Hamburgisches
WeltWirtschafts
Institut

CO_2 emission reduction potential of large-scale energy efficiency measures in power generation from fossil fuels in China, India, Brazil, Indonesia and South Africa

Benn J. Boehme, Matthias Krey

HWWI Research
Paper No. 5

Hamburg Institute of International Economics (HWWI) | 2005
ISSN 1861-5058 | ISSN (Internet) 1861-504X

This paper has been prepared on behalf of the HWWI.

Benn J. Boehme
Perspectives Climate Change GmbH
Bei der Apostelkirche 24 | 20257 Hamburg | Germany
Tel +49 (0)177 25 86 987 | Fax +49 (0)89 14 88 28 08
boehme@gmx.com

Matthias Krey
Perspectives Climate Change GmbH
Bei der Apostelkirche 24 | 20257 Hamburg | Germany
Tel +49 (0)40 21 97 97 61 | Fax +49 (0)89 14 88 28 08
krey@perspectives.cc

HWWI Research
Hamburg Institute of International Economics (HWWI)
Neuer Jungfernstieg 21 | 20354 Hamburg | Germany
Tel +49 (0)40 34 05 76 - 0 | Fax +49 (0)40 34 05 76 - 76
info@hwwi.org | www.hwwi.org
ISSN 1861-5058 | ISSN (Internet) 1861-504X

CO_2 emission reduction potential of large-scale energy efficiency measures in power generation from fossil fuels in China, India, Brazil, Indonesia and South Africa

November 2005

Benn J. Boehme, Matthias Krey

Abstract: We quantify the theoretical potential for energy-efficiency CDM projects using best available technology in coal, natural gas or oil fuelled power generation in China, India, Brazil, Indonesia and South Africa, looking at new power plants or retrofit measures. We then discuss the likelihood of the potential emission reductions materialising under CDM. Our results are very sensitive to choices of baseline and project efficiencies and the level of electricity generation from potential emission reduction projects until 2020. The highest emission reduction potential can be achieved from using supercritical power plants in China (275 Mt CO_2), India (130 Mt) and Indonesia (41 Mt), followed by retrofit measures in China (<62 Mt), India (<31 Mt). In Brazil, new gas power plants offer the most emission reduction potential (36 Mt), while in South Africa the complete refurbishments of currently mothballed 4 GW coal-fired power plants offer a moderate potential (<13 Mt). Especially the chances for natural gas power projects to qualify as CDM projects are slim due to their very high economic attractiveness. In India both new supercritical coal-fired power plants as well as refurbishment of coal power plants stand a fair chance to pass the additionality test as supercritical power plants have not been commissioned so far and (international) financing for power projects is harder to procure than in China.

Acknowledgement: This paper has been funded in the context of the “Future CDM” project by the Ministry of Economy, Trade and Industry, Japan

Key words: CDM, power generation, fossil fuel, efficiency improvement

Contents

1. Introduction

Fossil fuel-based electricity generation amounted to 66.4% of the world electricity production in 2003 of which 60% was coal-based (see IEA 2005a). In 2003, China and India had a 30% share in global coal-based electricity generation. Fossil fuel-based electricity generation accounted for 40% of world CO_2 emissions in 2000 and is estimated to contribute to 43% in 2030 – with a developing countries' share of 33% (see IEA 2002). In 2004, the share of coal based power generation was 90% in South Africa, 77% in China and 70% in India (see CIAB 2005). China and India will continuously build new coal fired power plants (see Lako 2004). Besides, natural gas based power production is becoming increasingly important in developing countries due to the growing liberalisation of the electricity markets. In contrast, a considerable number of developing countries without domestic coal reserves rely on oil-fired power generation.

Several studies have shown that the fossil fuel-based power sector in developing countries offers enormous potential for CO_2 emission reductions both through energy efficiency improvements in existing plants as well as utilisation of state-of-the-art technology for new capacity additions (see IPCC 2001).

The Clean Development Mechanism (CDM) could potentially help energy efficiency projects in power generation in developing countries to become economically attractive or remove barriers for implementation of state-of-the art technology in this area. The volume of CERs that potentially accrue from such project types is potentially huge.

This paper assesses the potential for energy efficiency CDM projects in power generation in selected key developing countries - China, India, Brazil, Indonesia and South Africa – on a quantitative basis.

The following chapter summarises the current status of fossil fuel-based electricity generation options. In the third chapter the methodology for quantification of potential CO_2 emission reductions is presented. Chapter four gives an overview of recent trends in the power sector of each country and presents the quantification results. Chapter five discusses the likelihood of the quantified emission reductions to materialise under CDM. The results of the paper are summarised in chapter six.

2. Current status of fossil fuel-based electricity generation options

2.1 Coal-based electricity generation

The standard technology for coal-fired electricity generation is pulverised coal (PC) fired sub- or supercritical simple Rankine Cycle (see Lako 2004). In OECD countries, the average generation efficiency of coal-fired power plants in 2002 was 36%. In developing countries the average was 30% (see Philibert et al. 2005). New plants with state-of-the-art supercritical steam technology can achieve 45% efficiency in temperate climate and sub-critical state-of-the-art plants can achieve up to 39% (see Philibert et al. 2005).

Examples for different technology options for large-scale power generation as well as their characteristics are displayed in Table 1.

Table 1: Different types of coal-fired power-plants built around the world

	Pulverised coal-fired power-plant[1] (PC)	Circulating fluidised bed combustion (CFBC)	Pressurised fluidised bed combustion (PFBC)	Integrated gasification combined cycle (IGCC)
General characteristics				
Status	Commercial	Commercial	Demonstrated	Demonstrated
Installed worldwide	~1,000 GW	~3 GW	~1 GW	~1 GW
Complexity	Medium	Low	Medium	High
Usage	Base/medium load	Base/medium load	Base/medium load	Base load
Fuel range	All coals	All coals, residues, biomass	All coals	All coals, residues, biomass
Fuel flexibility	Low	Very high	High	Medium
Operational flexibility	Medium	High	Medium	Low
Technical parameters				
Unit size (2000)	400-1,000 MW	≤ 460 MW	≤ 360 MW	≤ 318 MW
Max. GT[2] applied	-	-	~140 MW	198 MW
Max. efficiency 2000	44%	39%	41%	45%
Max. efficiency 2010	48-50%	43%	44%	50-52%
Max. efficiency 2020	50-53%	48%	50%	54-56%
Environmental parameters				
Desulphurisation	90%	90%	90%	99%
SO_2 emission (2000)	0.6 kg/MWh	0.66 kg/MWh	0.66 kg/MWh	0.06 kg/MWh

[1] Flue gas or dolomite ($CaMg(CO_3)_2$) addition desulphurisation included

[2] GT: gas turbine

NO_x emission (2000)	1.2 kg/MWh	0.8 kg/MWh	0.8 kg/MWh	0.4 kg/MWh
CO_2 emission (2000)	760 kg/MWh	860 kg/MWh	820 kg/MWh	740 kg/MWh
Financial parameters				
Investment cost[3] (2000)	€ 1,200/kW	€ 1,000/kW	€ 1,500/kW	€ 1,700/kW

Source: see Lako 2004

2.1.1 Pulverised coal (PC) power plants

Pulverised coal (PC) power plants use the single cycle steam turbine technology (ST) for power generation. High-temperature and high-pressure steam is generated by combusting the pulverised coal in a boiler, and then expanded in a steam turbine, which drives an electric alternator. One important measure for the generating efficiency of steam-turbine power plants is the steam pressure. In traditional so-called sub-critical power plants, the pressure is well below 22 MPa and steam and water can be well distinguished. Higher temperatures (by reheating the steam) along with higher pressures cause the water to form a supercritical fluid and superior efficiencies can be achieved as shown in Table 2.

Table 2: Classification of pulverised coal power plants according to UNIPEDE

Category	Unit	Sub-critical	Supercritical	Advanced Supercritical	Ultra Supercritical
Year		<1990	1990	1995-2000	>2000
Live steam pressure	[MPa]	16.5	≥22.1	27.5-30	≥30
Live steam temperature	[°C]	540	540-560	560-600	≥600
Reheat steam temp.	[°C]	- (No reheat)	560	580	≥600
Single reheat		No	Yes	Yes	No
Double reheat		No	No	No	Yes
Generating efficiency	[%]	~38	~41	~44	46+

Source: see Lako 2004

The most advanced PC technology, ultra supercritical (USC), can only achieve the high efficiency given in Table 2 when low temperature cooling water is available (see Lako 2004).

2.1.2 Fluidised bed combustion technology options (FBC)

More advanced than PC firing is fluidised bed combustion (FBC). FBC is mainly used for small- to medium- scale firing systems (3-100 MW_{th}). Further development led to the "Circulating Fluidised Bed Combustion" (CFBC) technique, which achieves high combustion efficiencies. CFBC often serves for combined heat and power generation (CHP), and it can be fed with different (low-grade) fuels like coal, peat and biomass. In 2000, CFBC plants with 250 MW_e were commercially available.

2.1.3 Integrated gasification combined cycle plants (IGCC)

IGCC combines the advantages of combined cycle gas-fired plants with the use of the most abundant fuel in the world. Coal is gasified and the resulting gas is combusted in a gas turbine. The hot

[3] € of 2004

combustion gas is used for firing a boiler for steam generation, the high-pressure, high-temperature steam is expanded in a steam turbine. IGCC plants are not common for commercial power generation yet while several demonstration plants exist. They achieve efficiencies of 45%.

2.2 Natural gas based electricity generation

2.2.1 Single cycle steam turbine (ST) and gas turbine (GT)

Some natural gas-fired power plants use the single cycle steam turbine technology (ST) used in PC power plants and their efficiency is similar to the coal-fired ones. Efficiencies of new plants can reach more than 40%, but the global average efficiency of existing plants is around 30% (see IPCC 2001). Single cycle gas turbines (GT) work like jet engines. Power generation efficiencies of modern (cooled) GT are around 38% with prospects to exceed 40% in the future (see Ausmeier 2002).

2.2.2 Combined Cycle Gas Turbines (CCGT)

The most efficient way to use the energy contained in the gas is to drive a gas turbine with the gas and use the hot combustion gas for steam generation in a boiler. This technology is called Combined Cycle Gas Turbine (CCGT). The steam is used to drive an additional steam turbine. Both turbines drive alternators to generate electricity. The generation efficiency of the most advanced combined cycle gas fired power plants is approximately 60%.

2.3 Oil based Electricity Generation

2.3.1 Single cycle steam turbine, gas turbine and Combined Cycle Gas Turbine

Like natural gas-fired power plants, some oil fired power plants also use single cycle steam turbines with efficiencies similar to the coal and gas fired ones (see IPCC 2001). Oil-fired gas turbines can be run in combined cycle mode as well. Current and expected future efficiencies for both GT and CCGT are the same as for a natural gas fired GT.

2.3.2 Internal combustion engines (diesel engines)

Fuel oil and diesel oil can also be used in internal combustion engines (e.g. diesel engines), which are used to drive an alternator. Small power stations without access to natural gas use this technology. Often diesel generators are backup systems e.g. in hospitals, industry or public grids in remote areas. The efficiency of diesel generators can be up to 40%.

2.4 Renovation & modernisation (R&M) of existing fossil fuel fired power plants

2.4.1 R&M in coal-fired power plants

There are several possibilities for increasing the efficiency of existing PC plants. Some low- and medium-cost options offer a potential of 2-3%. The IEA (2003) gives a list of typical smaller R&M measures for PC plants:

- Control of air levels (less excess air)
- Repair of leaking steam valves and condensers
- Improved boiler tubes (better material)
- Optimised water flow patterns for superheater banks
- Upgrading of boiler and turbine control hardware
- Replacing of outdated plant control systems
- Variable speed drives for less auxiliary electricity consumption
- Better seals in rotary air heaters
- Optimising of turbine stator blade design and material
- Upgrading/replacing of fuel preparation systems (e.g. coal mills)
- Introduction/improvement of coal beneficiation/washing/blending (where applicable)

Larger efficiency improvements can be made by replacing the old burners or boilers. Such refurbishment projects can be associated with the use of more advanced technology than used before but resulting efficiencies will always be lower than those of new power plants using the same technology. Examples could be conversion to (pressurised) fluidised bed combustion for smaller capacity or conversion to (advanced) supercritical steam parameters for larger capacity. Also installing state-of-the-art PC equipment can significantly improve the plant efficiency if the equipment currently operated has very low efficiencies.

2.4.2 R&M in natural gas fired power plants

For natural gas fired power plants, several measures for increasing the efficiency of an existing plant are available, too. A selection can be found below:

- Cooling the inlet air
- Heating the fuel gas (see Sue/Chuang 2004)
- Decreasing of the condenser pressure (see Chuang/Sue 2005)
- Converting single cycle to combined cycle
- Adding reheaters and superheaters to the steam cycle (see Beaver et al. 2005)

The measure with the largest efficiency improvement is the conversion of a single cycle plant to combined cycle. For the steam part of the combined cycle, some of the measures shown in 2.4.1 can be applied, too. The combination of the last two measures mentioned above can lead to economically attractive efficiency improvements of approx. 20%, while further improvement at additional cost is possible (see Beaver et al. 2005).

2.4.3 R&M in oil fired power plants

As most R&M measures are technology-specific rather than fuel-specific, oil-fired power plants have similar retrofit options for steam turbine plants and gas turbine plants as given in 2.4.1 and 2.4.2. A common retrofit measure for combustion engines is turbocharging of the engine (see Kesgin 2005).

3. Methodology for CO_2 emission reduction quantification

For each country two CO_2 emission reductions scenarios have been set up. The first scenario gives the emission reductions from new power plants built after 2005. The second gives the emission reductions from renovation and modernisation (R&M) of existing plants after 2005.

Both scenarios result from the following procedure. Based on a single electricity production scenario by fuel type until 2020 for each country (see steps 1 and 2), assumptions on the total amount of electricity generation from new power plants respectively R&M power plants from 2005 until 2020 by fuel type have been made for each country (see step 3). Subsequently, we have estimated average efficiency improvements of new power plants and average efficiency improvements by R&M activities until 2020 by fuel type for each country (see step 4)). In step 5, we determine the potential total amount of fuel savings and resulting CO_2 emission reductions by fuel type from new power plants and R&M activities until 2020 taking into account the total amount of electricity generation established in step 3 and the average efficiency improvements established in step 4.

Step 1: Scenario for electricity generation by fuel type from 2005 until 2020 (“total generation”)
Electricity production estimates by fuel type for 2005 has not been available for any of the countries surveyed. For China, India and South Africa most recent data was for 2002 – in the case of Brazil and Indonesia for 2003. For all countries scenarios for future electricity generation by fuel type until 2020 was available,. however, not in yearly intervals. 2005 generation data has been derived from the above scenarios by interpolation between the most recent data available (e.g. China 2002) and the generation value at the closest point in time available in the scenarios (e.g. China 2010). Subsequently, we have established a new scenario for electricity generation by fuel type from 2005 until 2020 by interpolation between the years for which generation data was available (e.g. China: 2005, 2010 and 2020). The total amount of electricity generated from 2005 until 2020 is in the following referred to as “total generation”.

Step 2: Determination of the “reference generation” by fuel type from 2005 until 2020
We define he “reference electricity production” as the total amount of electricity generated from 2005 until 2020 assuming that the annually produced electricity generation will be the same as in 2005.

Step 3: Scenario for electricity generation by fuel type from new power plants from 2005 until 2020 (“new generation”) and scenarios for electricity generation by fuel from refurbished and modernised (R&M) power plants until 2020 (“R&M generation”)
In order to estimate the future electricity generation from capacity additions from new power plants until 2020 we have assumed that any generation above the “reference electricity production” would come from new power plants. The total amount of electricity generated by new power plants until 2020, in the following referred to as “new generation”, is the “total generation” minus the “reference generation”.

In order to estimate the future electricity generation from renovation and modernisation (R&M) of power plants until 2020, in the following referred to as “R&M generation”, we assumed that generation from retrofitted power plants would be 1% or 5% of the "reference generation". In reality, "new generation" and "R&M generation" might potentially partly be displaced by each other, depending on the phase-out rate of currently operating power plants. Such an interrelation has not been taken into account due to non-availability of phase-out rates in the countries studied.

Step 4: Estimation of average efficiency improvements of new power plants and average efficiency improvements by R&M activities until 2020

Table 3 contains the six project types for which emission reductions are calculated in each country. For each country for each fuel/technology type "baseline scenario"-efficiency and "project activity"-efficiency have been assumed according to the procedure displayed in Table 3.

The necessary data and assumptions for estimation of "baseline scenario"-efficiency and "project activity"-efficiency for new power plants are explained in detail in the relevant country analysis chapters (see chapter 4). New oil power plants have not been taken into account as the "new generation" scenario for all countries showed declining oil based electricity generation until 2020. The only exception is Brazil, but the increase in oil fired power generation is negligible.

As shown in chapter 2.4 options for R&M and achievable efficiency increases depend on the specific plant conditions. We have estimated the general efficiency improvements given in Table 3 below. The necessary data and assumptions for estimation of "baseline scenario"-efficiency for R&M plants are explained in detail in the relevant country analysis chapters (see chapter 4).

Table 3: Assumed efficiencies for type "baseline scenario"-efficiency and "project activity"-efficiency

	Potential Project Types (Abbreviations)					
	New power plants		R&M activities			
	Coal (New, Coal)	**Natural Gas** (New, Gas	**Coal** (R&M, Coal)	**Natural Gas** (R&M, Gas) **SCGT** (R&M, SCGT)	**CCGT** (R&M, CCGT)	**Oil** (R&M, Oil)
"Baseline scenario"-Efficiency	Recently built sub-critical	Recently built CCGT	Average efficiency of all power plants	Average efficiency of all power plants	Average efficiency of all power plants	Average efficiency of all power plants
"Project activity"-Efficiency	BAT super-critical	BAT CCGT	+1%pt-Scenario & 2%pt-Scenario	+15%pt-Scenario & 20%pt-Scenario	+1%pt-Scenario & 2%pt-Scenario	+4%pt-Scenario & +5%pt-Scenario
Efficiency Improvements [%-pts]	Country-specific	Country-specific	+1 +2	+15 +20	+1 +2	Country-specific

Step 5: Determination of potential total amount of fuel savings and resulting CO_2 emission reductions by fuel type from new power plants and R&M activities until 2020

The amount of fuel saved FS until 2020 by each potential project type i in TJ has been calculated according to the following formula:

$$FS_{,i} = \left(\frac{GEN_i}{Eff(Bl)_i} - \frac{GEN_i}{Eff(\mathrm{Pr})_i} \right) \times \frac{3.6}{1000}$$

where:
GEN_i is the total electricity generation from the relevant project type i from 2005 until 2020 in TWh as calculated in step 3) above[4],
$Eff(Bl)_i$ is the "Baseline scenario"- Efficiency of the relevant project type i,
$Eff(Pr)_i$ is the "Project activity" – Efficiency of the relevant project type i, and
3.6/1000 is the conversion factor from TWh into TJ.

The amount of CO_2 emission reductions ER_i by each project type i from 2005 until 2020 in Mt CO_2 has been calculated according to the following formula:

$$ER_i = FS_i \times COEF(j)$$

where FS_i is the amount of fuel saved until 2020 by each potential project type i in TJ, and
COEF(j) is the CO_2 emission coefficient of fuel j (tCO_2 / mass or volume unit of the fuel) as given in Table 4 below.

Table 4: CO_2 emission factors per fuel type

Fuel	Coal	Gas	Oil
$EFCO_2$ (tCO_2/TJ)	94.6	56.1	77.37

Source: IPCC (1996)

[4] In order to derive the total electricity generation for the potential project types R&M, SCGT and R&M,CCGT from $GEN_{R\&M,Gas}$ a SCGT/CCGT ratio has been defined in the host country analysis chapters.

4. Host country analysis

4.1 China

4.1.1 Power sector overview

In China, almost 80% of the installed power capacity is coal-fired (see Sathaye et al. 2001). In China, mostly small units for power generation have been constructed. In 2000, about 65% of total capacity installed were in plants with less than 200 MW because financing was easier for small plants. Table 5 shows the division of the power plants in China by size and efficiency in 1988. More recent data is not available in such detail.

Table 5: Size and Origin of China's Generating Units (1995) and Their Efficiency (1988)

<table>
<tr><th>Capacity [MW]</th><th>No. of units</th><th>Installed capacity [GW]</th><th>% of total (1995)</th><th>% of total (1990)</th><th>Efficiency (Japanese average=100)</th><th>% of units imported[5]</th></tr>
<tr><td>>299</td><td>147</td><td>51.9</td><td>24</td><td rowspan="2">38.8</td><td>87</td><td>38</td></tr>
<tr><td>200-299</td><td>202</td><td>41.8</td><td>19</td><td>83</td><td>13</td></tr>
<tr><td>100-199</td><td>318</td><td>36.8</td><td>17</td><td>19.7</td><td>n.a.</td><td>13</td></tr>
<tr><td>50-99</td><td>402</td><td>22.2</td><td>10</td><td rowspan="5">41.5</td><td rowspan="2">77</td><td>22</td></tr>
<tr><td>25-49</td><td>577</td><td>16.3</td><td>8</td><td>25</td></tr>
<tr><td>12-24</td><td>955</td><td>12.5</td><td>6</td><td rowspan="2">65</td><td>21</td></tr>
<tr><td>6-11</td><td>1575</td><td>11.5</td><td>5</td><td>37</td></tr>
<tr><td>0-5</td><td>n.a.</td><td>24.2</td><td>11</td><td>42</td><td>n.a.</td></tr>
<tr><td>Sum</td><td>n.a.</td><td>217.2</td><td>100</td><td>100</td><td>82.2</td><td>24</td></tr>
</table>

Source: see Michaelowa et al. 2003

Electricity consumption is estimated to grow at approx. 4.3% p.a. until 2025. Coal based generation is expected to see the largest increase in absolute terms while the largest pro rata increase will come from natural gas power plants (see EIA 2005).

Since last years small power plants are being closed down. All plants with a capacity less than 50 MW are planned to be replaced by larger units by 2010. It remains to be seen if the Chinese government will be able to achieve this goal in spite of imminent power shortages in many Chinese provinces (see Philibert et al. 2005).

The actual Chinese generating capacity is approx. 450 GW of which 50 GW is assumed to be captive power (see Suding 2005). There was a generating capacity shortage of approx. 30 GW at the end of 2004. 120 GW were under construction in 2004. The demand and supply gap is expected to be closed around 2007 (see EIA 2005). For 2010 and 2020 a total capacity of 530 GW respectively 800 GW is planned (see Michaelowa et al. 2003).

[5] The high import share of extremely small units can be explained through the prevalence of imported diesel generators.

The share of coal-fired electricity generation was 81% in 2001 (see World Bank 2004). The major share was supplied by sub-critical PC power plants. The first supercritical PC plant (2 x 600 MW) was built in Shanghai Shidongkou in the early 1990s (WCI 2004). Currently, nine supercritical plants are in operation, sixteen under construction and a further eight planned (IEA CCC 2004).

The (projected) development in specific coal consumption in China and the corresponding electricity generation efficiency is given in Table 6.

Table 6: Development of specific coal consumption and average efficiency in China (1996-2020)

	1996	2003	2005	2010	2020
Specific coal consumption [gce/kWh]	410	381	377	360	320
Efficiency [%]	30.0	32.2	32.6	34.1	38.4

Source: see CIAB 1999; Suding 2004; Lu 2005, own calculations

Gas-fired generation in public utilities is estimated to increase sharply. In 1997, 80 plants with an installed capacity of 7.2 GW generated 7 TWh, representing 0.6% of total generation. Estimates for 2010 and 2020 are 101 TWh respectively 209 TWh which would mean an increase to 6% of total generation (see IEA 2002a). Li (2003) gives even higher values, which have been used for this scenario (see Table 8).

Table 7 shows fuel consumption, electricity generation and average efficiencies for Chinese power plants per fuel type. The efficiencies have been calculated based on IEA data from 2002 (see IEA 2005). The efficiency calculated for coal power plants compares fairly well with the value given for 2003 in Table 6.

Table 7: Average efficiencies of fossil fuelled power plants by fuel type in China in 2002

Fuel type	Fuel consumption [PJ]	Electricity generation [TWh]	Efficiency [%]
Coal	13,847	1,270.9	33.0
Oil	522	49.,4	34.1
Gas	48	4.7	35.0

Source: IEA 2005, own calculations

For recent efficiencies of new (sub-critical) Chinese PC power plants Farley (2005) gives an estimate of 38% for Chinese technology. A 2×600 MW supercritical plant (Huaneng-Qinbei Phase I) has been recently been built with imported technology and assistance of foreign companies. The efficiency is estimated to be 41.4% (see World Bank 2004).

4.1.2 Results for CO_2 emission reduction scenarios

For the determination of electricity generation in 2005 and “total generation” by fuel type until 2020 data from the IEA from 2002 (see IEA 2005) and Li (2003) were used. The scenario for future fossil fuel power generation by Li (2003) is shown in Table 8.

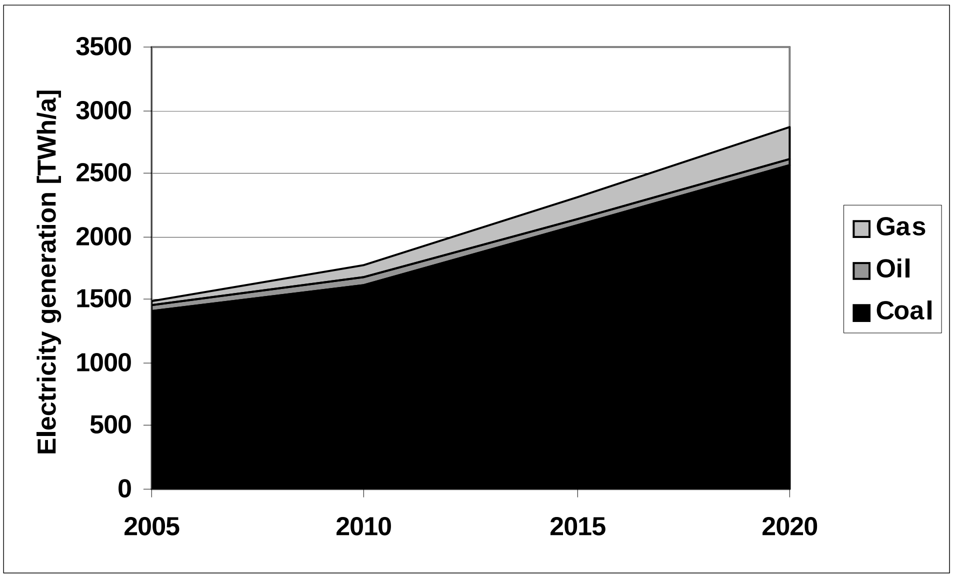
Table 8: Scenario for future fossil electricity generation in China until 2020

Fuel	Electricity generation [TWh]	
	2010	2020
Coal	1,622	2,559
Oil	49	49
Gas	103	255

Source: see Li 2003, own calculations

Figure 1 shows the resulting "total generation" until 2020.

Figure 1: Projected development of fossil-fuelled electricity generation in China from 2005-2020



Source: see Li 2003, IEA 2005, own calculations

For new coal power plants the "baseline scenario"-efficiency is estimated to be 39.6% as a weighted average of the efficiencies of sub-critical (38%) and supercritical (42%) PC plants (see Farley 2005). The ratio assumed is 60% sub-critical and 40% supercritical, which is the ratio of ordered plants in 2004 (see Spalding 2005). Accordingly, as "project activity" efficiency for coal the efficiency of supercritical plants (see Farley 2005) was chosen. This is a conservative estimate, because even higher efficiencies of approx. 45-46% could be achieved using e.g. ultra-supercritical technology (see Spalding 2005).

The "baseline" efficiency for new natural gas fired power plants (55%) is the average efficiency for natural gas fired power plants in the 2020 business-as-usual scenario (see Kroeze et al. 2004). For the project activity – as a conservative estimate – the CCGT typical average efficiency of 2000 (58%) is chosen (see van Aart et al. 2004).

The "baseline" efficiency of coal R&M of 33% is the average efficiency of all coal-fuelled power plants in China in 2002 given in Table 7. This value has been chosen because the R&M target plants will usually have substandard efficiencies. For oil fired power plants the average efficiency of 34.1% has been chosen as "efficiency before R&M" for the same reasons.

For gas fired power plants it has been assumed that (almost) no combined cycle power plants are installed yet. This assumption is based on the 35% average efficiency of natural gas fired electricity generation in China in 2002 in Table 7.

Table 9 contains the efficiency estimates used for CO_2 emission reduction calculations.

Table 9: Efficiency estimates for the Chinese "baseline scenario" and "project activity" according to project type

	Potential Project Types (Abbreviations)					
	New power plants		R&M activities			
	Coal (New, Coal)	**Natural Gas** (New, Gas	**Coal** (R&M, Coal)	**Natural Gas** (R&M, Gas) **SCGT** (R&M, SCGT)	**CCGT** (R&M, CCGT)	**Oil** (R&M, Oil)
"Baseline scenario"-Efficiency	39.6 %	55.0 %	33%	35.0 %	no CCGT plants (assumed)	34.1 %
"Project activity"-Efficiency	42.0 %	58.0 %	+1%pt-Scenario & 2%pt-Scenario	+15%pt-Scenario & 20%pt-Scenario	+1%pt-Scenario & 2%pt-Scenario	+1%pt-Scenario & +2%pt-Scenario
Efficiency Improvements [%-pts]	+2.4	+3.0	+1 +2	+15 +20	+1 +2	+1 +2

Figure 2 and Figure 3 show the quantification results from the new power plant scenario and the R&M scenarios respectively. Both show huge emission reductions from coal fired power plants, resulting from the high share of coal in actual and future power generation in China. The comparably high values for gas in the R&M scenarios are due to the high assumed efficiency improvement by converting single cycle to combined cycle plants. According to Table 7, Chinese oil fired power plants on average operate with reasonably high efficiencies and we therefore only assume an efficiency increase of 1-2%.

Figure 2: Potential emission reductions by improving efficiency of new power plants in China from 2005-2020 (Mt CO_2e)

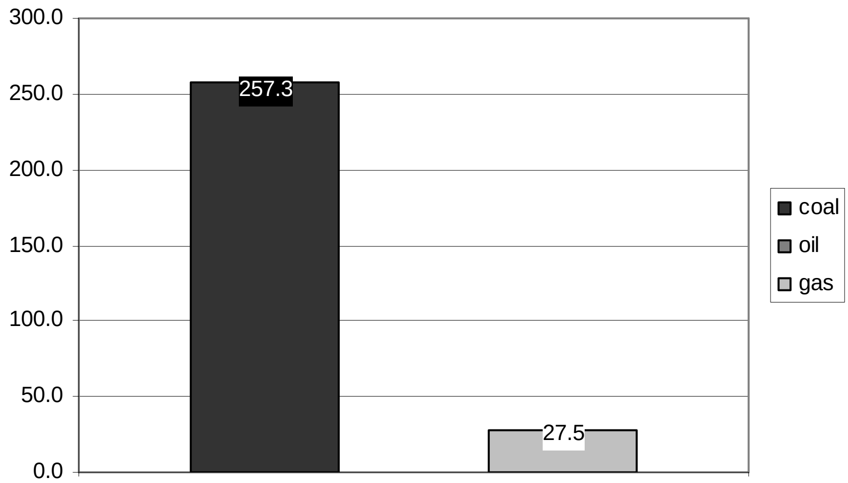
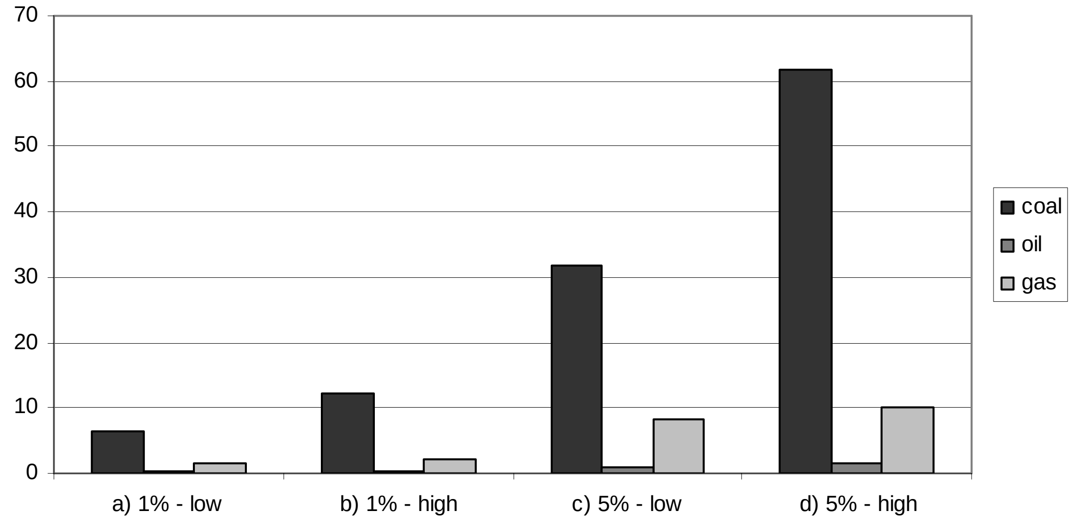


Figure 3: Four scenarios for the emission reduction potential of R&M in China from 2005-2020 (Mt CO_2e)



4.2 India

4.2.1 Power sector overview

Total Indian power generation amounted to 587 TWh in 2004 (see NTPC 2005). In 2005, 55% of installed public generating capacity was coal fired, 10% was gas fired and 1% was oil fired as shown in Table 10 (see MoP 2005). Around 12% of electricity generation capacity in India is assumed to be captive (see Gupta et al., 2001). The public capacity expansion plans by fuel type of the Indian Government are also given in Table 10. While coal capacity is expected to be increased by 70% until 2012, natural gas capacity is planned to be increased by around 150% during the same period.

Table 10: Installed capacity and projected capacity in India for 2005-2020

Fuel	Capacity [GW]	
	2005	2012 (planned)
Coal	67.688	114.49
Gas	12.171	31.425
Oil	1.202	
Hydro	31.745	57.789[6]
Renewables (non-hydro)	6.158	0
Nuclear	3.310	12.1
Total installed capacity	**122.275**	**215.8**

Source: see MoP (2005) and GoI (2002)

In 2002, 22.5% of the coal fired electricity generation capacity had an efficiency below 30% as shown in Table 11 below.

Table 11: Efficiencies of Indian coal-fired power plants (>20MW, >15% efficiency) in 2002

Efficiency range	Capacity installed [GW]	No. of plants
>30%	37.259	38
25-30%	10.308	24
20-25%	3.827	8
15-20%	1.085	5

Source: see MoP 2002

Table 12 shows similarly low efficiencies for Indian PC power plants ordered by plant capacity and year of commission.

Table 12: Average efficiencies of Indian coal-fired power plants in 1999

Plant capacity [MW]	Design efficiency [%]	Operating efficiency [%]	Year of commission
500	34.2	30.15	1991
210	31.4-32.7	24.8-29.23	1979-1991
120	29.7	23.14-24	1976-1977
110	29.7	21.3-24.56	1972-1974
63	26.8	20.76-21.76	1968-1971
30	24.7	19.23-19.33	1965

Source: see Bhatt 1999

Ansbach (2005) reports efficiencies of recently built Indian PC power plants of 500 MW capacity to be lower than 33%, despite a theoretical potential to operate them at 37%.

[6] Including non-hydro renewable sources.

Own calculations of average efficiencies of fossil fuelled power plants based on 2002 IEA data are shown in Table 13. For coal the result compares well with efficiencies given above. For gas power plants they are significantly higher than in China.

Table 13: Average efficiencies of fossil-fuelled power plants by fuel type in India in 2002

Fuel type	Fuel consumption [PJ]	Electricity generation [TWh]	Efficiency [%]
Coal	5,430	418.1	27.7
Oil	305	27.8	32.8
Gas	462	62.9	49.0

Source: IEA 2005, own calculations

TERI (2005) estimated expected efficiencies of coal fired power plants in India and their expected scale of penetration until 2012. The estimates are presented in Table 14. It also includes an estimate for capacity additions by R&M measures and achievable R&M efficiency improvements. Supercritical PC, Ultra-supercritical PC and IGCC are not expected to play a mayor role until 2012.

Table 14: Technologies and efficiencies expected in thermal power projects in India

Technology	Efficiency [%]	2002-2007	2007-2012
Sub-critical	35.0	Base technology	Base technology
Supercritical	37.1	Not expected to materialise	1,980 MW
Ultra-supercritical	40.0	Not expected to materialise	Not expected to materialise
IGCC	41-42	Not expected to materialise	Demonstration project expected
R&M	5 to 8	28,332 MW	28,000 MW

Source: see TERI (2005)

4.2.2 Results for emission reduction scenarios

Based on 2002 data from IEA (2005) and the scenario for electricity generation by fuel type until 2020 by Gupta et al. (2001) and Kroeze et al. (2004) shown in Table 15, the "total generation" scenario was established. It is shown in Figure 4.

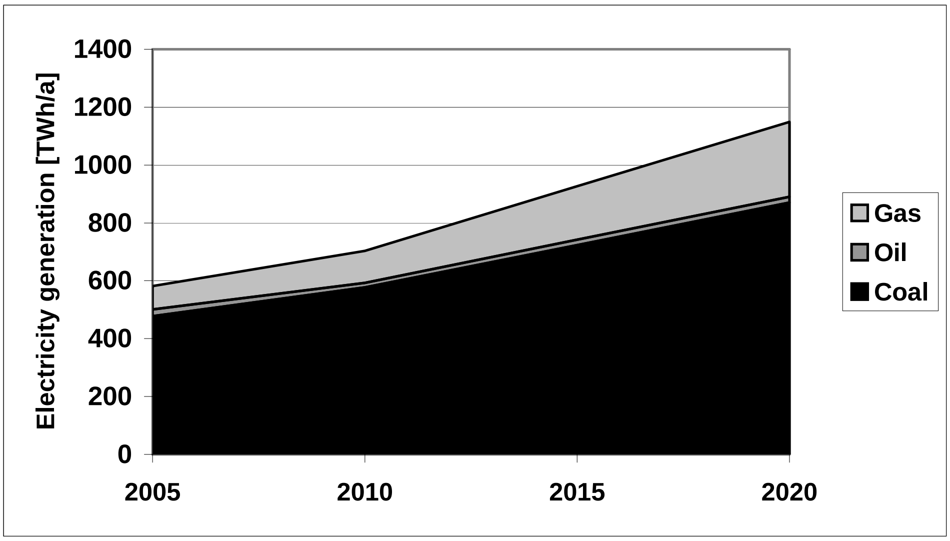
Table 15: Scenario for future fossil electricity generation in India until 2020

Fuel	2010 electricity generation [TWh]	2020 electricity generation [TWh]
Coal	577	871
Oil	16	20
Gas	111	259

Source: See Gupta et al. 2001 and Kroeze et al. 2004, own calculations

The 2005 electricity generation values by fuel were estimated using the 2002 data from the International Energy Agency (see IEA 2005) and the 2010 scenario of Kroeze et al. (see Kroeze et al. 2004).

Figure 4: Projected development of fossil-fuelled electricity generation in India from 2005-2020



Source: based on Gupta et al. 2001, Kroeze et al. 2004, IEA 2005, own calculations

The estimated "baseline" efficiency for coal is based on efficiencies of 38% for recently built sub-critical plants with a capacity of more than 500 MW as given in Kroeze et al. (2004) and of 42% efficiencies for supercritical plants as given in Farley (2005). The share of electricity generation from sub-critical and super-critical until 2020 were assumed to be 90% and 10% respectively. The assumption for the "project" efficiency for PC coal power plants was 42% efficiency.

The "baseline" efficiency chosen for new natural gas power plants is the average efficiency for natural gas fired power plants in the 2020 business-as-usual scenario in Kroeze et al. (2004). The "project" efficiency is – like in the China scenario – the CCGT typical average efficiency of 2000 (see van Aart et al. 2004).

The "baseline" efficiency of coal R&M of 27.7% is the average efficiency of all coal fuelled power plants in India in 2002 given in Table 13. This value has been chosen because the R&M target plants will usually have substandard efficiencies. Also for oil fired power plants the average efficiency given in Table 13 was chosen as the "baseline" efficiency.

For natural gas, separate efficiencies for single cycle and combined cycle power plants were not available. The efficiency of a single cycle plant was assumed to be 36% (estimate based on IEA 2000 and Ausmeier 2002) and of a combined cycle plant to be 55% (see Kroeze et al. 2004). The share of the respective plant types was calculated using the average efficiency in Table 13 and the rule of proportion. The resulting shares are 31.5% of single cycle and 68.5% of combined cycle. These shares have been used for apportioning the values of electricity generation in order to be able to display the results for SC and CC R&M separately.

Table 16: Efficiency estimates for the Indian “baseline scenario” and “project activity” according to project type

	Potential Project Types (Abbreviations)					
	New power plants		R&M activities			
	Coal (New, Coal)	**Natural Gas** (New, Gas	**Coal** (R&M, Coal)	**Natural Gas** (R&M, Gas)		**Oil** (R&M, Oil)
				SCGT (R&M, SCGT)	**CCGT** (R&M, CCGT)	
“Baseline scenario”-Efficiency	38.4 %	55 %	27.72 %	36 %	55 %	32.79 %
“Project activity”-Efficiency	42 %	58 %	+1%pt-Scenario & 2%pt-Scenario	+15%pt-Scenario & 20%pt-Scenario	+1%pt-Scenario & 2%pt-Scenario	+4%pt-Scenario & +5%pt-Scenario
Efficiency Improvements [%-pts]	+3.6	+3	+1 +2	+15 +20	+1 +2	+4 +5

Figure 5 and Figure 6 show the quantification results. Both show, as for China, huge emission reductions from coal fired power plants. This is due to the high share of coal in actual and future power generation in India and the poor efficiency of the plants. Gas fired power plants in India are very efficient compared to coal fired plants. Hence, the emission reduction potential for natural gas is less significant. The potential for oil fired power plants depends strongly on the possible efficiency improvement. A possible improvement of 4% and 5% respectively has been assumed due to the extremely low average efficiency.

Figure 5: Potential emission reductions by improving efficiency of new fossil power plants in India from 2005-2020 (Mt CO_2e)

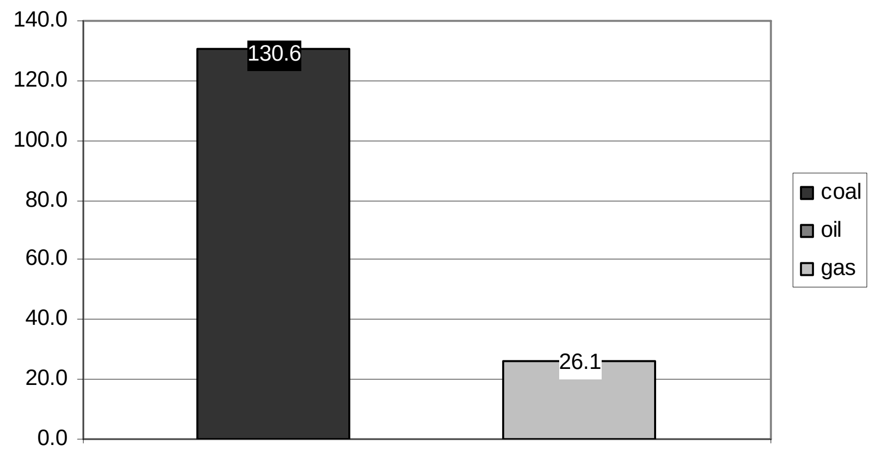
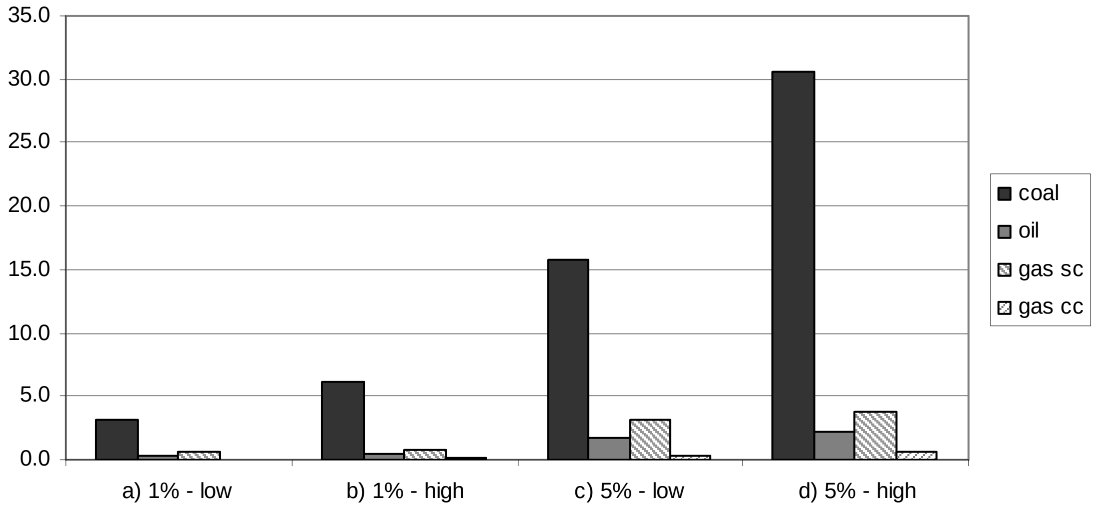


Figure 6: Four scenarios for the emission reduction potential of R&M in India from 2005-2020 (Mt CO_2e)



4.3 Brazil

4.3.1 Power sector overview

The installed capacity in Brazil in 2003 was 86.5 GW. 93% of which was installed in public utilities, 7% in captive power plants. Total electricity generation in 2003 was 364.9 TWh (see MME 2004). The hydropower share in electricity production was 93% (see MME 2004). The fossil-fuelled share of electricity generation in Brazil is very low with around 7%. Table 17 gives fuel consumption, electricity generation and efficiency data for the fossil fuelled based power generation in Brazil including auto-generation by industry. It can be seen that natural gas is the most important fossil fuel for electricity generation in Brazil. The share of captive power plant capacity in thermal power generation in Brazil is 30% (see MME 2004, own calculations).

Table 17: Average efficiencies of fossil fuelled power plants by fuel type in Brazil in 2003

Fuel type	Fuel consumption [PJ]	Electricity generation [TWh]	Efficiency[%]
Coal	66.0	5.4	29.6
Oil	98.,4	9.4	34.2
Gas	110.4	13.,1	42.7

Source: see MME 2004, own calculations

IEA (2000) gives standard efficiencies of power plants that were built in Brazil in 2000 (see Table 18). As these values are already five years old and seem too low, they were increased by estimated two percentage points in order to get a conservative estimate.

Table 18: Assumed standard efficiencies for recently built power plants in Brazil

Fuel	Technology	Efficiency (%)
Coal, fuel oil	Steam turbine	37
Diesel	Internal combustion engine	35
Natural gas	Open cycle gas turbine	34
Natural gas	Combined cycle gas turbine	52

Source: own assumptions based on IEA 2000

Table 19 includes assumptions on standard efficiencies for future power plant projects in Brazil made by Lora et al. (2005) and changed by us concerning the CCGT – from 58% to 55% - as 58% is too high.

Table 19: Standard efficiencies for new power plants in Brazil (BAT)

Fuel	Technology	Efficiency (%)
Coal, fuel oil	Steam turbine	41
Diesel	Internal combustion engine	38
Natural gas	Open cycle gas turbine	36
Natural gas	Combined cycle gas turbine	55

Source: see Lora et al. 2005

4.3.2 Results for emission reduction scenarios

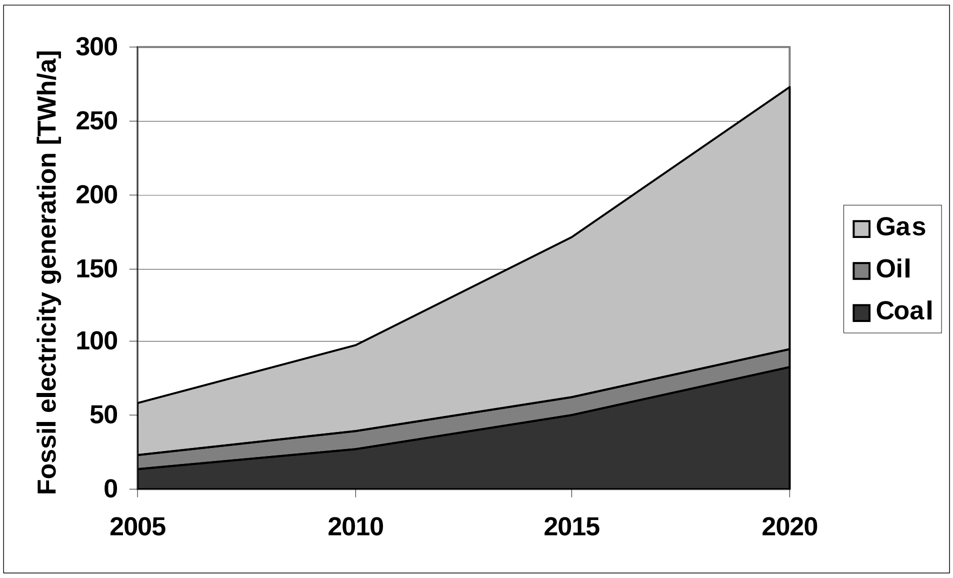
The "total generation" scenario was established on the basis of La Rovere and Americano (2002) as illustrated in Table 20 and Figure 7.

Table 20: Scenario for future fossil electricity generation in Brazil until 2020

Fuel	Electricity generation [TWh]			
	2005	2010	2015	2020
Coal	13.6	27.7	50.7	82.7
Oil	9.8	11.3	11.8	12.8
Gas	34.6	59.3	108.3	177.4

Source: see La Rovere/Americano (2002), own calculations

Figure 7: Projected development of fossil fuelled electricity generation in Brazil from 2005-2020



Source: based on La Rovere/Americano 2002, own calculations

The "baseline" efficiency for new coal fired power plants is 39% which is the average between efficiencies of recently built plants in Brazil as contained in Table 19 and the estimates of efficiencies of power plants soon going to be built in Brazil (see Lora et al. 2005). For new CCGT power plants we have chosen a "baseline" efficiency of 55% and for oil 37%.

The "project activity" efficiency chosen for new coal fired power plants is the efficiency for supercritical plants of 42% (see Farley 2005). The "project activity" efficiencies for oil-fired diesel engines and natural gas combined cycle plants are 40% and 58% respectively.

The "baseline" efficiency for R&M is the average efficiency of all (public utility and auto-generation) plants in 2003 (see Table 17). For natural gas fired power plants the shares of single cycle and combined cycle power plants were estimated from the average efficiency (see Table 17) and the assumed efficiencies of single cycle (35%) and combined cycle (53%) plants respectively, using the rule of proportion (based on IEA 2000 and Ausmeier 2002). The calculated shares are 57.1% of single cycle and 42.9% of combined cycle. These shares have also been used for apportioning the values of electricity generation (in gas fired power plants) in order to be able to display the results for SC and CC R&M separately. According to Table 17, Brazilian oil fired power plants on average operate with reasonably high efficiencies and we therefore only assume an efficiency increase of 1-2%.

Table 21: Efficiency estimates for the Brazilian "baseline scenario" and "project activity" according to project type

	Potential Project Types (Abbreviations)						
	New power plants			R&M activities			
	Coal (New, Coal)	**Oil** (New, Oil)	**Natural Gas** (New, Gas)	**Coal** (R&M, Coal)	**Natural Gas** (R&M, Gas) **SCGT** (R&M, SCGT)	**Natural Gas** (R&M, Gas) **CCGT** (R&M, CCGT)	**Oil** (R&M, Oil)
"Baseline scenario"-Efficiency	39 %	37 %	55 %	29.6%	35 %	53 %	34.2 %
"Project activity"-Efficiency	42 %	38 %	58 %	+1%pt-Scenario & 2%pt-Scenario	+15%pt-Scenario & 20%pt-Scenario	+1%pt-Scenario & 2%pt-Scenario	+1%pt-Scenario & +2%pt-Scenario
Efficiency Improvements [%-pts]	+3	+1	+3	+1 +2	+15 +20	+1 +2	+1 +2

In Figure 8 and Figure 9 it can be seen that emission reduction potential is low compared to China and India, due to the heavy reliance on hydropower in Brazil. The demand for security of electricity supply even during severe droughts and the already high exploitation of the technical hydropower potential will cause the construction of many fossil-fuelled power plants in the future. This explains the comparably high emission reduction potential for new power plants.

Figure 8: Potential emission reductions by improving efficiency of new power plants in Brazil from 2005-2020 (Mt CO_2e)

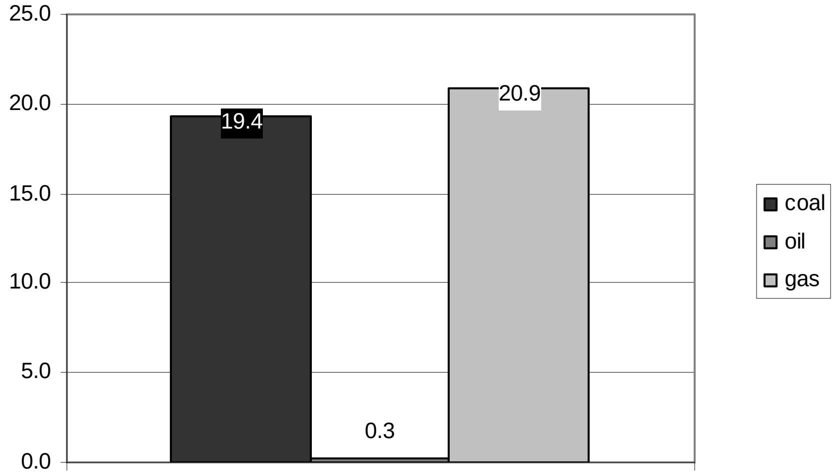
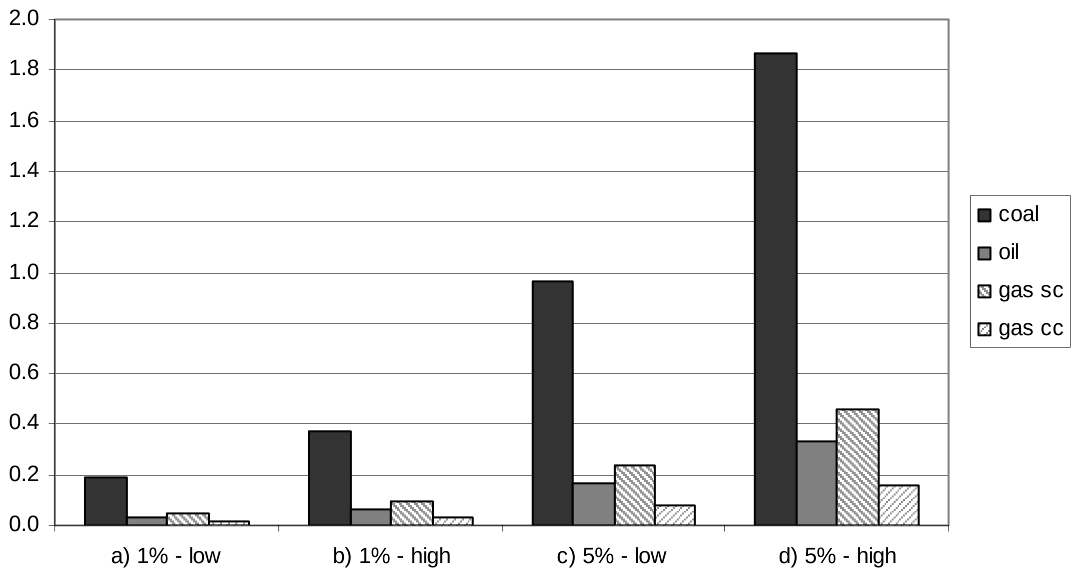


Figure 9: Four scenarios for the emission reduction potential of R&M in Brazil from 2005-2020 (Mt CO_2e)



4.4 South Africa

4.4.1 Power sector overview

In 2005, the total electricity generating capacity in South Africa was 38.3 GW. More than 90% of the electricity is generated from coal (see DOE South Africa n.d.) Of the total capacity, 91.5% are owned by Eskom, a governmentally-owned company. Municipalities own 6.4% of South African generating capacity, while private generation amounts to 2.2%. In contrast to India and China, South Africa has overcapacity of (coal-fired) power generation capacity and consequently several low-efficiency plants have been mothballed in the past decade (see Sathaye et al. 2001). Currently, 3,800 MW of Eskom's coal fired generating capacity is mothballed (see EIA 2005a).

Future growth in electricity demand is expected to be between 2 and 3 % per year, depending on GDP development (see Davidson et al. 2003). Eskom started demand management programs and estimates to be able to provide peak demand in the future by bringing currently mothballed plants online (see DOE South Africa n.d.). However, non-Eskom sources expect that from 2012 onwards electricity demand will exceed the existing generation capacity (see Davidson et al. 2003). This capacity is planned to be met by importing either liquefied natural gas or electricity from hydro-generation (see Davidson et al. 2003). For simplification, we assumed that only hydro electricity is imported and the capacity addition will offer no CDM potential (as a conservative assumption).

Table 22 shows average efficiencies of fossil-fuelled power plants in South Africa calculated based fuel consumption and IEA electricity generation data from 2002 (see IEA 2005) As most of the coal-fired power plants were built during the 1980s, the average efficiency is reasonably high. Data for oil and gas were not available.

Table 22: Average efficiencies of fossil fuelled plants by fuel type in South Africa in 2002

Fuel type	Fuel Consumption [PJ]	Electricity generation [TWh]	Efficiency [%]
Coal	1,981	203.3	36.9
Oil	-	-	-
Gas	-	-	-

Source: see IEA 2005, own calculation

4.4.2 Results for emission reduction scenario(s)

Table 23 and Figure 10 illustrate the expected development of fossil electricity generation in South Africa between 2005 and 2020 based on IEA (2005) and Davidson et al. (2003). Until 2012 the generation increase is solely supplied by the "demothballed" plants. Afterwards, the coal-fuelled electricity generation remains constant. Reason for this is the policy to import electricity and the intention of building additional nuclear power plants (see EIA 2005 b).

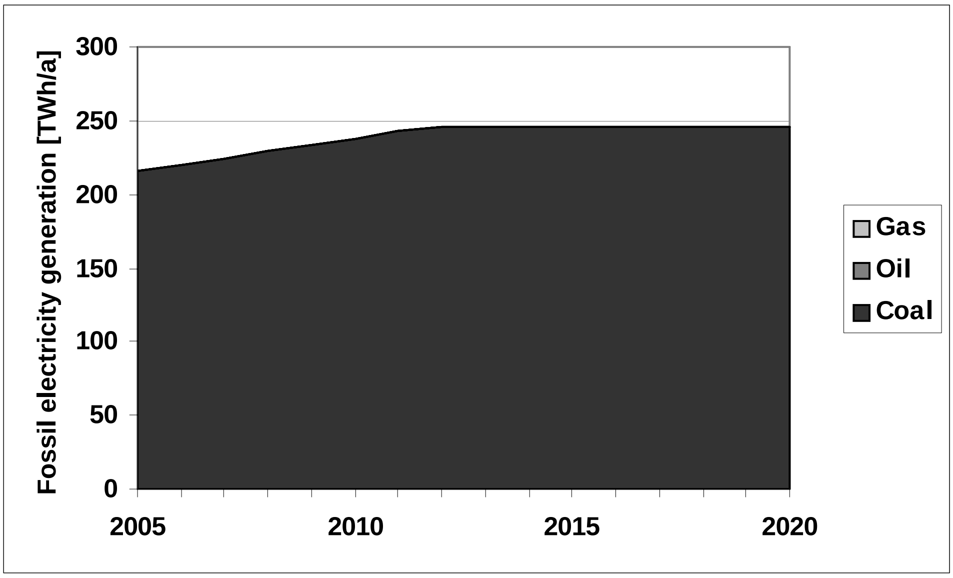
Table 23: Scenario for future fossil electricity generation in South Africa until 2020

Fuel	2010 electricity generation [TWh]	2020 electricity generation [TWh]
Coal	238	246
Oil	-	-
Gas	-	-

Source: estimate based on IEA 2005, Davidson et al. 2003, own calculations

According to the expected trends in the South African electricity generating sector (no capacity addition by new fossil fuelled power plants), no "new power plants" scenario has been set up. The production in 2005 was estimated based on the 2002 production and an assumed annual production increase of 2% (see Davidson et al. 2003).

Figure 10: Projected development of fossil fuelled electricity generation in South Africa from 2005-2020



Source: based on IEA 2005, Davidson et al. 2003, own calculations

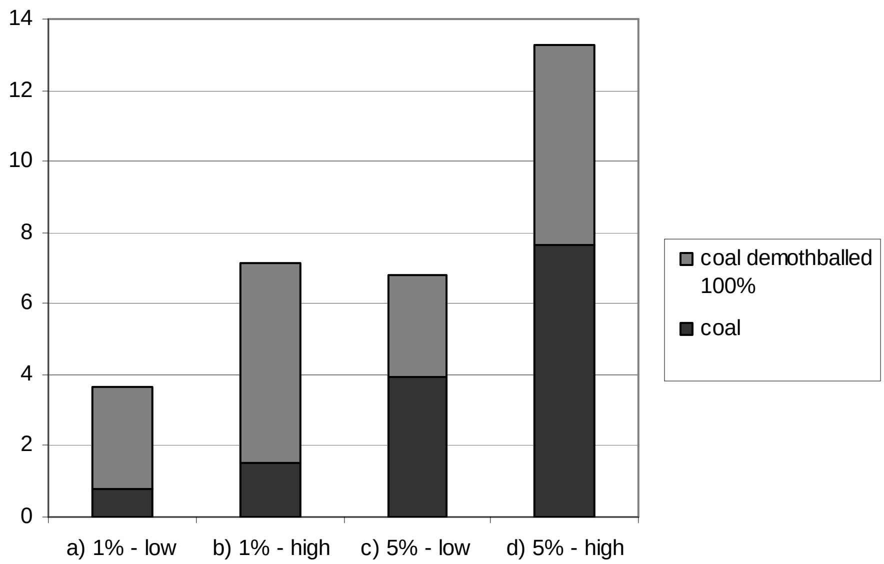
The "baseline efficiency" for coal R&M is the average efficiency of the 2002 production as contained in Table 22. For the plants to be "demothballed" a separate scenario was set up. Davidson and Winkler (2003) estimate that recommissioning of mothballed plants would cost about 40% of building new capacity and estimated the capacity to be recommissioned 3,556 MW between 2005 and 2009. We assumed that the whole design capacity of 3,800 MW can be recommissioned due to capacity increases because of refurbishment. The production from the "demothballed" plants will be sufficient to match the demand until short after 2010 (own calculation). As a baseline efficiency, 38% were assumed in order to get a conservative estimate (original design efficiency was just over 32%). For further "R&M" projects, additional efficiency improvements of 1%-point and 2%-points respectably were assumed for 100% of the generation of "demothballed" plants until 2020, in contrast to the 1% and 5% of coal-fired generation from other plants.

Table 24: Efficiency estimates for the South African "baseline scenario" and "project activity" according to project type

	Potential Project Types (Abbreviations)				
	"Demothballed" plants R&M	R&M activities			
			Natural Gas (R&M, Gas)		Oil
	Coal (Demothballed, Coal)	Coal (R&M, Coal)	SCGT (R&M, SCGT)	CCGT (R&M, CCGT)	(R&M, Oil)
"Baseline scenario"-Efficiency	38 %	36.9 %	none	none	none
"Project activity"-Efficiency	+1%pt- Scenario & 2%pt- Scenario	+1%pt- Scenario & 2%pt- Scenario	none	none	none
Efficiency Improvements (%-pts)	+1 +2	+1 +2	none	none	none

Figure 11 shows the quantification results of the R&M scenarios. The relatively high share of emission reductions from "demothballed" plants results from the assumption that 100% of their generation will come from additionally renovated and modernised plants.

Figure 11: Four scenarios for the emission reduction potential of R&M in South Africa from 2005-2020 (Mt CO_2e)



4.5 Indonesia

4.5.1 Power sector overview

The total Indonesian generating capacity in 2003 was 25.5 GW. 83% of which was owned by the state utility PLN (see ESDM n.d.). Indonesia has problems to provide enough electricity to meet the increasing demand, which is estimated to grow at a rate of 10% p.a. in the next decade. In order to boost the electricity generation at a higher pace, PLN made contracts with independent power producers (IPPs) (see EIA 2004).

In the statistics of the Ministry of Energy and Mineral Resources (MEMR) and the Directorate General of Electricity and Energy Utilization (DGEEU), the capacity and production data are given until 2003 in detail. We calculated the average efficiencies by fuel type based on this data (see Table 25).

Table 25: Average efficiencies of fossil fuelled plants by fuel type in Indonesia in 2003

Fuel type	Consumption [PJ]	Electricity generation [TWh]	Efficiency[%]
Coal	575.2	465	29.1
Oil	282.8	28.2	35.6
Gas[7]	202.1	22.9	40.9

Source: see DGEEU 2004, MEMR 2004, own calculations

4.5.2 Results for emission reduction scenarios

The values for the scenario (see Table 26) are taken from Sugiyono (2001). The “total generation” derived from this scenario is illustrated in Figure 12.

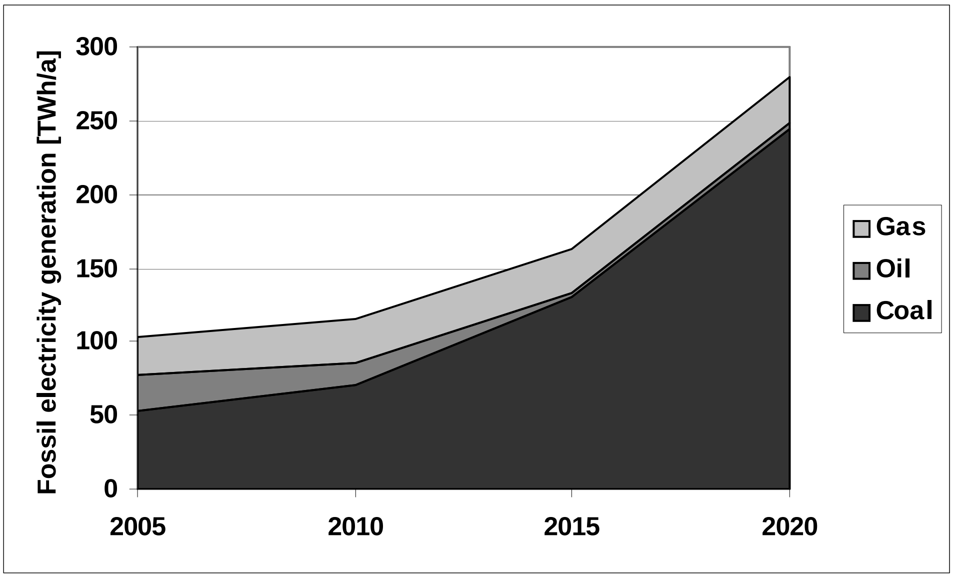
Table 26: Scenario for future fossil electricity generation and efficiencies in Indonesia until 2020

Fuel	2010 electricity generation [TWh]	2020 electricity generation [TWh]
Coal	70	245
Oil	15	4
Gas	22	22

Source: see Sugiyono 2001

[7] The generation from natural gas data includes 41.8 GWh from gas turbines of independent power producers. This data is not distinguished between oil fired and gas fired gas turbines, so the actual gas efficiency is slightly lower (and the oil efficiency correspondingly higher). But due to the small influence this fact is neglected.

Figure 12: Projected development of fossil-fuelled electricity generation in Indonesia from 2005-2020



Source: based on Sugiyono 2001, DGEEU 2004, MEMR 2004, own calculations

The “baseline” efficiency for new coal fired plants is the efficiency of sub-critical plants in China as efficiency figures of recently built Indonesian power plants were not available. Due to the lower average efficiency of coal fired power generation in Indonesia compared to China it was assumed that the Chinese efficiencies would be applicable as conservative estimates, too. The “baseline” efficiency chosen for natural gas-fired power plants is the average efficiency of power plants in the 2020 business-as-usual scenario for India (see Kroeze et al. 2004). The project efficiency is – like in the China and India scenarios – the CCGT typical average efficiency (58%) of the year 2000 as a conservative assumption (see van Aart et al. 2004).

The “baseline” efficiency for R&M of coal fired plants (29%) is the average value of coal- fired Indonesian power plants in 2003 as given in Table 25. This assumption has been made because the small share of production from renovated and modernised plants (1% and 5% respectively) will come from plants with substandard efficiencies.

For oil-fired power plants the average value calculated from the 2003 data (see Table 24) has been chosen as “baseline” efficiency before R&M for the same reasons.

Gas-fired power plants are assumed to have average efficiencies of 36% (single cycle) and 55% (combined cycle). For natural gas fired power plants the shares of single cycle and combined cycle power plants were estimated from the average efficiency (see Table 24) and the assumed efficiencies of single cycle (35%) and combined cycle (53%) plants respectively, using the rule of proportion (based on IEA 2000, Kroeze et al. 2004 and Ausmeier 2002). The calculated shares are 74.4% of single cycle and 25.6% of combined cycle. These shares have also been used for apportioning the values of electricity generation (in gas fired power plants) in order to be able to display the results for SC and CC R&M separately.

Table 27: Efficiency estimates for the Indonesian "baseline scenario" and "project activity" according to project type

	Potential Project Types (Abbreviations)					
	New power plants		R&M activities			
	Coal (New, Coal)	Natural Gas (New, Gas	Coal (R&M, Coal)	Natural Gas (R&M, Gas) SCGT (R&M, SCGT)	CCGT (R&M, CCGT)	Oil (R&M, Oil)
"Baseline scenario"-Efficiency	38 %	55 %	29.1 %	36 %	55 %	35.9 %
"Project activity"-Efficiency	42 %	58 %	+1%pt-Scenario & 2%pt-Scenario	+15%pt-Scenario & 20%pt-Scenario	+1%pt-Scenario & 2%pt-Scenario	+4%pt-Scenario & +5%pt-Scenario
Efficiency Improvements (%-pts)	+4	+3	+1%pt +2%pt	+15%pt +20%pt	+1%pt +2%pt	+1%pt +2%pt

Figure 13: Potential emission reductions by improving efficiency of new power plants in Indonesia from 2005-2020 (Mt CO_2e)

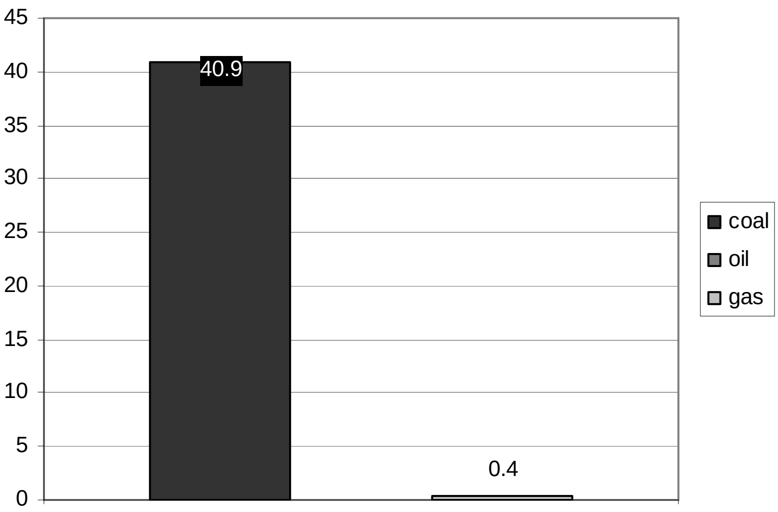
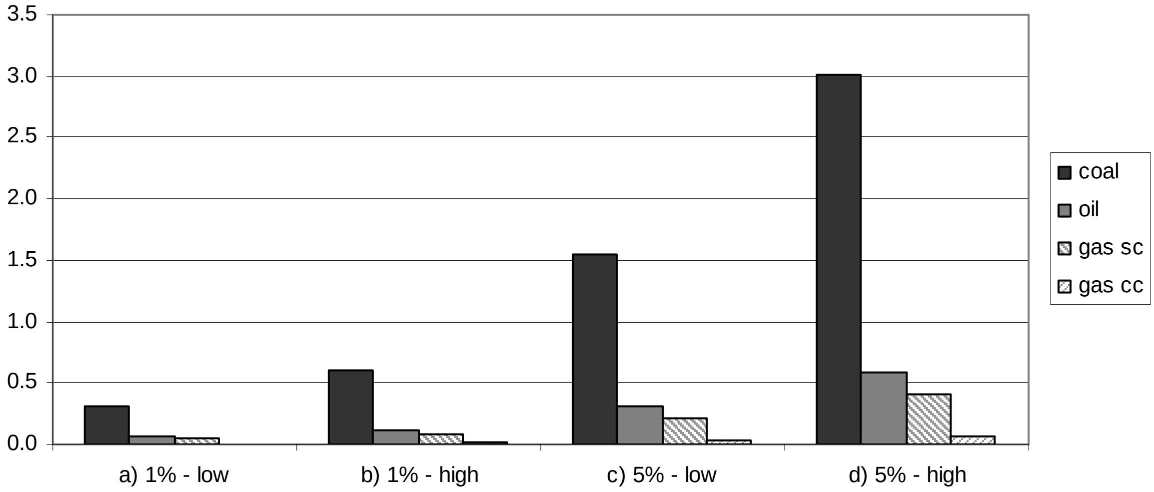


Figure 13 shows the result of the new power plant scenario for Indonesia. The results of the R&M scenarios can be seen in Figure 14. Both show strong dominance of coal, resulting from the high and increasing importance of coal for the Indonesian power generation sector.

Figure 14: Four scenarios for the emission reduction potential of R&M in Indonesia from 2005-2020 (Mt CO_2e)



5. Discussion of the CDM potential of most promising project types in selected countries

Figures 15 to 21 at the end of this chapter summarise the CO_2 emission reduction potential for each country for each project type from 2005-2020. Due to the underlying assumption that the whole production from new fossil-fuelled power plants will come from CDM projects and R&M only has a share of 1-2%, the emission reduction potential for new power plants is far higher than that of R&M measures. It thus assumes a complete penetration of the CDM in the decisions on new power plant investment, which is extremely unlikely. We will now discuss what a realistic share could be.

In how far the volumes for fossil-fuel power plant efficiency increase can materialise under the CDM will depend on if concrete CDM projects with project and baseline efficiencies as defined in chapter 4 will be able to receive CDM registration. The most important hurdle for registration is the additionality test as defined by the CDM Executive Board. The additionality test involves five steps:

1. Identification of alternatives to the project activity.
2. Investment analysis to determine that the proposed project activity is not the most economically or financially attractive.
3. Barrier analysis.
4. Common practice analysis, and
5. Impact of registration of the proposed project activity as a CDM project activity.

Project developers can choose whether they want to do the investment or barrier analysis.

The barrier analysis mentions three main barriers: investment barriers, technological barriers and barriers due to prevailing practice. It is clearly stated what the result of the barrier analysis has to be: "Provide transparent and documented evidence, and offer conservative interpretations of this documented evidence, as to how it demonstrates the existence and significance of the identified barriers" (CDM EB 2004).

The investment analysis and/or barrier analysis is the core element of the additionality test. In the following it is discussed what this means for the chances of the identified most promising project types to qualify under CDM in practice.

<u>New coal-fired supercritical power plants</u>

In general, a power plant with same or slightly higher efficiencies than currently installed power plants of the same type in the respective host country will have no chance to pass the additionality test as it is already proven in practice that development of such type of power plant is commercially attractive. Only if project developers aim for significantly higher efficiencies they stand a chance to pass. That is why project efficiencies for new fossil fuelled power plants in chapter 4 chosen are higher than efficiencies of the same type of power plants currently under construction in the respective host country. For all countries the project efficiency for new coal-fired supercritical power plants was assumed to be 42% which is best available technology for supercritical power plants and has not been achieved in any of the countries surveyed. However, the difference in baseline efficiency and project efficiency differs significantly from country to country: in Brazil the difference is 4%, while in India it is only 3.6% and in China a mere 2.4% as in China a number of supercritical power plants have started operation during recent years – however with lower efficiencies than 42%. In Brazil and India no supercritical plants have been built so far; however in India the first two plants are being planned. This fact illustrates that in Brazil and India supercritical power plants currently seem not economically attractive and/or barriers prevent their implementation. The same rationale holds for Indonesia. However, this does not rule out the possibility that in China CDM supercritical coal power plant projects are possible due to barriers specific to locations and availability of high-quality coal but the bigger practical potential should be seen in countries where supercritical power plants have not been built so far. This situation may change over time, for example if in India local technological know- how for super-critical plant components lowers investment costs for such plants.

New natural gas power plants

Combined cycle natural gas power plants recently built in the surveyed countries have common practice efficiencies of 55%. A natural gas power plant proposed under CDM should therefore a least have an efficiency of 58% as chosen as our project efficiency. Although this might make the investment in the power plant theoretically economically more attractive a number of barriers to the uptake of the new technology might exist and the CDM might provide a good opportunity to remove such barriers.

Retrofit measures in coal-fired power plants

As refurbishment costs are lower than the costs of building new plants, refurbishing of plants close to the end of their technical lifetime can be economically very attractive. However, the practice in key developing countries such as China and India shows that for decades necessary investments in efficiency improvements have been delayed due to the lack of financing. In India, no coal-fired power plant has ever been decommissioned except one that literally exploded. This is due to the fact that power plants operated by state companies do not get budget allocation to cover more than the most necessary repairs (Verghese 2005). If it can be consistently and transparently proven that the CDM helped overcoming the financing barrier retrofit measures have a good chance to register as CDM.

The case of South Africa is special in the sense that it can be expected that the currently mothballed plants with a capacity of almost 4GW will undergo serious renovation and modernization anyway. The CDM could be a real incentive for Eskom to install the most efficient technology at the plants that they probably otherwise would not have installed without the CDM.

Retrofit measures in gas-fired power plants

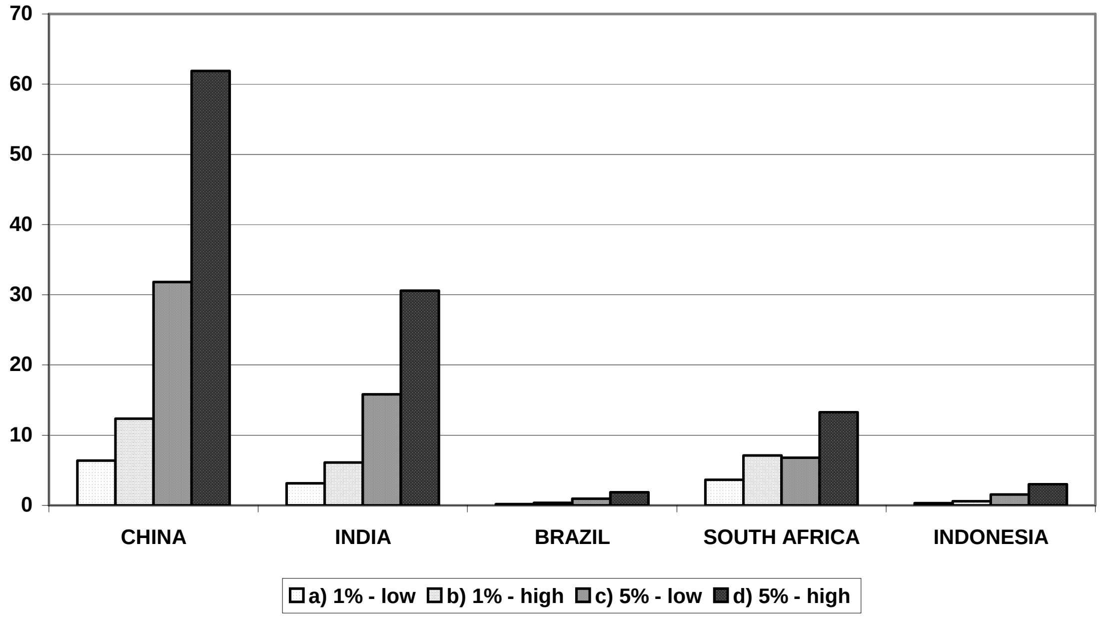
In China, the share of combined cycle gas turbines in natural gas-based power capacity is still low. Conversion from single cycle to combined cycle power plants can theoretically regarded as a promising CDM project type. However, to the huge efficiency increases resulting from this retrofit measure and the relatively low retrofit costs for this project type is unlikely to qualify under CDM unless severe financing problems exist.

Table 28: Emission reductions for promising project types until 2020 (Mt CO_{2e}) and preliminary additionality screen

Country	New coal	Additionality	New gas	Additionality	R&M coal	Additionality	R&M gas	Additionality
China	275.3	Case-by-case	27.5	Low	6.4 - 61.8	High	1.6 - 10.0	Low
India	130.6	Currently high	26.1	Low	3.2 - 30.6	High	-	-
Brazil	19.4	High	20.9	Case-by-case	-	-	-	-
South Africa	-	-	-	-	3.7-13.3	Case-by-case	-	-
Indonesia	40.9	High	-	-	-	-	-	-

Table 28 once again summarises the promising project types in the respective host countries and gives preliminary scores for the likelihood of the relevant project type to pass the additionality test.

Figure 15: Comparison of R&M scenarios for coal fired power plants[8] (Mt CO_2e)



[8] South Africa: Incl. 100% R&M of mothballed plants.

Figure 16: Comparison of R&M scenarios for oil fired power plants (Mt CO_2e)

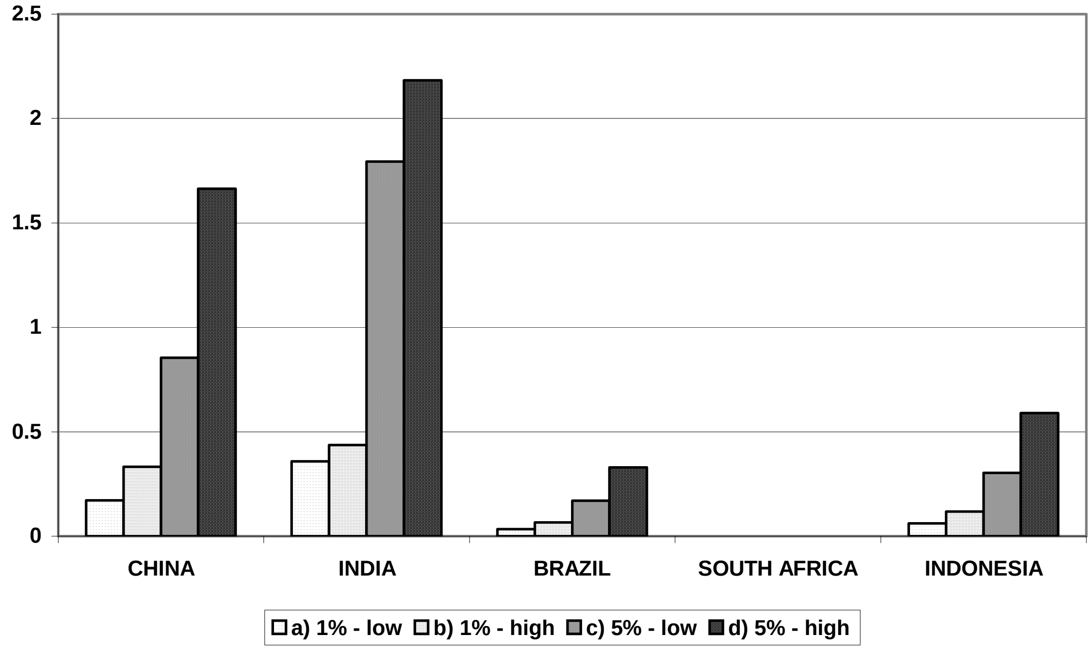


Figure 17: Comparison of R&M scenarios for single cycle gas fired power plants (Mt CO_2e)

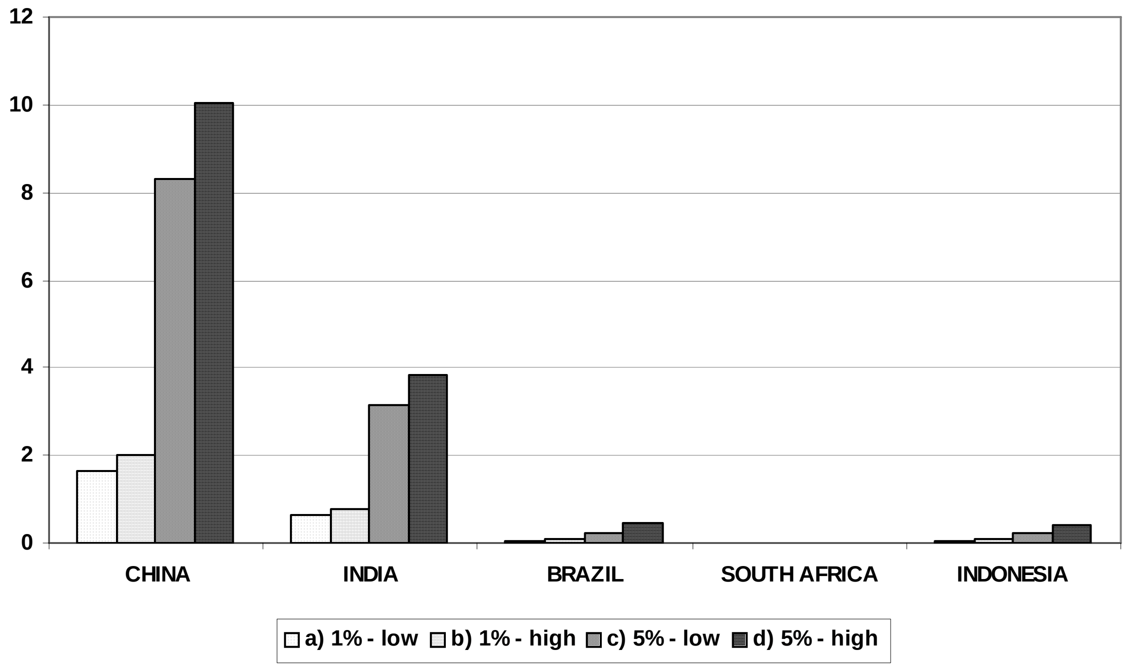


Figure 18: Comparison of R&M scenarios for combined cycle gas fired power plants (Mt CO_2e)

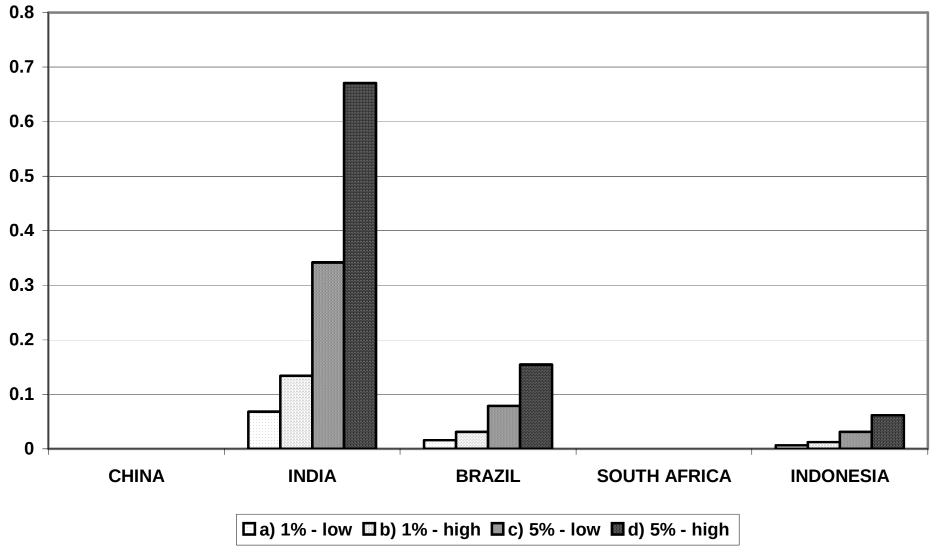


Figure 19: Comparison of the new power plant scenarios for coal fired power plants (Mt CO_2e)

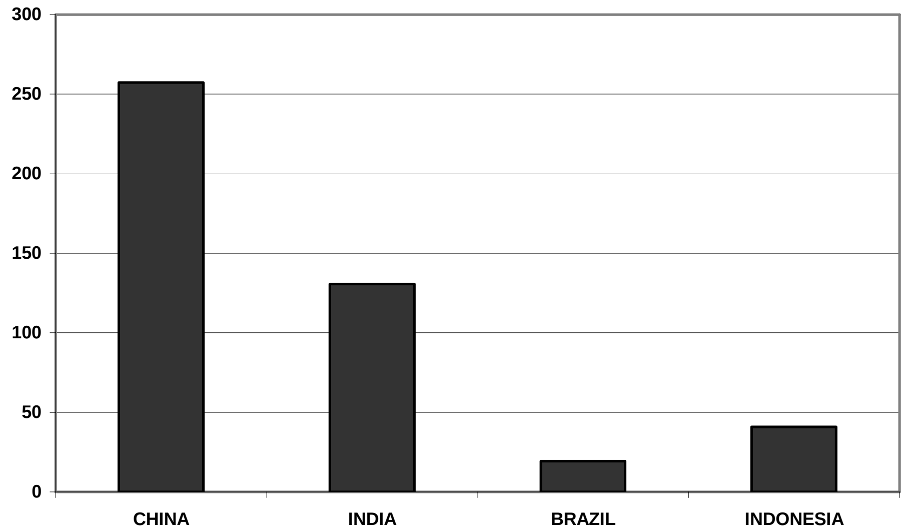


Figure 20: Comparison of the new power plant scenarios for oil fired power plants (Mt CO_2e)

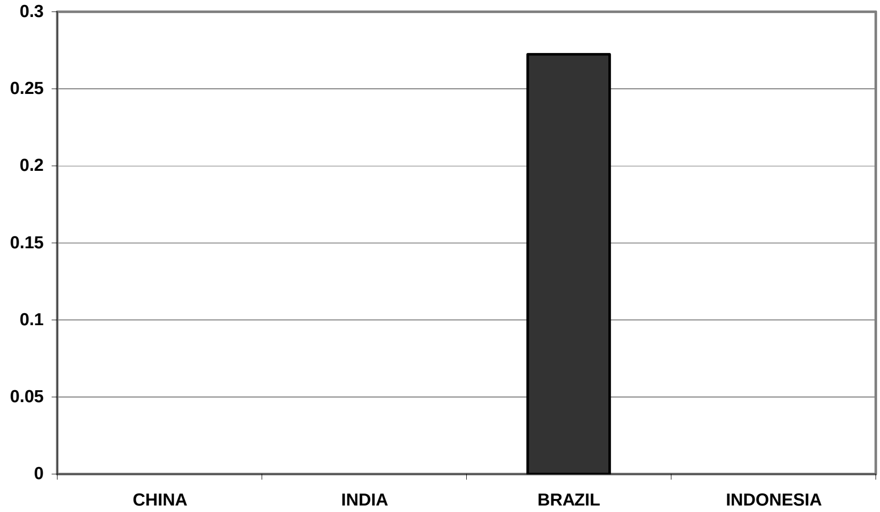
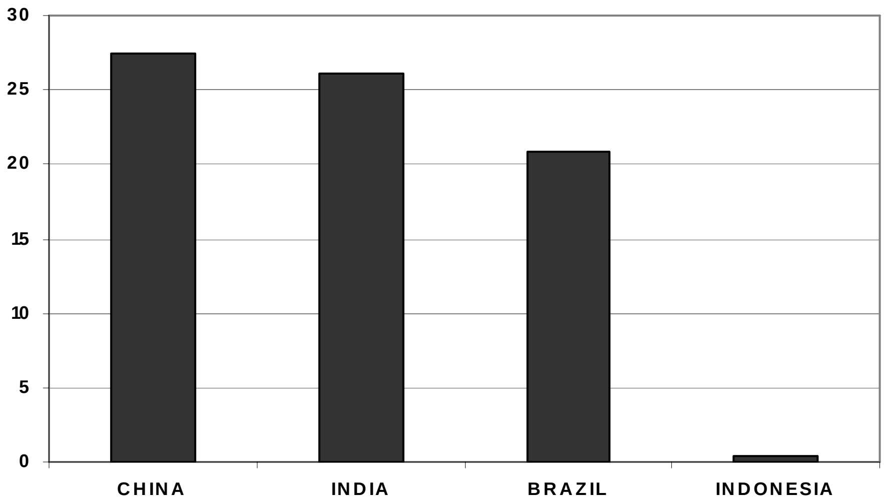


Figure 21: Comparison of the new power plant scenarios for gas fired power plants (Mt CO_2e)



6. Conclusions

In the surveyed countries the dominating fuel, both in share of power generation and in emission reduction potential, is coal. The only exception is Brazil, where natural gas is expected to play a major role in the construction of new power plants (and the emission reduction potential of gas is 1.8 times that of coal until 2020).

The country with the highest emission reduction potential is China, followed by India, Brazil, Indonesia and South Africa.

The quantification results are very sensitive to efficiencies chosen and the estimate for electricity generation from potential emission reduction projects until 2020. If higher shares of R&M would be assumed, the R&M scenarios would be significantly higher. Accordingly, if higher efficiencies for new power plants (which are achievable) would be assumed, the emission reduction potential of the new power plant scenarios would be even higher. Of course, the CER generation potential in unlikely to equal the whole emission reduction potential, but the underlying assumption of 1% and 2% of the whole electricity generation makes the R&M scenario conservative.

In any case the concrete CDM potential will depend on the proposed CDM projects to pass the additionality test. Especially, the chances for natural gas power projects to qualify as CDM projects are slim. In India both new supercritical coal-fired power plants as well as R&M coal projects stand a fair chance to pass the additionality test as supercritical power plants have not been commissioned and (international) financing for power projects is harder to procure than in China. However, this may become more similar to the Chinese situation if the actual plans for super-critical plants and local technological capacity for this technology materializes. For Indonesia and Brazil the same rationale applies – although the investment climate in Brazil is somewhat better than in Indonesia and India. For South Africa the CDM might provide an incentive to install BAT technology in the currently mothballed plants once they go online.

7. References

van Aart, F.; Kok, W., Ploumen, P. (2004): Energy Efficiency in Power Plants, paper provided for the plenary session “Producing more with less: Efficiency in Power Generation” at the European Conference “Energy Efficiency in IPCC Installations”, Vienna, 21.-22.10.2004

Ausmeier, S. (2002): Innovative Gasturbinen-Prozesse zur Steigerung von Wirkungsgrad und Wirtschaftlichkeit, dissertation. Universität Essen, Fachbereich Maschinenwesen (in German)

Beaver, S.; Matamoros, J.; Prokopec, A.; Retallick, W.B.; Churchill, S.W. (2005): An analysis of the effect of heat exchange and heat refluxing in the generation of electricity with a gas turbine, in: Energy 30, pp.103-110

Bhatt, M.S; Mandi, R.P.; Jothibasu, S.; Rajkumar, N. (1999): Performance enhancement in coal fired thermal power plants. Part IV: overall system, in: International Journal of Energy Research 23, pp.1239-1266

Chuang, C.-C.; Sue, D.-C. (2005): Performance effects of combined cycle power plant with variable condenser pressure and loading. In: Energy 30, pp.1793-1801

CDM EB (2004): Annex 1 - Tool for the demonstration and assessment of additionality. Clean Development Mechanism Executive Board, from: http://cdm.unfccc.int/EB/Meetings, access 26-10-05

CIAB (1999): Coal in the Energy Supply of China, report of the CIAB Asia Committee. IEA/OECD Coal Industry Advisory Board

CIAB (2005): Reducing Greenhouse Gas Emissions. The Potential of Coal, OECD/CIAB, Paris, France

DGEEU (2004): Indonesian Directorate General of Electricity and Energy Utilization (DGEEU) Statistics, 2004 (in Indonesian)

DOE South Africa (no date): An Energy Overview of the Republic of South Africa, International Energy Information Administration, Department of Energy, United States of America

EIA (2004): Indonesia Country Analysis Brief, International Energy Information Authority, Department of Energy, USA

EIA (2005): China Country Analysis Brief, International Energy Information Authority, Department of Energy, United States of America

EIA (2005a): South Africa Country Analysis Brief, International Energy Information Authority, Department of Energy, United States of America

ESDM (no date): Kapasitas Terpasang Pembangkit Listrik, Ministry of Energy and Mineral Resources, Indonesia, from: http://www.esdm.go.id/downloads/statistik/ind/6 .4.1_R.htm, access 2005-10-27 (in Indonesian)

Farley, M. (2005): Carbon Abatement Technologies for Coal Fired Power Plant, Presentation held at the All-Energy Conference & Exhibition, Aberdeen, May 25th, 2005

Gupta, J.; Vlasblom, J.; Kroeze, C. (2001): An Asian Dilemma. Modernising the electricity sector in China and India in the context of rapid economic growth and the concern for climate change, report number E-01/04

IEA CCC (2004): Coal Power 4, London

IEA (2002): Energy Outlook 2002, Paris

IEA (2002a): Developing China's natural gas market. The energy policy challenges, IEA/OECD, Paris, France

IEA (2003): Improving efficiencies of coal-fired power plants in developing countries, IEA Clean Coal Centre Profiles, PF 03-01, January, London

IEA (2003a): Control and Minimisation of Coal-fired Power Plant Emissions, Working Party on Fossil Fuels, International Energy Agency, Paris, France

IEA (2005): International Energy Agency Energy Balances, from: http://www.iea.org/Textbase/stats/index.asp, access 2005-11-16

IEA (2005a): Key World Energy Statistics, Paris

IPCC (1996): Revised 1996 Guidelines for National Greenhouse Gas Inventories, Institute for Global Environmental Strategies, Kanagawa

IPCC (2001): Climate Change 2001 – Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK

Kesgin, U. (2005): Effect of turbocharging system on the performance of a natural gas engine, in: Energy Conversion and Management, 46, pp.11-32

Kroeze, C.; Vlasblom, J.; Gupta, J.; Boudri, C.; Blok, K. (2004): The power sector in China and India: greenhouse gas emissions reduction potential and scenarios for 1990-2020, in: Energy Policy, 32, pp. 55-76

Lako, P. (2004): Coal-fired power technologies. Coal-fired power options on the brink of climate policies, ECN Policy Studies project number 7.7585

La Rovere, E.L.; Americano, B.B. (2002): Domestic actions contributing to the mitigation of GHG emissions from power generation in Brazil, in: Climate Policy, 2, pp.247-254

Li, Z. (2003): An econometric study on China's economy, energy and environment to the year 2030, in: Energy Policy 31, pp. 1137-1150

Lora, E.E.S.; Salomon, K.R. (2005): Estimate of ecological efficiency for thermal power plants in Brazil, in: Energy Conversion and Management, 46, pp.1293-1303

Lu, W. (2005): China Medium and Long term Energy Conservation Plan, Department of Environment and Resources Conservation, National Development and Reform Commission, presentation held on "CTI Industry Joint Seminar on Technology Diffusion of Energy Efficiency in Asian Countries", February, Bejing, China

MEMR (2004): Indonesian Ministry of Energy and Mineral Resource (MEMR) Statistics, 2004 (in Indonesian)

Michaelowa, A.; Asuka-Zhang, S.; Krause, K.; Grimm, B.; Koch, T. (2003): The Clean Development Mechanism and China's Energy Sector: Opportunities and Barriers, in: Harris, P. (ed.): Global warming and East Asia, Routledge, London, pp. 109-132

MME (2004): Brazilian Energy Balance, Ministry of Mining and Energy, Brazil

MoP (2002): Ministry of Power, Government of India: Presentation on COP 8, Oct. 2002

MoP (2005): Indian Ministry of Power: Power Sector at a Glance "All India", "Installed capacity update", from http://powermin.nic.in/JSP_SERVLETS/internal.jsp, access 2005-09-22

NTPC (2005): NTPC in Indian power sector, from http://www.ntpc.co.in/aboutus/company.sh tml, access 2005-09-22

Philibert, C.; Podkanski, J. (2005): International Energy Technology Collaboration and Climate Change Mitigation, Case Study 4: Clean Coal Technologies, OECD Environment Directorate and International Energy Agency

GoI (2002): Government of India, Planning Commission. Tenth Five-Year Plan (chapter 7.3: Energy), New Delhi, India

Sathaye, J.; Price, L.; Worrell, E.; Ruth, M.; Schaeffer, R.; Costa, M.M.; Wang, Y.; Roy, J.; Spalding-Fechner, R.; Afrane-Okese, Y.; Davidson, O. (2001): Multi-project baselines for evaluation of industrial energy-efficiency and electric power projects, Environmental Energy Technologies Division, Ernest Orlando Lawrence National Laboratory, Berkeley, California. LBNL-48242

Spalding, D. (2005): Future-proofing Options for Carbon Abatement of Advanced Supercritical Coal Fired Power Plants, presentation held at the IEA CCT 2005, Sardinia, Italy 10.-12.5.2005

Suding, P. (2004): Chinas Energieversorgung: Viele Wege – ein Ziel, in: WEC-DNK 2004 (?), pp. 9-40

Suding, P. (2005): Chinas Energieversorgung: strategische Energiepolitik eines Global Player, in: Energiewirtschaftliche Tagesfragen, 55, 8, pp.518-522

Sue, D.-C.; Chuang, C.-C. (2004): Engineering design and exergy analyses for combustion gas turbine based power generation system, in: Energy 29, pp.1183-1205

Sugiyono, A. (2001): Renewable energy development strategy in Indonesia: CDM funding alternative, proceeding of the 5th Inaga annual scientific conference & exhibitions, Yogyakarta, Indonesia

TERI (2005): CDM Implementation in India - The National Strategy Study, Energy and Resources Institute, New Delhi, India

Verghese, J. (2005): Personal communication, New Delhi, Oct. 5, 2005

World Bank (2004): Clean Development Mechanism in China. Taking a Proactive and Sustainable Approach. 2nd edition

WCI (2004): Clean Coal Building a Future through Technology, London

HWWI Research Papers

1. Lessons from the submission and approval process of energy-efficiency CDM baseline and monitoring methodologies
   Felicia Müller-Pelzer, Axel Michaelowa
   Hamburg, September 2005

2. Climate or development: Is ODA diverted from its original purpose?
   Axel Michaelowa, Katharina Michaelowa
   Hamburg, November 2005

3. CDM: current status and possibilities for reform
   Axel Michaelowa
   Hamburg, November 2005

4. CDM potential of SPV pumps in India
   Pallav Purohit, Axel Michaelowa
   Hamburg, November 2005

The **Hamburgisches WeltWirtschaftsInstitut (HWWI)** is an independent economic research institute, based on a non-profit public-private partnership, which was founded in 2005. The University of Hamburg and the Hamburg Chamber of Commerce are shareholders in the Institute .

The HWWI's main goals are to:

- Promote economic sciences in research and teaching;
- Conduct high-quality economic research;
- Transfer and disseminate economic knowledge to policy makers, stakeholders and the general public.

The HWWI carries out interdisciplinary research activities in the context of the following research programmes: Economic Trends and Hamburg, International Trade and Development, Migration Research and International Climate Policy.

Hamburg Institute of International Economics (HWWI)

Neuer Jungfernstieg 21 | 20354 Hamburg | Germany
Tel +49 (0)40 34 05 76 - 0 | Fax +49 (0)40 34 05 76 - 76
info@hwwi.org | www.hwwi.org