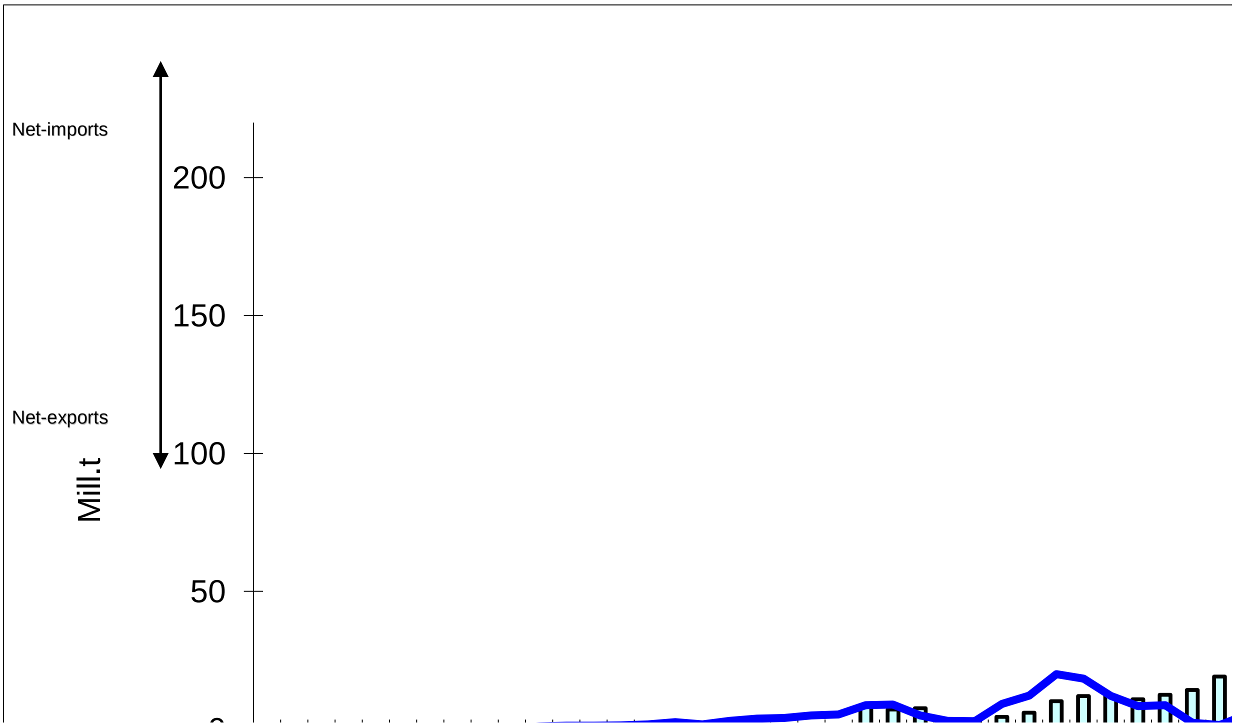
Table 1:
Portion of China of the world production of different mineral raw materials, semi-manufactured and manufactured products in the iron and steel sector
(1950-2004, in %)

Year	***Coal***	***Coke***	***Iron ore***	***Pig iron***	***Raw steel***
1950	3,2	1,2	0,5	n.a.	n.a.
1960	21,0	25,3	6,8	10,5	5,4
1970	17,1	7,2	3,2	4,0	3,0
1980	22,7	13,5	6,6	7,6	5,2
1990	30,6	22,4	10,6	11,8	8,6
1995	37,1	39,2	13,5	20,1	13,3
2000	28,7	37,3	12,2	22,7	15,2
2001	30,9	39,9	12,4	26,9	17,8
2002	34,7	42,5	12,4	28,0	20,2
2003	38,6	52,7	12,9	32,4	22,9
2004	34,1*	45,8*	13,3	35,1*	25,8*

Source: BGR (2006), State Statistical Bureau (diff. issues). *) China = World market leader.

As for iron ore China only has a world production share of 13,3% and is increasingly dependent on imports (Figure 2). Compared to 2000, imports of iron ore increased by 200% in 2004. In the past years, the net imports of rolled steel were between 10 and 30 Mill. tons and only amounted to 5-10% of the visible consumption of the respective years of reference.

Figure 2:
Net-imports of selected raw materials, semi-manufactured and manufactured products in China
(1956-2004, in Mill. t.)

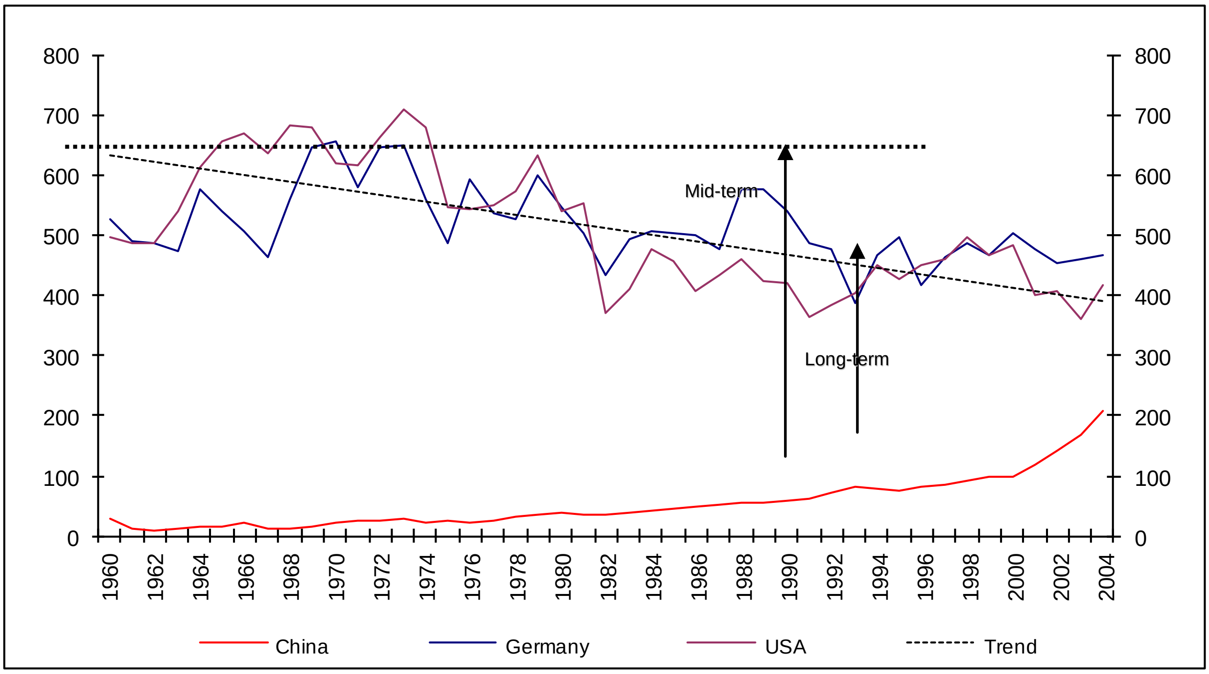


Source BGR (2006), State Statistical Bureau China (diff. issues). 1) incl. Stock changes. 2) Rolled steel according to the definition of the Treaty establishing the European Coal and Steel Community.

Since the economic reforms up to 2000 the Chinese GDP increased by 8,4% p.a. and quadrupled in absolute terms. A plan of the Chinese government up to the year 2020 is a further quadrupling of the material Gross Domestic Product compared to 2000 (Oberheitmann 2005). With a moderate population growth the average per-capita GDP growth rate is one per cent point below this.

Comparing the raw material intensity of China with selected industrialized countries such as Germany or the US, long-term, these developments seem to converge. However, in the year 2004, per capita consumption of raw steel in China was approximately 200 kg, still twice as high as the trend in Germany and the USA (Figure 3).

Figure 3:
Visible raw steel consumption per capita in China, Germany and the US
(1960-2004 in kg)



Source: BGR (2006), State Statistical Bureau China (diff. issues), Wirtschaftsvereinigung Stahl (diff. issues).

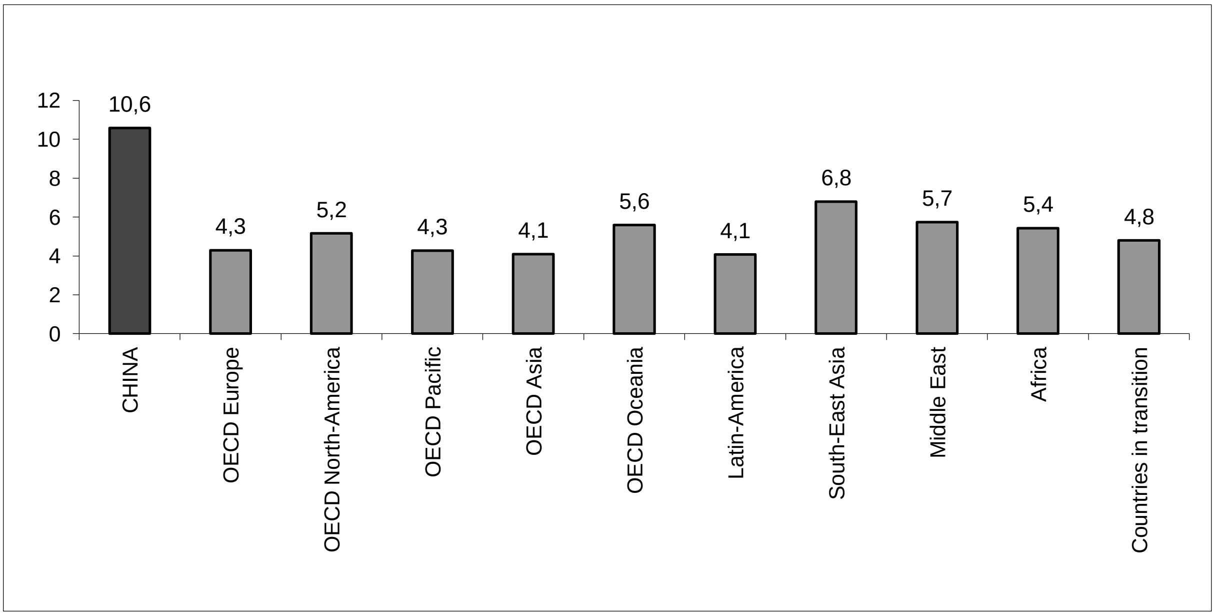
Since China is still not yet in a matured phase of its development, it can be assumed that the Chinese raw material intensity will follow that of the industrialized countries. In the medium term, the level of the industrialized countries of the 1970's may be reached (700-800 kg per head). Long-term, it may fall to the 400 kg level of the industrialized countries.

As a first assumption, China's steel consumption may triple or quadruple in 2025 compared to 2000 result if China reaches the steel intensity level of the industrialized nations of the 1970s.

However, the per capita steel-consumption is only a first guess of the future raw steel demand in China as the consumption is not mainly determined by the development of the population, but by the development of the economy.

In order to compare the development of China's GDP with those of other countries, it should not be based on exchange rates but on purchasing power parities (PPP).

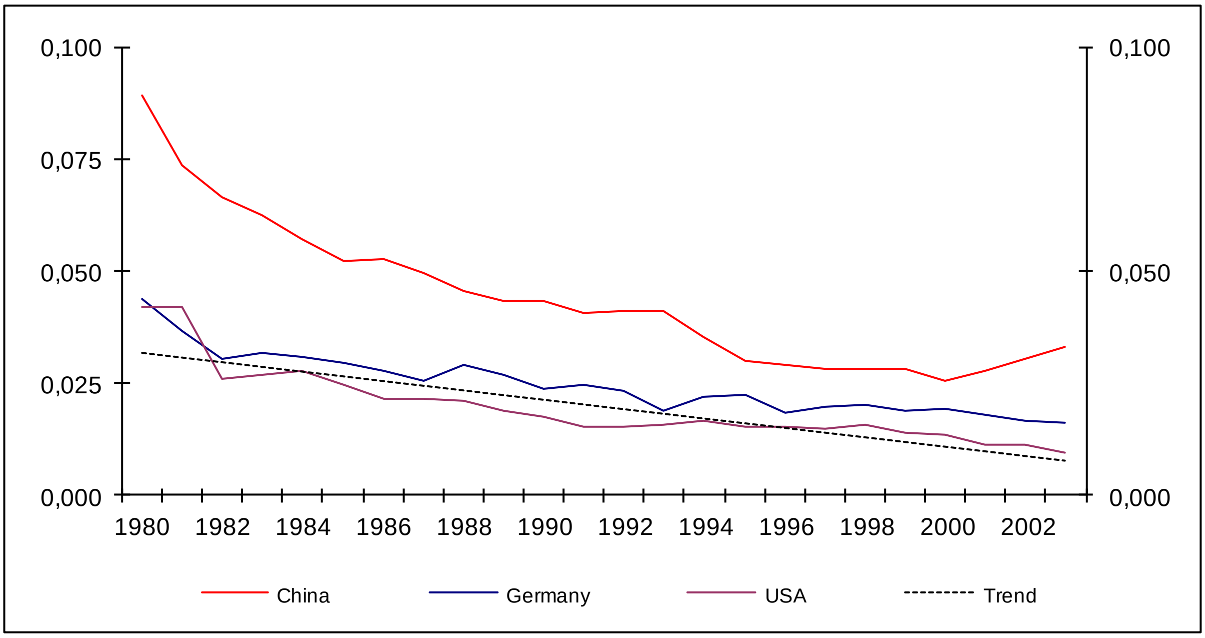
Figure 4:
Average annual GDP growth rates in selected world regions
(1980-2004, billion US$ in PPP)



Source: World Bank (2006).

Figure 4 shows the average annual growth rates of GDP in purchasing power parities, which the World Bank publishes since 1980. During the period 1980 to 2004 the Chinese GDP grew by around 10.6%. In absolute terms, China already has the second highest GDP in the world after the USA.

Figure 5:
Visible raw steel intensity of the gross domestic product in China, Germany and the US
(1980-2004 in kg/US$ in purchasing power parities)



Source: BGR, State Statistical Bureau China (diff. issues), Wirtschaftsvereinigung Stahl (diff. issues).

Calculating the raw steel intensity of GDP in purchasing power parities, Figure 5 shows

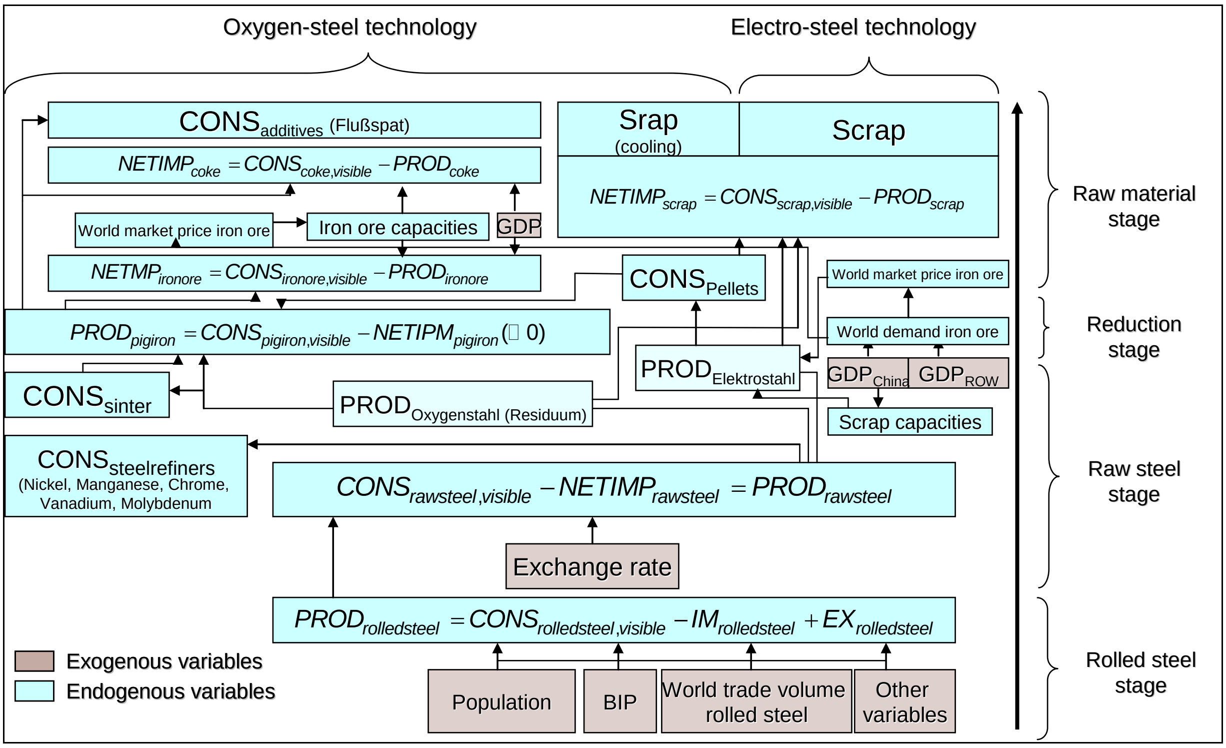
- a falling steel intensity until 2000 as well as
- a constantly increasing raw steel consumption per GDP in China after 2000.

The decreasing steel intensity was due to a strong economic growth with a growing contribution of non-steal-intensive industries like the service sector to GDP. Since 2000, however, a development moving an opposite directions is to be seen, especially due to an over-proportional growth of steel demand in the automotive industry (cars, ships, railways) and in the building sector.

2.2 Future situation

Methodical basis of the analysis of China's future situation China in the raw material value chain of the iron and steel industry is an econometric top-down model of the iron and steel sector in China (Figure 6). Top-down in this context means that the raw material demand is modeled from the rolled steel demand downward to the raw material demand.

Figure 6:
Model scetch



Source: Own depiction.

For better understanding of the method, in the following, the model framework will be described (Chapter 2.2.1). In order to include the uncertainties of the future development into the analysis, a scenario analysis is used (Chapter 2.2.2). I.e. different development paths of the Chinese economy are assumed (high growth, middle growth, low growth) and their implications for the raw material demand and the position of China on the international raw material markets analyzed (Chapter 2.2.3).

2.2.1 Model description

Basic assumption of the model is that economic development in China determines the Chinese rolled steel demand.

Equation (1) shows the OLS estimation for the Chinese *rolled steel demand* for 1980 to 2004:

(1) $\log(AC\_ROLLEDSTEEL) = -1.052 \cdot C + 0.720 \cdot \log(GDP\_PPP)$

t-value (-3.372) (17.592)

R^2 (adj.): 0,93

In a double-logarithmic estimation, the coefficients can be interpreted as elasticities. This means in this case that a 1% growth of GDP China induces an increase of rolled steel consumption of around 0.72%.

The exports of rolled steel can be estimated in similar way with the world trade volume of rolled steel, the imports of rolled steel can be estimated with the Chinese GDP in purchasing power parities and the visible consumption of rolled steel in China. Rolled steel production results by the definition of visible consumption (visible consumption = production + import - export), dissolved for production (Equation 2):

(2) $PROD_{ROLLEDSTEEL} = CONS_{ROLLEDSTEEL, VISIBLE} - IM_{ROLLEDSTEEL} + EX_{ROLLEDSTEEL}$

Without showing every single equation, below the rolled steel stage the model logic is the following:

- The production of the downstream stage determines the visible consumption of the raw material and/or production input in the upstream stage.
- The net-imported goods are determined by exogenous factors like the exchange rate.
- Production results by definition.

This means on the *raw steel stage:* the production of rolled steel ($PROD_{ROLLEDSTEEL}$) determines the consumption of raw steel in the oxygen blown steel process as well as the consumption of iron scrap iron and pellets in the electric furnace steel procedure. The exchange rates have influence on the net-import demand. The raw steel production results by definition (Equation 3):

(3) $PROD_{RAWSTEEL} = CONS_{RAWSTEEL, VISIBLE} - IM_{RAWSTEEL} + EX_{RAWSTEEL}$

Empirically, since beginning of the 1990s a decrease of the pig iron to raw steel relation with a simultaneous increase of the imported scrap iron in China can be seen.

Initially, the assumption may arise that in this time a substitution of pig irons by iron scrap for electric steel making had taken place. However, analyzing the data more carefully, it is to be stated that the portion of electric furnace steel even decreased until 2002. Reasons for this were

- the bad iron scrap quality (the quality of the steel depends crucially on the iron scrap quality),
- notorious scarcities of electricity and
- a still subsidized coal price for the industry in China.

The decrease of the portion of pig iron and the increasing iron scrap imports were rather due to a substitution of the old Siemens-Martin processes by modern oxygen blown steel and to the increased employment of iron scrap as chill scrap in the oxygen blown steel production.

On the *reduction stage,* production determines the visible consumption of pig iron, chill scrap, sinter, additives and other alloying elements in the blast furnace oxygen blown production of raw steel. Empirically, in China a sinking specific employment of iron ore in the pig iron production can be seen since the beginning of the 1990s (1990: 3.1 t iron ore per t pig iron; 2004: 2.1 t iron ore per t pig iron). Main reason for this development were rising portions of sinter in the pig iron production. In the past, sinter was shown in the statistics separately, so that this phenomenon could be proven. Since 1998, however, there is no separately published sinter production (World Steel Association diff. issues). Against this background, this phenomenon cannot be empirically proven any longer and the sinter portion in the model therefore will be assumed as constant. The net-import of pig iron varies around the value zero over time is set as zero in the model.

On the *raw material stage,* production determines the visible consumption of iron ore and coke in the oxygen steel process of pig iron. The iron ore production capacities determine the production of iron ore. The net-imports of iron ore are given by definition. Empirically, the coke intensity of pig iron production, i.e. the coke utilization for pig iron production decreased continuously between 1980 (1.14 t coke per ton of pig iron) and 2003 (0.77 t coke per ton of pig iron) (World Steel Association diff. issues). Possible reasons for it could be:

- The substitution of coke by injecting coal and fuel oil as reducing agents as well as
- A procedure change away from the classical blast furnace route to the modern direct reduction or smelting reduction processes.

For the future, a further dropping of the coke intensity down to the international level (Germany: 0.23 t coke per ton of pig iron) can be assumed. As for the coking process in China, between 1980 and 2003 a reduction of the coal input from 1,57 t to 1,34 t can be seen (for comparison Germany: 1.25 t) (World Steel Association diff. issues). In the model, it can be assumed that the technically possible minimum is almost reached. The domestic coal supply in China is sufficient. Chinese coal imported goods are therefore relatively small.

2.2.2 Scenarios of economic development in China

In order to illustrate the uncertainties of the future development in the model, a scenario approach is used. I.e., for GDP in purchasing power parities three development paths are assumed. These scenarios are:

- HIGH: Extrapolation of the trend of the Chinese Gross Domestic Product in purchasing power parities of the past 10 years (8% per annum)
- LOW: lower growth trend of GDP in purchasing power parities because of slower development of the global markets and frictions in the Chinese reform politics (4% per annum)
- MEDIUM: Starting with the present high growth rates (10% per annum) until 2010 and dropping gown until 2025 slowly to low growth (4% per annum).

Table 2 shows the assumed development of the gross domestic product in China in the different scenarios. The population trend is unchanged the three scenarios.

Table 2:
Assumptions over the development of the population and the Gross Domestic Product in purchasing power parities in China
(1980-2025, in Mill. persons and/or billion US$)

	1980a	*1990 A*	*2000 A*	*2005*	*2010*	*2015*	*2020*	*2025*
Population1	987	1143	1267	1312	1372	1435	1500	1569
GDP (HIGH)	414	1521	4883	7921	11639	17101	25127	36919
GDP (LOW)	414	1521	4883	7628	9280	11291	13737	16713
GDP (MEDIUM)	414	1521	4883	8068	12993	18053	24159	29393

Source: World Bank (2006), State Statistical Bureau (diff. issues). [1] 0,9% p.a starting from 2005, 0,7% starting from 2021.

2.2.3 Forecast

2.2.3.1 Rolled steel stage

On the basis of the assumptions on the economic development between 2005 and 2025, visible consumption of raw steel in China increases between 420% (HIGH), 300% (MEDIUM) and 130% (LOW). The MEDIUM scenario (Table 3) may be the most probable outcome.

Table 3:
Visible consumption, foreign trade and production of rolled steel in China
(2005-2025, in Mill. t)

	2005	***2010***	***2015***	***2020***	***2025***
			HIGH		
Visible consumption	339	517	783	1179	1764
Production	309	477	728	1099	1645
Exports	8	12	17	23	32
Imported goods	38	51	72	104	152
Net imported goods	30	39	55	81	119
			LOW		

Visible consumption	324	399	493	610	754
Production	296	368	459	571	708
Exports	8	10	13	17	22
Imported goods	36	41	48	57	68
Net imported goods	29	31	35	40	46
			MEDIUM		
Visible consumption	346	584	831	1131	1388
Production	316	539	771	1053	1299
Exports	8	11	16	22	32
Imported goods	38	57	76	100	120
Net imported goods	30	46	60	78	89

Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

2.2.3.2 Raw steel stage

This development continues on the raw steel stage (Table 4). The first assumption specified above (tripling to quadrupling of raw steel consumption in China) can be confirmed in the medium scenario (2005-2025: 283%). However, by the year 2025, with 1100 kg the per-capita consumption goes well beyond the high level of the industrial nations in the middle of the 1970´er years (~ 700-800 kg). Assuming a continuously high economic growth until 2025 (8% per annum in the HIGH scenario), a quintupling (394%) of raw steel consumption cab be expected. In the LOW-scenario (4% per annum), only a duplication (125%) of raw steel consumption can be expected.

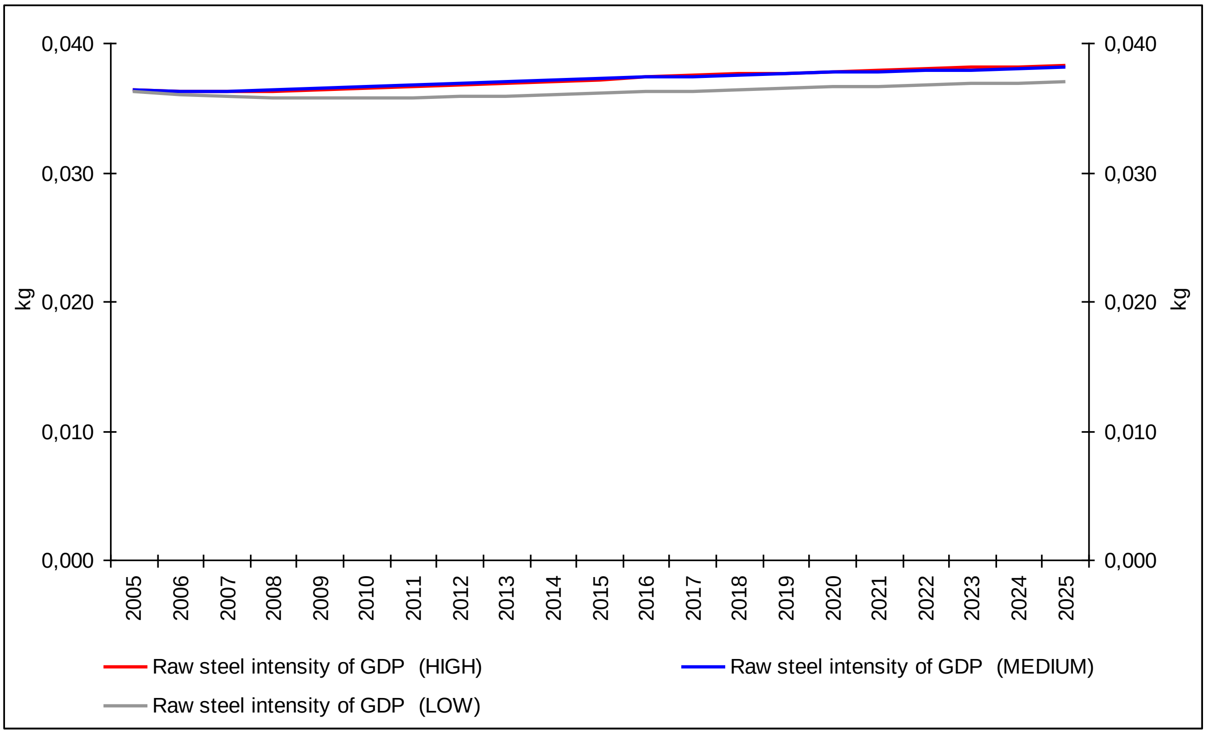
Table 4:
Visible consumption, net imported goods and production of raw steel in China
(2005-2025, in Mill. t)

	2005	***2010***	***2015***	***2020***	***2025***
			HIGH		
Visible consumption	288	424	636	949	1411
Net imported goods	-2	-2	-2	-2	-2
Production	290	427	638	951	1413
Oxygen steel	235	340	505	750	1111
Electric furnace steel	55	86	133	201	302
Production capacity	328	483	723	1079	1603
			LOW		
Visible consumption	276	332	407	502	618
Net imported goods	-2	-2	-2	-2	-2
Production	278	334	410	504	621
Oxygen steel	226	267	325	398	488
Electric furnace steel	53	67	84	106	132
Production capacity	315	378	464	571	703
			MEDIUM		
Visible consumption	293	476	672	910	1119
Net imported goods	-2	-2	-2	-2	-2
Production	295	478	674	912	1121
Oxygen steel	239	381	533	719	880
Electric furnace steel	56	97	141	194	241
Production capacity	334	542	764	1035	1271

Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

The raw steel intensity of GDP will easily rise to about the average of the industrialized country level of the 1980s (0.030-0.045 kg) (Figure 7). A decrease of the raw steel intensity of GDP in China is to be expected maybe after 2030.

Figure 7:
Visible raw steel intensity of GDP in China
(2005-2025, in kg/US$ in purchasing power parities)



Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues)

On the raw steel stage different steel-noble and/or alloying elements are used. In this paper, for China

- Chrome,
- Manganese and
- Nickel

will be examined more closely.

Chrome is a steely-gray, hard metal and has a high melting point. In the steelmaking and non-ferrous metal production it is used for chromium plating and as an alloying element. Chromium and ferrochromium are produced from the commercially viable ore, chromite. As alloying element chrome is used for corrosion and heatproof high-grade steels and NE-alloys.

China has only relatively small chromite ore reserves and must cover the largest part of its visible consumption through imports (Table 5). During period of 2005 to 2025, visible consumption increases between 100% (LOW) and 367% (HIGH), in the same time net imports grow between 150% (LOW) and 550% (HIGH).

Table 5:
Visible consumption, net-imports and production of chromite ore in China
(2005-2025, in Mill. t)

	2005	*2010*	*2015*	*2020*	*2025*
			HIGH		
Visible consumption	3	4	6	9	14
Net imported goods	2	4	6	8	13
Production	0	0	1	1	1
			LOW		
Visible consumption	3	3	4	5	6
Net imported goods	2	3	3	4	5
Production	0	0	0	0	1
			MEDIUM		
Visible consumption	3	5	6	9	11
Net imported goods	2	4	6	8	10
Production	0	0	1	1	1

Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues)

The demand for manganese depends directly on the needs of the steel industry. There are numerous grades of steel and each requires a different amount of manganese. Unit consumption is determined by calculating the average requirement of manganese per ton of steel. Some manganese which is to be converted into steel is present in the iron (hot metal) coming either from the iron ore charge or from the addition of manganese ore to the blast furnace. This manganese is only a small part of the total requirement and it is partly oxidized during the different processes that convert the hot metal into steel. Hence most of the manganese addition is made in the steel melting shop. The majority of it is in the form of manganese ferro-alloys, but there are some cases when it can be added in the form of ore.

Part of the manganese is lost in the steelmaking process through oxidation. In the 1960s and 70s, when the oxygen-blown process progressively replaced the open hearth, Bessemer and Thomas processes, the subsequent improved manganese yield caused a decline in unit consumption. In the 1980s further improvements in steelmaking (brought about by the development of combined blowing processes) meant even better manganese yields. Today, the average unit consumption for industrialized countries is a little over 7.5 kg of manganese per ton of steel. Changes in steel grade chemistry have had an effect on manganese requirements. For a constant unit consumption, manganese demand follows the growth in steel production. Manganese requirements for other metallurgical applications or for non-metallurgical uses do not represent a quantity large enough to significantly affect the evolution of the overall manganese demand as a direct function of steel production growth.

Against the background of China's economic growth, in the years 2005 to 2025 visible consumption of manganese ore in China will grow between 92% (LOW) and 286% (HIGH), the consumption of concentrated metallic manganese between 133% (LOW) and 418% (HIGH) (Table 6). Since China has considerable domestic reserves and production capacities are not working at full capacity, the country can supply the international raw material markets beyond the satisfaction of own consumption starting from 2020.

Table 6:
Visible consumption, net-imports and production of manganese ore and unfinished manganese metal in China
(2005-2025, in Mill. t)

	2005	*2010*	*2015*	*2020*	*2025*
			HIGH		
Manganese ore					
Visible consumption	2	3	4	5	8
Manganese metal, unfinished					
Net-imports	0	0	0	-1	-1
Visible consumption	0	0	0	0	1
Production	0	0	1	1	2
			LOW		
Manganese ore					
Visible consumption	2	2	3	3	4
Manganese metal, unfinished					
Net-imports	0	0	0	0	0
Visible consumption	0	0	0	0	0
Production	0	0	0	1	1
			MEDIUM		
Manganese ore					
Visible consumption	2	3	4	5	6
Manganese metal, unfinished					
Net-imports	0	0	0	-1	-1
Visible consumption	0	0	0	0	0
Production	0	1	1	1	1

Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues)

In the periodic system nickel belongs to the group of iron. Because of its resistance to oxidation, nickel is used in coins and as coats for other metals and alloys such as iron and brass, in addition in chemical apparatuses and in some alloys. Nickel is magnetic and in its ores is frequently accompanied by cobalt. Nickel is available either as ore or as mat. From ore or mat, metallic nickel is won.

Table 7:
Visible consumption, net-imports and production of nickel ore, nickel mat and nickel metal in China
(2005-2025, in Mill. t)

	2005	*2010*	*2015*	*2020*	*2025*
			HIGH		
Nickel ore					
Visible consumption	0,1	0,1	0,2	0,3	0,4
Nickel, mat					
Visible consumption	0,1	0,1	0,2	0,3	0,5
Nickel, in an unfinished way					
Net-imports	-1	-1	-1	-2	-2
Visible consumption	2	3	5	8	12
Production	3	5	7	9	14
			LOW		
Nickel ore					
Visible consumption	0,1	0,1	0,1	0,2	0,2
Nickel, mat					
Visible consumption	0,1	0,1	0,1	0,2	0,2
Nickel, in an unfinished way					
Net-imports	-1	-1	-1	-1	-1
Visible consumption	2	3	3	4	5
Production	3	4	5	5	7
			MEDIUM		
Nickel ore					
Visible consumption	0,1	0,1	0,2	0,3	0,3
Nickel, mat					
Visible consumption	0,1	0,2	0,2	0,3	0,4
Nickel, in an unfinished way					
Net-imports	-1	-1	-2	-2	-2
Visible consumption	2	4	5	7	9
Production	3	5	7	9	11

Source: Own calculations based on data of BGR (2006), State Statistical Bureau China (diff. issues)

Between 2005 to 2025, visible consumption of nickel or and nickel mat is likely to grow between 108% (LOW) and 334% (HIGH), resp. 125% (LOW) and 382% (HIGH). In the same period, China's net exports of metallic nickel will grow between 40 and 100% (Table 7). Against this background, the supply of the international markets with nickel from China is secured.

2.2.3.3 Reduction and raw material stage

2.2.3.3.1 Pig iron

Due to the technological dependencies, there will be a similar picture on the reduction stage (Table 8) as on the raw steel stage. As a function of the economic development, in the period 2005 to 2025 consumption of pig iron increases between 116% (LOW) and 363% (HIGH). In the medium scenario, consumption rises around 262%. Since pig iron is not a genuine internationally traded good, net imports are zero, production and visible consumption are identical.

Table 8:
Visible consumption, net-imports and production of pig iron in China
2005-2025, in Mill. t

	2005	***2010***	***2015***	***2020***	***2025***
			HIGH		
Visible consumption	268	390	574	845	1241
Net-imports	0	0	0	0	0
Production	268	390	574	845	1241
			LOW		
Visible consumption	258	308	374	456	556
Net-imports	0	0	0	0	0
Production	258	308	374	456	556
			MEDIUM		
Visible consumption	273	435	605	811	989
Net-imports	0	0	0	0	0
Production	273	435	605	811	989

Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

The strong growth of pig iron production in the oxygen blown steel process and a under-proportional growth of the electric furnace steel process induces a strong increase of production and net-imports of iron ore (Table 9).

2.2.3.3.2 Iron ore

With an average GDP growth of around 8% per annum (HIGH), between 2005 and 2020 consumption of iron ore grows around 384%, in the LOW scenario, of a 4% per annum GDP growth it is only 104%. In the MEDIUM scenario visible iron ire consumption of will grow by 272%.

Table 9:
Visible consumption, net-import, production and production capacity of iron ore in China
(2005-2025, in Mill. t)

	2005	***2010***	***2015***	***2020***	***2025***
			HIGH		
Visible consumption	250	369	549	817	1211
Net-imports	136	218	349	547	841
Production	114	151	200	271	370
Production capacity	128	170	225	305	416
			LOW		
Visible consumption	256	300	358	431	522
Net-imports	128	154	193	244	308
Production	114	130	147	167	191
Production capacity	128	146	165	187	214
			MEDIUM		
Visible consumption	268	436	613	820	997
Net-imports	139	254	374	520	644
Production	115	162	213	266	313
Production capacity	128	182	240	300	353

Source: Own computations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

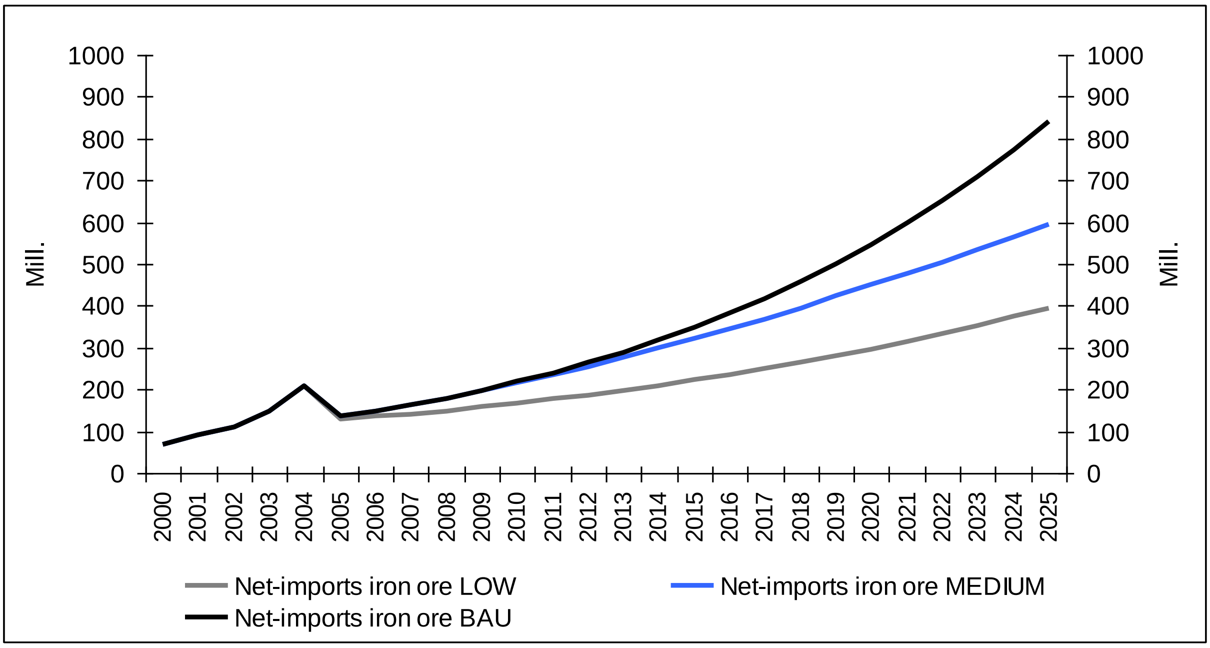
Important for the world markets is the growth of the Chinese iron ore import demand. Between 2005 and 2025, it will grow between 141% (LOW) and 518% (HIGH). In the medium scenario the growth rate is about 363% (Figure 8).

The most important reasons for the rising import demand for iron ore in China are:

- the small Fe-content of the Chinese iron ore (Ross and Feng 1991) as well as
- decreasing domestic iron ore reserves in China.

The Fe-content of Chinese iron ore is 32-33%, a low content compared to iromn ore from Brazil or Australia (approx. 60%). This means, one ton imported iron ore can substitute two tons domestic iron ore. Against this background, domestic production (LOW: 67%, HIGH: 274%) will grow much less in the comparison to visible consumption (LOW: 104%; HIGH: 384%) in China.

Figure 8:
Net import-of iron ore in China
(2000-2025, in Mill. t Fe)



Source: Own calculation based on data of BGR (2006), State Statistical Bureau China (diff. issues).

In addition to that, domestic reserves at iron ore in China are decreasing (BGR, 2006). In 1999 reserves were 7.8 billion tFe (10.6% of the world reserves), in 2004 only approx. 7.0 billion tFe or 8.9% of the world reserves.

2.2.3.3.3 Sinter and pellets

In China iron ore is also used in the form of sinter and pellets. Depending on the economic development, between 2005 and 2025, visible consumption of sinter increases between 55% (LOW) and 197% (HIGH). The visible consumption of pellets, which is essentially dependant on the share of the electric furnace steel of the entire raw steel production, in all three scenarios increases by around 110% (Table 10).

Table 10:
Visible consumption and production of von iron scrap, sinter and pellets in China
(2005-2025, in Mill. t)

	2005	*2010*	*2015*	*2020*	*2025*
			HIGH		
Visible consumption iron scrap	60	86	120	166	229
Production iron scrap	57	86	125	181	263
Visible consumption sinter	71	90	118	156	211
Visible consumption pellets	10	14	17	19	21
			LOW		
Visible consumption iron scrap	58	73	88	105	125
Production iron scrap	54	69	85	103	124
Visible consumption sinter	69	76	85	95	107
Visible consumption pellets	10	13	16	19	21
			MEDIUM		
Visible consumption iron scrap	60	94	126	161	191
Production iron scrap	58	96	132	175	212

Visible consumption sinter	71	98	123	151	172
Visible consumption pellets	10	14	17	19	21

Source: Own calculations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

2.2.3.3.4 Iron scrap – Impact of circular economy approaches

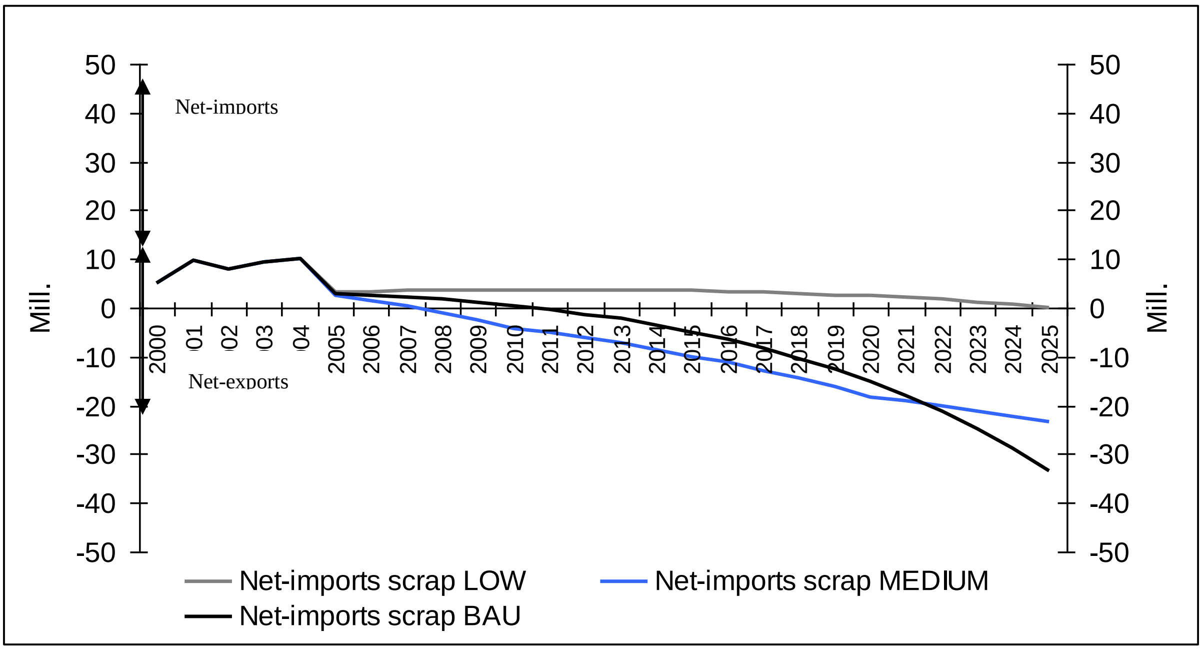
The utilization of iron scrap can be seen related to circular economy approaches in China. Circular economy has received growing political prominence in China since the late 1990s as a mechanism to help balance China's runaway economic development that is increasingly seen as producing unsustainable social and environmental costs and consequences (Zhu, 1998; Heymann, 2006). In 2008, China adopted a circular economy law, it came into force on 1 January 2009 (China Daily, 2008). Each year, more than 60 million tons of scrapped iron and steel, non-ferrous metals, electric and electronic products, papermaking materials and chemical materials have been recovered (Zhou, 2006).

The waste material recovery and processing system has helped to employ lots of people and improved the financial situation in some localities. In circular economy approaches in the iron and steel industry, the utilization of iron scrap can be used to substitute domestic iron ore and could also contribute to a decrease to imported iron ore, which has to be shipped over long distances, e.g. from Brazil. However, the visible consumption of iron scrap iron in China only increases under-proportionally in the different scenarios. Between 2005 and 2025, in the HIGH scenario it grows by 282%, in the MEDIUM scenario by 218% and in the LOW scenario by 116%. The most important reasons for the low substitution of pig iron by iron scrap iron is due to the under-proportional increase of the electric steel making in China (2004: 18.4%; 2025:20,6). Most important reasons for that are:

- The coal dominance of China's primary energy supply with low production costs which favors oxygen blown steel processes, and to a smaller extent
- continuous scarcities of electricity, which lead to bottlenecks during the electric steel production.

Against the background of a larger iron scrap supply (HIGH: 361%; MEDIUM: 266%, LOW: 130%) in the comparison to the iron scrap demand (see above,), export surpluses of scrap iron are even possible (Figure 9).

Figure 9:
Net imports of iron scrap iron in China
2000-2025, in Mill. t



Source: Own calculations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

2.2.3.3.5 Coke

In China, only a relative small decrease of the classical oxygen blown steel in favor of modern direct reduction processes without the utilization of coke will only lead to a moderate dropping of the specific coke intensity of pig iron production (t coke per t pig iron; 2004: 0.69; 2025: 0.53) towards the international level (e.g. Germany: 0.23 t). (World Steel Association diff. issues) Therefore, the visible coke demand in the HIGH scenario rises by around 244%, in the MEDIUM scenario around 170% and in the LOW scenario by around 73% (Table 11).

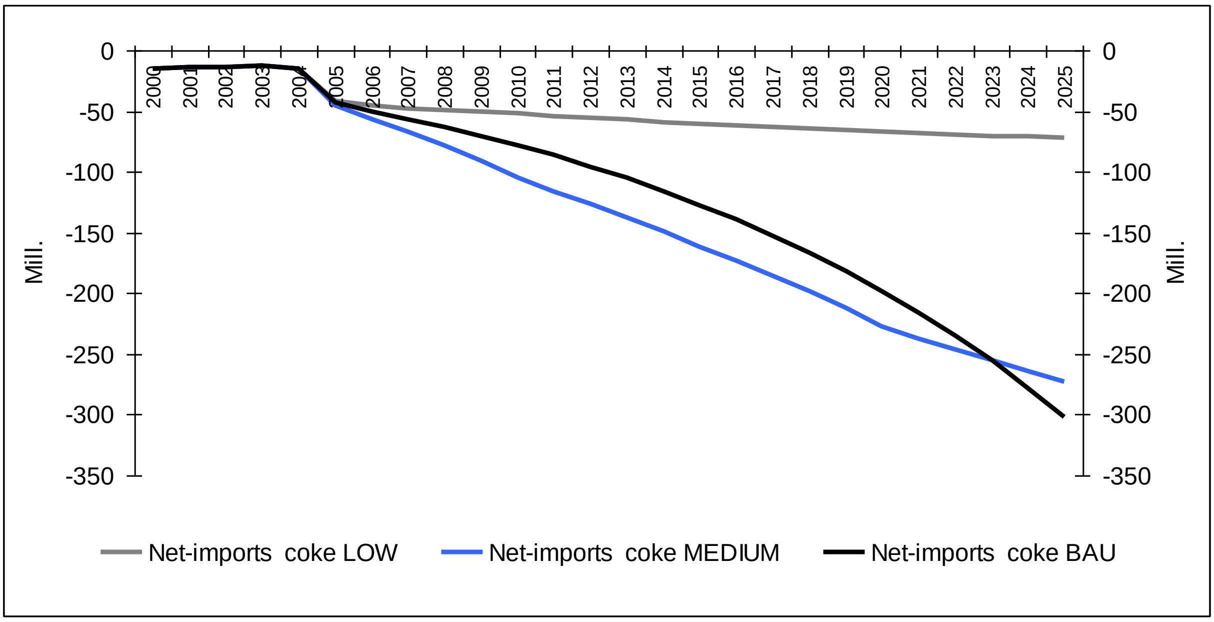
Table 11:
Visible consumption and production of coke in China
2005-2025, in Mill. t

Coke	***2005***	***2010***	***2015***	***2020***	***2025***
			HIGH		
Visible consumption	193	254	343	473	663
Production	235	332	470	672	965
			LOW		
Visible consumption	187	211	242	278	323
Production	230	272	322	383	455
			MEDIUM		
Visible consumption	196	278	358	453	529
Production	238	365	498	651	783

Source: Own calculations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

Higher growth rates of production (HIGH: 311%; MEDIUM: 229%; LOW: 98%) and large potentials for coal production together with surplus-capacities of coking favor net-exports of coke (Figure 10).

Figure 10:
Net imports of coke in China
2000-2025, in Mill. t



Source: Own calculations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

By 2025, net exports of coke will increase by between 130 mill. t (LOW) and 300 mill. t (HIGH). Long-term, this has a stabilizing effect for the international coke markets.

3. Summary and conclusions for the international raw material situation

In modern industrial economies, due to its versatile characteristics and recycling potential, steel is the basis for a sustainable development. Steel can be used in nearly all important industrial sectors: Apparatus and mechanical engineering, bridge construction, steel construction, energy and environmental technology, transport, packaging industry etc.

China is not only one of the world’s largest consumer of steel and steel-related raw materials, because of its large reserves, the country is also world-leading producer of important raw materials used for the iron and steel production (coal, coke, fluor-spar) as well as of semi-manufactured (pig iron, raw steel) and manufactured products (rolled steel).

Against the background of the forecast results of the employed top-down model of the Chinese iron and steel sector, the following results can be summarized:

- Basically, the international raw material situation for iron and steel is not endangered by economic growth in China.
- The supply of the raw material markets with coke, scrap iron, manganese and nickel from China is secured also in the future. China has an increasing net-export position in all scenarios.

However, an increasing import demand will be for Chromite (2005-2020: 150-550%) and iron ore (2005-2020: 150-200%), which is a central raw material of the iron and steelmaking process. The most important reasons for the rising import demand for iron ore are:

- A low Fe-content of the Chinese iron ore (32-33%) compared to imported iron (approx. 60%). The consequence: smaller growth of domestic production (LOW: 67%, HIGH: 225%) compared to the growth of visible consumption (LOW: 104%; HIGH: 384%).
- Decreasing domestic iron ore reserves: 1999: 7.8 billion tFe (10.6% of the world reserves), 2004: approx. 7.0 billion tFe (8.9% of the world reserves).

In this context, circular economy approaches relating to iron scrap can help to reduce the demand of domestic iron ore and transport-intensive imports of iron ore, e.g. from Brazil. However, the growth rates of steel produced in electric furnaces is under-proportional. Most important reasons for that are:

- the coal dominance of China's primary energy supply with low production costs which favors oxygen blown steel processes, and to a smaller extent; and
- continuous scarcities of electricity, which lead to bottlenecks during the electric steel production.

Probably, iron ore reserves in China further decrease in however due to the growth of domestic production in the classical oxygen blown processes. Result will be a growth of the Chinese import demand on the world market. An import share of 100% in China would take places i starting from 2049 (LOW, reserve reduction 2% per annum), if not even earlier starting from 2031 (HIGH, reserve reduction 5% per annum) (Table 12).

Table 12:
Static availability and reserves of iron ore in China for different reserve reductions
(starting from 2025, in billion t and years)

Scenario (reserves in 2025)	*2% per annum. (5.1 billion t)*	*3% per annum. (4.3 billion t)*	*4% per annum. (3.6 billion t)*	*5% per annum. (3.1 billion t)*
HIGH	12	10	8	6
LOW	24	19	16	12
MEDIUM	15	12	9	8

Source: Own calculations based on data of BGR (2006), State Statistical Bureau China (diff. issues).

The increasing import demand of China will have influence on the world market price for iron ore. However, although the Chinese demand may be an important determinant of the future market price of iron ore, it covers only one part of the influence. The demand of the OECD states will surely also are of great importance.

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