Wuppertal Institute
for Climate, Environment
and Energy

giz

CCS Global

Prospects of Carbon Capture and Storage Technologies (CCS) in Emerging Economies

Final Report

to the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)

Part V:

Comparative Assessment of Prospects of CCS in the Analysed Countries

GIZ-PN 2009.9022.6

Wuppertal, 30 June 2012

This project is part of the International Climate Initiative (ICI).

Supported by:

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety

based on a decision of the Parliament of the Federal Republic of Germany

Final Report

The project on which this report is based was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) through the GIZ (Project Number 2009.9022.6). The sole responsibility for the content of this report lies with the authors.

The total report consists of 6 parts:

Concluding Hypotheses / Zusammenfassende Thesen

I. General Status and Prospects of CCS

II. Country Study India

III. Country Study China

IV. Country Study South Africa

V. Comparative Assessment of Prospects of CCS in the Analysed Countries

Elaborated by

Wuppertal Institute
Dipl.-Umweltwiss. Andrea Esken
Dipl.-Umweltwiss. Samuel Höller
Dr. Daniel Vallentin
Dr. Peter Viebahn (Project Co-ordinator)

With subcontracts to
Dr. Pradeep Kumar Dadhich (The Energy and Resources Institute, New Delhi)
Prof. Dr. Can Wang (Tsinghua University, Beijing)
Prof. Dr. Rosemary Falcon (University of the Witwatersrand, Johannesburg)
Dr. Werner Zittel (Ludwig-Bölkow-Systemtechnik, Ottobrunn, Germany)
Teresa Gehrs (LinguaConnect, Osnabrück)

Assistance by
Holger Liptow (GIZ)
Christina Deibl, Bianca Falk, Florian Knüfelmann, Geo Kocheril (Wuppertal Institute)

Contact

Dr. Peter Viebahn
Wuppertal Institute for Climate, Environment and Energy
Research Group “Future Energy and Mobility Structures”
Döppersberg 19
42103 Wuppertal
Germany
Tel.: +49 202/2492-306
Fax: +49 202/2492-198
E-mail: peter.viebahn@wupperinst.org
Web: www.wupperinst.org/CCS/

Table of Contents

V. Comparative Assessment of Prospects of CCS in the Analysed Countries

36 Results of the Comparative Assessment of the Prospects of CCS

36.1 Objective of the Study

The aim of this study is to explore whether carbon capture and storage (CCS) could be a viable technological option for significantly reducing CO_2 emissions in emerging countries such as India, China and South Africa. These key countries have been chosen as case studies because all three, which hold vast coal reserves, are experiencing a rapidly growing demand for energy, currently based primarily on the use of coal. The study therefore focuses mainly on how to reduce CO_2 emissions from coal-based electricity generation via CCS, supplemented by a rough analysis of emissions from industry.

The analysis is designed as an integrated assessment, and takes various perspectives. The main objective is to analyse how much CO_2 can potentially be stored securely and for the long term in geological formations in the selected countries. Based on source-sink matching, the estimated CO_2 storage potential is compared with the quantity of CO_2 that could potentially be separated from power plants and industrial facilities according to a long-term analysis up to 2050. This analysis is framed by an evaluation of coal reserves, levelised costs of electricity, ecological implications and stakeholder positions. The study finally draws conclusions on the future roles of technology cooperation and climate policy as well as research and development (R&D) in the field of CCS.

36.2 Assessment of Storage Capacities in the Analysed Countries

The concept of the “techno-economic resource-reserve pyramid for CO_2 storage capacity” was applied to undertake the analysis (Fig. 36-1). Essentially, the pyramid consists of four categories: theoretical, effective, matched and practical capacity. The theoretical capacity is the maximum volume that could be filled with CO_2, independent of economic and volumetric aspects. Geologically, the most important capacity is the effective capacity, which is a subset of the theoretical capacity derived by applying physical, geological and engineering cut-off limits. The matched capacity is a subset of the effective capacity, derived by matching large CO_2 sources with potential sinks. Finally, the practical storage capacity, which includes technical, legal, economic and acceptance barriers, reveals the capacity that may realistically be used. Since the practical capacity can only be determined at an advanced process stage, when the impact of other factors have become clear, this study aims to derive a rough matched capacity for orientation purposes.

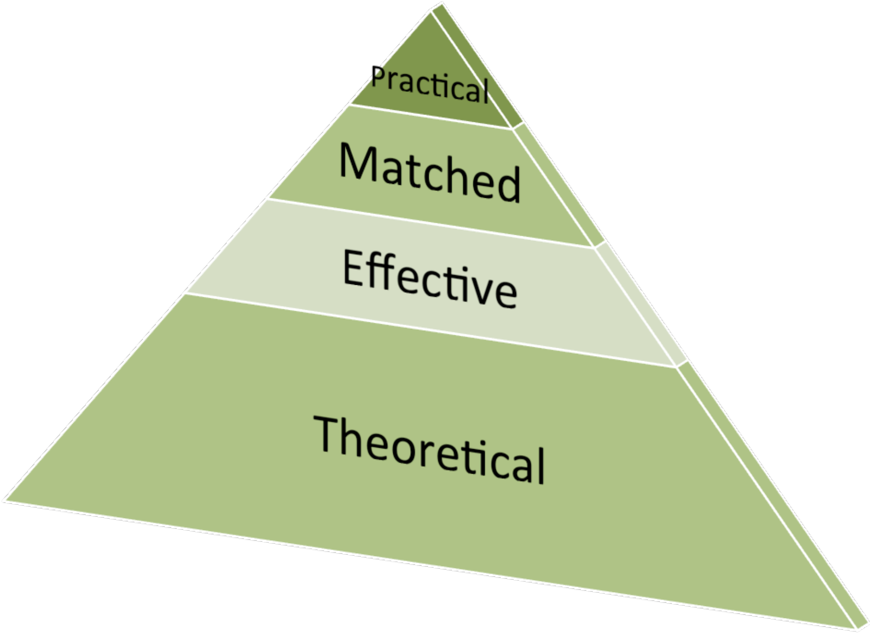

Fig. 36-1 Modified version of the storage potential pyramid suggested by the Carbon Sequestration Leadership Forum

Source: Authors' composition based on Bachu et al. (2007)

The objectives of this study were to:

- Systematically analyse and compare existing capacity estimates for the CISA countries with regard to their assumptions, the applied methodologies, the chosen parameters and the data sources;
- Present a range of theoretical capacities;
- Develop three storage scenarios of effective capacities for each country;
- Match the effective capacities of these scenarios with the cumulated amount of CO_2 to be captured by 2050, derived from different development pathways of the national energy and industry sector.

Finally, the results of the capacity calculation matched between the CO_2 sources and geological CO_2 storage sites yield a range within which CCS might be able to contribute to a reduction of CO_2 emissions into the atmosphere.

36.2.1 Review of existing storage capacity studies and estimation of effective storage capacities

The few estimates available in the literature indicate a wide range of storage capacities:

- *India:* 47 to 572 Gt CO_2 (theoretical capacity);
- *China:* 36 to 3,090 Gt CO_2 (theoretical capacity);
- *South Africa*: 150 Gt CO_2 (effective capacity, efficiency factor of 10 per cent).

For *India*, the existing studies are very uncertain and the results are not linked to the resource-reserve pyramid. Due to the lack of clear methodologies, the derived capacity was classified as the theoretical capacity.

The large deviations in the estimates for India and China are mainly explained by variations in saline aquifers (and basalts in case of India). However, even the lowest values imply severe constraints. As a general rule, because of the lack of geological data, any calculations of storage capacity quantity in the analysed countries can only be highly speculative and therefore should be treated with caution.

In the next step, the theoretical capacity yielded for India and China had to be reduced to an effective potential by applying appropriate efficiency factors. Since the true efficiency factors are not known, an “if … then” approach was used to show how the effective storage capacity would vary depending on different efficiency factors. To this end, three storage scenarios *S1: high*, *S2: intermediate* and *S3: low* were developed for each country. These scenarios are based on different efficiency factors applied in the study that appeared to be the most realistic of the existing studies. The main potential storage sites are saline aquifers, and a small capacity is considered within oil and gas fields. Storage in basalts and coal seams was excluded from all scenarios due to the high level of technical uncertainties.

In the case of *India*, it was decided not to apply general efficiency factors because no adequate information was available. Existing studies for India are very uncertain and the results are not linked to the resource-reserve pyramid. Due to the lack of clear methodologies, the derived capacity was classified as the theoretical capacity.

In the case of *China*, efficiency factors of 2, 16 and 50 per cent were derived from existing regional storage capacity assessments. These were applied to the capacity for the whole of China. In the case of *South Africa,* the estimate based on an efficiency factor of 10 per cent was expanded by taking into account efficiency factors of 1, 4 and 10 per cent. The storage scenarios result in the following range of storage capacities:

- *India (S1–S3):* 45 to 143 Gt CO_2 (theoretical capacity, no efficiency factor derivable, without basalts and coal seams);
- *China (S1–S3):* 65 to 1,542 Gt CO_2 (effective capacity applying efficiency factors of 2, 16 and 50 per cent to a study of Dahowski et al., without coal seams);
- *South Africa (S1–S3):* 15 to 149 Gt CO_2 (effective capacity applying efficiency factors of 1, 4 and 10 per cent, without onshore storage).

36.2.2 Modelling the amount of CO_2 emissions that could potentially be captured from power plants and industrial sites

In order to be able to estimate the relevance of the derived figures, the range of CO_2 storage capacity was compared with the cumulated amount of CO_2 emissions that could potentially be captured from power plants and industrial facilities in the long term. Due to the extent of uncertainty regarding the future development of the energy system in each of the analysed countries, again, an “if … then” analysis was performed. Firstly, three long-term coal development pathways for power plants *E1: high*, *E2: middle* and *E3: low* were devised. These pathways, based on existing long-term energy scenarios for the respective countries, project different trends of coal-based power plant capacities up to 2050, but do not illustrate their own scenario framework. They are merely used to sketch different CCS development pathways to gain an understanding of how much CO_2 emitted from power plants could potentially be available for storage under different conditions. The project's remit did not allow new energy scenarios including CCS to be developed from scratch.

Pathways E1 to E3 result in installed coal-fired power plant capacities in 2050 for

- *India:* 176 to 624 GW;
- *China:* 350 to 1,560 GW;
- *South Africa*: 15 to 91 GW.

These pathways were supplemented by industrial development pathways which illustrate how much CO_2 emitted from industrial sites could potentially be available for storage. In the case of India and China, one pathway, *I,* was provided; three pathways (for coal-to-liquid plants) *I1: high*, *I2: middle* and *I3: low* were developed for South Africa.

In the next step, the quantity of CO_2 that could be separated from the time when CCS may become commercially available was calculated for both the coal development pathways and the industrial development pathways. This refers to the time when the complete CCS chain will be in commercial operation, incorporating large-scale CCS based power plants, transportation and storage. It is assumed that CCS will not be in commercial operation before 2030 in any of the three analysed countries. It seems unlikely that CCS will be launched before 2030 in India, China and South Africa not only because there are country-specific reasons against it but also, more importantly, because its deployment in industrialised nations is undergoing constant delays.

The derived amount of CO_2, cumulated over the power plants' lifetime of 40 years, results in:

- *India:* 13 to 111 Gt CO_2 emissions (27 to 124 Gt CO_2 in the case of power plants and industry);
- *China:* 34 to 221 Gt CO_2 emissions (60 to 250 Gt CO_2 in the case of power plants and industry);
- *South Africa:* 4 to 22 Gt CO_2 emissions (0 to 2 Gt CO_2 in the case of coal-to-liquid plants and 4 to 24 Gt CO_2 in the case of power plants and coal-to-liquid plants).

36.2.3 Correlating geological storage capacities and available CO_2 emissions while taking into account a maximum distance between sources and sinks (source-sink matching)

Finally, source-sink matching was performed taking into account a maximum distance between sources and sinks (500 km for India and China; 600 km for South Africa). These limits were assumed because longer distances would significantly affect the cost balance and create infrastructural barriers. Combining development pathways E1–E3 and I1–I3 (sources) with storage scenarios S1–S3 (sinks) results in a matched capacity for:

- *India* (based on theoretical capacity): 5 Gt (lowest scenario) to 75 Gt (highest scenario) of stored CO_2 (10 to 83 Gt CO_2 in the case of power plants and industry);

- *China* (based on effective capacity): 30 Gt (lowest scenario) to 192 Gt (highest scenario) of stored CO_2 (36 to 216 Gt CO_2 in the case of power plants and industry);
- *South Africa* (based on effective capacity): 4 Gt (lowest scenario) to 22 Gt (highest scenario) of stored CO_2 (0 to 2 Gt CO_2 in the case of coal-to-liquid plants and 4 to 24 Gt CO_2 in the case of power plants and coal-to-liquid plants).

A comparison of the matched results with both the theoretical storage potential and the amount of separated CO_2 emissions reveals that in:

- *India,* less than 60 per cent of the theoretical storage potential is used in most cases, even in the low storage scenario S3. This is due to the long distance between most sources and the considered sinks. The degree of utilisation of the amount of separated CO_2 emissions is low (24 to 64 per cent) with storage scenarios S2 and S3 and high (67 to 96 per cent) with storage scenario S1;
- *China,* 70 per cent or less of the effective storage potential could be used in all combinations and less than 50 per cent in most cases. With the low storage scenario S3, between 55 and 70 per cent of the sites are filled, due to the long distance between the sources and the considered sinks, most of which are outside the considered range of 500 km. The degree of utilisation of the separated CO_2 emissions is low with the low storage scenario S3, where only 18 to 29 per cent of the emissions from coal development pathways E1 and E2 could be sequestered (60 to 87 per cent with E3). In contrast, with the high and middle storage scenarios S1 and S2, it would be possible to store 82 to 87 per cent of all separated CO_2 emissions;
- *South Africa,* the proportion of CO_2 emissions that could be stored is 100 per cent in most cases. The low storage scenario S3 is the only one where – for both the high and middle coal development pathway – less than 50 per cent of the emissions could be stored. The emissions in these pathways could only be fully sequestered in the high storage scenario. The share of effective storage capacity used is less than 30 per cent in all cases because only the two closest sinks, which are within 600 km, are integrated in the source-sink match.

It should be noted that for *India* the source-sink match is based on the theoretical capacity since it was decided not to apply general efficiency factors (see above). Had general efficiency factors been applied, it would also have been necessary to reduce the theoretical storage potential, and therefore the matched capacity.

In practice, the derived potential for each country is further reduced to the practical storage potential when technical, legal, economic and acceptance barriers are taken into account. This also reduces the matched capacities.

To conclude, estimates of the storage potential in the considered countries are currently highly speculative. This means that the basis upon which the large-scale deployment potential of CCS is estimated is unreliable. One main constraint for the deployment of CCS in the analysed countries is the lack of detailed knowledge about potential storage sites and their connection to CO_2 emission sources. If extremely optimistic assumptions are applied, a large amount of CO_2 emissions could theoretically be stored (75, 192 and 22 Gt CO_2 in India, China and South Africa, respectively). If more realistic estimates of the countries' effective and "matched" storage potential are taken into account, only a fraction of the separable CO_2 emissions may potentially be sequestered (less than 5, 30 and 4 Gt CO_2 in India, China and South Africa, respectively). In practice, this potential will decrease further with the impact of technical, legal, economic and acceptance factors. In the future, more in-depth assessments of the countries' effective and matched storage potentials are required to verify the high expectations that some storage scenarios attribute to CCS.

The matching of CO_2 sources and geological sinks provides an indicative framework to illustrate to what extent CO_2 could be sequestered given the technical and geological constraints. To complete the picture, a supplementary technology assessment considering socio-economic and ecological conditions in the respective countries was prepared as part of this study.

36.3 Economic Analysis

To investigate the economic viability of CCS-based power plants, the long-term development of the levelised costs of CCS-based electricity production in India, China and South Africa was modelled for the first time. This development is based on learning rates applied to the aforementioned power plant development pathways E1 to E3, using the most reliable data for capital costs, O&M expenses and fuel price development.

- The analysis reveals a significant barrier to the economic viability of CCS under current conditions, which are characterised by a low CO_2 price development in all of the considered countries. The introduction of a CO_2 pricing scheme would therefore be a crucial prerequisite for CCS commercialisation.
- The CO_2 pricing pathway calculated in this study is assumed to start at USD 42 per tonne of CO_2 in 2020 and to increase up to USD 63 per tonne of CO_2 by 2050.
- Of the countries investigated, China has the lowest threshold to the economic viability of CCS. In the presence of the assumed CO_2 penalty, the levelised cost of electricity production (LCOE) calculated for CCS plants is clearly lower than the LCOE of an equivalent non-CCS plant (US-ct 7.89/kWh_{el} versus US-ct 10.63/kWh_{el}). Consequently, the assumed CO_2 pricing pathway would provide a strong incentive for installing CCS equipment in China's coal-fired power stations.
- The LCOE of CCS plants in China is significantly lower than in India and South Africa, mainly due to cheaper labour and equipment costs. Consequently, the incentive derived from the same CO_2 pricing pathway is significantly weaker in India and South Africa. India has the highest level of LCOE for coal-fired power generation with CCS of the three countries, as it combines rather high capital costs (due to complex ambient conditions)

with high fuel prices. South Africa's capital costs for large-scale power plants are also comparatively high, but fuel prices are low. For the future, the costs were updated using learning factors for CCS expenditures.

- As a consequence, the LCOE of India's CCS plants is only slightly lower than that of non-CCS plants (US-ct 12.49/kWh_{el} versus US-ct 13.42/kWh_{el}) by 2050 if a CO_2 price is added. In South Africa, the LCOE of CCS plants is also somewhat lower than the LCOE of non-CCS plants (US-ct 10.03/kWh_{el} versus US-ct 11.56/kWh_{el}).

A more ambitious CO_2 pricing scenario would be required to generate a strong economic advantage of CCS plants over non-CCS plants in India and South Africa.

36.4 Resource Analysis

In each of the considered countries, a high coal demand development pathway may lead to significant resource constraints and rising coal prices in the medium term. This trend would be strengthened by the increased coal consumption of CCS-based coal-fired power plants, questioning the underlying assumptions on the economic feasibility of CCS. All of the investigated countries have a typical coal production supply curve. Assuming the current proven coal reserves, even the present growth rates will not facilitate continued coal production in the long run. Since both India and China are importing increasing amounts of coal, coal trading prices are expected to increase on the global market. These trends would be reinforced by a rise in coal consumption per unit of electricity, caused by the application of CCS.

- *India*: Applying the typical supply pattern curve, it becomes obvious that proven recoverable reserves may be insufficient to meet the demand in the assumed high case energy scenario with CCS (*E1: high,* 46 to 50 Gt coal). Moreover, based on total recoverable reserves of about 60 Gt, it seems very uncertain whether a continuation of the trend for increased coal production can be supported until 2050. Most probably, prices will rise much more considerably to suppress demand, forcing a production peak long before 2050, probably around 2030. Scenarios with a cumulative demand below 30 to 40 Gt by 2050 (*E2: middle*, *E3: low*) could allow a continued growth in the rate of production in 2050. Although the peak event could be shifted to a certain extent by the discovery of new resources, a shift to sometime around 2050 seems highly unrealistic.

- *China*: China's proven coal reserves are between 114.5 and 182 Gt. When possible reserves are included, this figure rises to 319 Gt, as reported for the end of 2009 in the Chinese Statistical Yearbook. What is even more problematic is the rising demand for coal imports. In 2010, China became the world's second largest importer of coal, requiring 166 Mt. It is clear that reserves may be insufficient for meeting demand in the assumed high case coal development pathway (*E1: high*). Although it only covers power plants installed up to 2050, this pathway would require 102 to 137 Gt of coal, which would rise to 110 to 146 Gt if CCS were applied. The pathway with the lowest cumulative demand (56 to 74 Gt with *E3: low*) could still allow growth in the production rate.

- *South Africa*: The estimates of coal reserves in South Africa have been revised downwards several times. At present, they are believed to be between 15 and 27 Gt. The rate of development of new projects and the construction of infrastructure will determine whether the production peak lies ahead or whether it has already taken place. It is clear that proven recoverable reserves may be insufficient for meeting demand in the assumed high case coal development pathway (*E1: high*). Although it covers only power plants installed up to 2050, this pathway would require 7.5 to 8.5 billion tonnes of coal, which would increase to 8.3 to 9.5 billion tonnes if CCS were applied. The pathway with the lowest cumulative demand (4 to 5 billion tonnes with *E3: low*) could still allow a growth in the production rate.

36.5 Ecological Analysis

The prospective life cycle analysis (LCA) of future CCS-based pulverised power plants and integrated gasification combined cycle (IGCC) plants yields conflicting results regarding the environmental impacts of CCS.

- On the one hand, CCS-based power plants could provide lower-carbon electricity by 2030 since, from a life cycle perspective, both the CO_2 emissions and the total greenhouse gas emissions per kilowatt hour of electricity are considerably reduced. Where there is a CO_2 capture rate of 90 per cent at the power plant's stack, the overall CO_2 emissions per kilowatt hour of electricity are reduced by 75 to 77 per cent in the case of *India*; 75 per cent in the case of *China* and 74 to 78 per cent in the case of *South Africa*. Total greenhouse gas emissions per kilowatt hour of electricity are reduced by 71 to 74 per cent in the case of *India;* 59 to 60 per cent in the case of *China* and 67 to 72 per cent in the case of *South Africa*. The differences between these three countries are mainly due to the quantity of methane emissions released during coal mining, which is highest in China. Emissions from coal fires were not considered within this equation. Furthermore, it was presumed that there would be no leakages at the storage sites, which would significantly change the balance of CO_2 emissions.
- However, the reduction rates are lower than the CO_2 capture rate due to the additional energy consumption, which increases the environmental burdens upstream. The effects of transporting and storing the carbon dioxide must also be considered as well as further second- and third-order emissions.
- On the other hand, most other environmental and social impacts would increase. Most environmental impact factors increase for both pulverised power plants and IGCC (eutrophication, human toxicity, terrestrial ecotoxicity, freshwater and marine aquatic ecotoxicity and stratospheric ozone depletion) whilst acidification and summer smog decrease in the case of pulverised power plants and increase in the case of IGCC. Because of CCS's additional primary energy demands, other environmental and social issues not included in the life cycle assessment increase (for example, air quality, noise, mine waste, health risks, displacement and resettlement).

36.6 Stakeholder Analysis

Last but not least, the perceptions of decision makers and the public acceptance of CCS have to be taken into account. The interviews conducted during this study led to the following conclusions:

- The *Indian* government has a cautious attitude towards the commercialisation of CCS. India's foremost energy policy priority is to provide all Indian citizens with access to electricity. Since a large proportion of the additional electricity will be provided by central power plants and since CCS leads to substantial efficiency losses in power plants, it contradicts this aim.
- The *Chinese* government is not an enthusiastic advocate of CCS, mainly due to the high costs and energy penalty incurred by the technology. However, political and industrial decision-makers in China regard CCS as a back-up or emergency technology for complying with possible long-term CO_2 mitigation obligations.
- In *South Africa*, key players have taken important steps in terms of the research, development and politics of CCS. The South African government recognises that CCS could become an important CO_2 mitigation technology in South Africa. However, it also brings with it potential conflicts with other important policy objectives, such as affordable electricity rates, reducing water usage and improving the efficiency of electricity generation in order to give the whole population access to electricity.
- *Public awareness* of CCS in India, South Africa and China is very low. Hence the public debate, in contrast to Europe, has not yet started.

36.7 Results of Integrated Assessment of CCS

In Tab. 36-1, the results presented for the individual assessment dimensions are assembled so that an integrated assessment can be undertaken. The effect of each assessment dimension on the future role of CCS is ranked between 1 and 5 in five categories. Whilst the highest score (5) illustrates a strong incentive, the lowest score (1) represents a strong barrier to CCS development.

Fig. 36-2 shows the results for each country. For the crucial parameters – storage capacity and cost development – the lines above the columns projects the range within which these could develop in the event of different framework conditions or assumptions.

Tab. 36-1 Integrated assessment of CCS in India, China and South Africa – assessing the individual dimensions ranging from 1 (strong barrier) to 5 (strong incentive)

Assessment dimension	Categorisation of sub-dimensions	Incentive or barrier for the future role of CCS in		
		India	**China**	**South Africa**
Storage capacity and source-sink matching	High storage scenario	5	5	5
	Intermediate storage scenario	3	5	5
	Low storage scenario	1	1	2
Assessment of coal reserves		2	2	2
Cost assessment	Low CO_2 price development	1	1	1
	Assumed CO_2 price development	3	4	3
	Higher CO_2 price development	4	5	4
Ecological assessment	Reduction in CO_2 emissions per kWh of electricity	4	4	4
	Reduction in total GHG emissions per kWh of electricity	4	3	4
	Impact on other environmental impact categories	1.5	1.5	1.5
	Impacts on local environment and health	1	2	2
Stakeholder analysis	Current perspective	1	2	3.5
	Long-term prospects	3	3	4

GHG = greenhouse gas

The dimensions are classified from 1 to 5, whereby 5 illustrates a strong incentive for CCS development in each country and 1 represents a strong barrier to CCS.

Source: Authors' composition

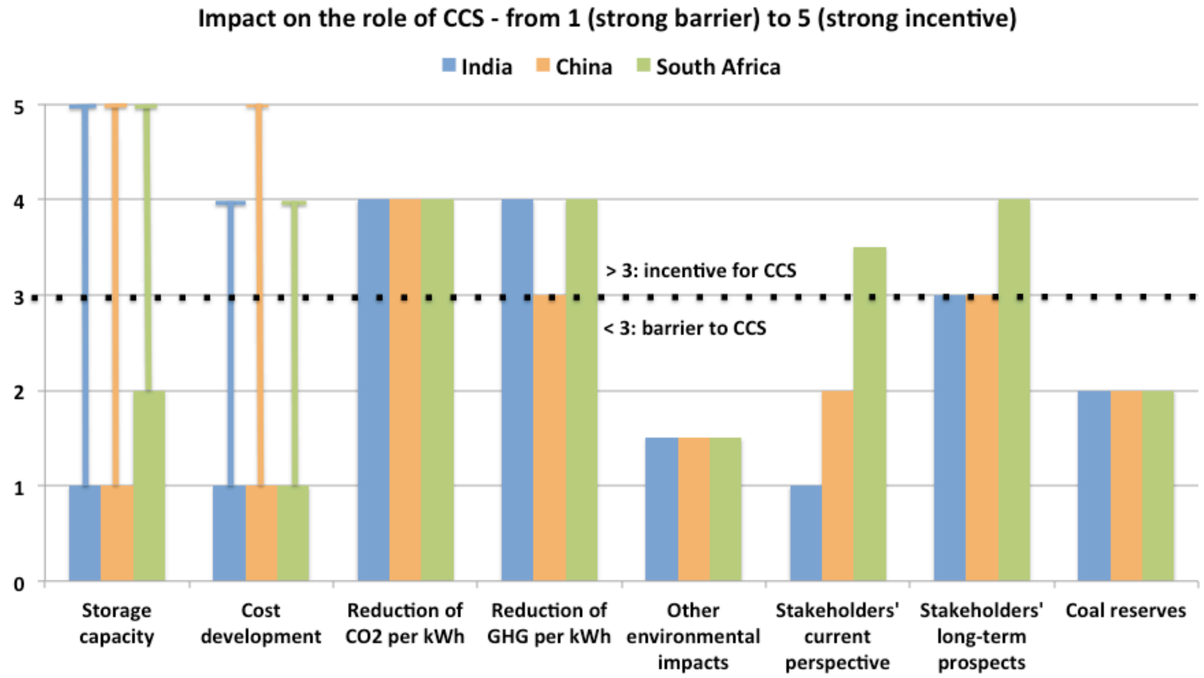

Fig. 36-2 Integrated assessment of CCS in the analysed countries, including the possible impact variations of storage capacity and cost development

Source: Authors' composition

As the results show, several preconditions need to be fulfilled if CCS is to play a future role in reducing CO_2 emissions in the analysed countries. Matching CO_2 storage capacities based on reliable storage capacity assessments, accessible coal reserves, cost-effectiveness, ecological requirements and public support need to be fulfilled to establish conditions for a prominent development of CCS in the analysed countries. If the effect of each assessment dimension is ranked from 1 to 5 across five categories (strong barrier to strong incentive for CCS), both storage capacity and costs could develop within the whole range with different framework conditions or assumptions. The other assessment dimensions score between 2 and 4 (weak barrier to weak incentive for CCS).

36.8 Overall Conclusions for Future Strategies

- Existing scenario studies for the analysed countries yield various strategies for reducing CO_2 emissions in the electricity sector.
- One option is for considerable efforts to made in order to achieve drastic improvements in *energy efficiency* together with an ambitious increase in the use of all forms of *renewable energy*. The *Energy [R]evolution Scenarios* from EREC and Greenpeace, for example, show that in such a pathway a certain amount of conventional coal-fired power plants would still be necessary to satisfy energy needs over the next two or three decades but, nonetheless, the climate targets calculated in these scenarios would be met without using CCS and nuclear energy. However, such a scenario would pose a significant challenge as it would require the systematic integration of renewable energies into the current energy system. This would be a complex process which would depend on numerous factors.
- The second option is to pursue a fossil fuel-based policy, supplemented by varying shares of nuclear energy or renewable energies as assumed, for example, in the *BLUE Map Scenario* of the IEA and as adopted in the CO_2 emission pathways used in this study. Due to the striking dominance of coal-fired power generation in the countries' electricity sector, this option would require the introduction of CCS on a different scale, acknowledging the consequences shown in the integrated assessment. Without CCS, a coal-dominated route would be unable to reduce fossil-related carbon dioxide emissions as substantially as required by climate scientists. However, preconditions for opting for CCS would be the commercial viability of CCS; a decrease in CCS-based electricity costs; long-term policy support and a sufficient amount of proven and safe storage capacity.

In order to overcome the existing barriers, experts and decision-makers from each country have made it very clear in the various interviews conducted within this study that a stronger commitment from the industrialised world in terms of technology demonstration, cooperation and transfer to developing countries and emerging economies would be required alongside national actions and analysis, both for CCS and for improvements in energy efficiency or the deployment of renewable energies.