Carbon mitigation technologies for emerging economies

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Abstract

This report provides a review of the various options being pursued to reduce carbon intensities in five developing countries, namely Brazil, China, India, Indonesia and South Africa. These are major emerging economies, all of which are vulnerable to adverse effects from climate change, with their governments having to balance economic, environmental and social priorities. All have large carbon footprints; however, in each case, they have made commitments to reduce carbon intensities over the period to 2030 and, in some cases, beyond. The approach to be adopted varies from country to country, depending on both technical and economic drivers. China, India, Indonesia and South Africa have fossil fuel based economies, in which in three cases coal is the dominant energy source while for the other (Indonesia) coal is an important and growing component of the energy mix. In all four countries, while the introduction of renewable energy and nuclear power is being addressed to varying degrees, establishing higher efficiency coal-fired power plants is seen as an important and near-term step in reducing carbon intensities. At the same time, China, Indonesia and South Africa have shown interest in CCS as a future mitigation option, with government policies identifying it as a key development priority. In contrast, in India, there is at present little interest in the technology. In the case of Brazil, the very different energy mix compared to the other four countries means that there is little interest in CCS for the power sector since that is dominated by renewable energy use. However, while there is a lack of policies to support CCS, the government's limitations on CO_2 release from oil and gas extraction from the newly discovered deposits has provided a powerful driver for CCS related R&D. Following a description of the respective programmes, suggestions are made on the need to accelerate the development and deployment of CCS technologies, especially in those developing countries that have established policies to counter climate change and have recognised the potential importance of CCS as a carbon mitigation technique. It is also suggested that it is important to support the nearer-term but equally critical initiatives to establish higher efficiency and cleaner coal units for power and non-power applications.

Acronyms and abbreviations

APEC	Asia Pacific Economic Cooperation
CBM	coalbed methane
CCS	carbon capture and storage
CCUS	carbon capture, utilisation and storage
CDM	clean development mechanism
CEC	China Electricity Council
CO_2	carbon dioxide
CO_2-e	carbon dioxide equivalent
CPO	crude palm oil
CSLF	Carbon Sequestration Leadership Forum, USA
CSP	concentrated solar power
DECC	Department of Energy & Climate Change, UK
EOR	enhanced oil recovery
EGR	enhanced gas recovery
EIA	Energy Information Administration, USA
FYP	Five-Year Plan
GDP	gross domestic product
GHG	greenhouse gas
GIS	Geographic Information System
IEA	International Energy Agency
IPP	independent power producer
IRP	integrated resource plan
LHV	lower heating value
MOST	Ministry of Science & Technology, China
NAPCC	National Action Plan for Climate Change
NDRC	National Development & Reform Commission, China
NEA	National Energy Administration, China
NETL	National Energy Technology Laboratory, USA
NOx	nitrogen oxides
NRDC	National Resource Defense Council, USA
PC	pulverised coal
R&D	research & development
SC	supercritical
SO_2	sulphur oxides
USA	United States of America
US$	United States dollars
UK	United Kingdom
UNDP	United Nations Development Programme
USC	ultra-supercritical

Units:

g	gramme
Gt	gigatonne
Gtce	gigatonne coal equivalent
GWe	gigawatt electric
GWh	gigawatt hour
kWh	kilowatt hour
km	kilometre
%	per cent
m^3	cubic metres
MJ	megajoule
Mt	million tonnes
Mtoe	million tonnes oil equivalent
MPa	megapascal
MWe	megawatt electric
MWh	megawatt hour
MWth	megawatt thermal
TWh	terrawatt hour

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1 Introduction

Global fossil energy (those amounts that have been broadly estimated to be available in various deposits without any assessment of either the technical or economic feasibility of extraction) comprise some 21,000 Gtce. Of this amount, coal constitutes 78.5%, natural gas 18.6% and oil 2.9%. The energy reserves (those resources that should be recoverable and economically extractable using current technology under current market conditions) comprise some 1400 Gtce (Ricketts, 2011). The current annual usage rate is about 16 Gtce. As such, fossil fuel sources are readily available, especially coal which very many nations see as an integral means to ensure the availability, reliability and security of a country's overall energy supply. Consequently, major infrastructures have been, and continue to be, established to ensure the steady production, transport and utilisation of fossil fuels on a global basis. At the same time, there is an increasing recognition that the use of fossil fuels must meet ever tighter environmental standards for conventional (SO_2, NOx and fine particulates) emissions while also addressing the growing concerns regarding carbon intensities by limiting emissions of CO_2.

1.1 Background

The IEA has forecast that, by 2030, 44% of the global generation mix will be from coal and 80% of the growth will take place in non-OECD countries (IEA, 2010). Consequently, given the growing concerns regarding carbon intensities, there is a need to use the abundant and reliable coal-based energy sources in a way that will minimise emissions of CO_2. The most promising way identified to date is carbon capture and storage (CCS). This is a technique for capturing some 90% of CO_2 from large point source emitters such as fossil fuel power stations and other large energy-intensive industrial processes, with subsequent transport and long-term storage in geological formations deep underground. Such storage options also offer the possibility of using the CO_2 to enhance oil (EOR) and gas (EGR) recovery from production wells.

The IEA estimates that CCS could account for about one-fifth of the total mitigation efforts required by 2050 in order to avoid major climate change, making it the largest single contributor after energy efficiency. Indeed, the IEA has further estimated that not using CCS would increase the total costs of meeting these mitigation goals by at least 70% (IEA, 2009a). Consequently, it is seen as one of the core technologies for tackling climate change. However, the IEA also estimates that this would require the development of some 3400 CCS projects worldwide, of which some 65% would need to be established in non-OECD countries.

In many developing countries, increasing demand for power is driving the introduction of new, modern coal-fired plants, and such new, efficient generating fleets will not start to be decommissioned for at least forty years. These countries have great concerns about energy security and, as such, coal is an integral and major part of the economy, providing jobs for many of the population. Since these countries are often susceptible to climate change impacts, the introduction of CCS, both for new and retrofit applications, offers a means to maintain economic sustainability while ensuring effective carbon mitigation. Consequently, the successful introduction of CCS in developing countries has profound implications for future energy utilisation.

In addition to reducing energy usage through demand and supply side management, the alternative carbon mitigation approaches include the introduction of renewable energy sources such as biomass, geothermal, hydropower, solar and wind, together with nuclear power. While these are either very low or zero CO_2 emitters, there are issues in most cases with their lack of load-following capability for power generation while having limited applicability in many non-power energy-intensive industries (European Energy Review, 2011). However, in many developing countries, they offer some potentially attractive options and consequently there are some major deployment programmes under way.

1.2 Scope of the report

This report focuses on the development of the power sectors in five developing countries, namely Brazil, China, India, Indonesia and South Africa within the framework of an international need to limit energy use and control greenhouse gas (GHG) emissions. All show continued increased energy demand and, in most cases, continuing population growth. Four of these countries have economies underpinned with coal and/or natural gas use, of which two are major fossil fuel energy exporters. The fifth country, Brazil, meets much of its energy demand through hydropower, although there is an increasing use of fossil fuels and it too has the potential to become a significant oil and gas exporter.

Following this introduction, this report provides an overview of the various carbon mitigation technologies available to the power generation sector, including information on maturity, carbon footprints and comparative costs. This is followed by five chapters – one for each of the five designated countries. In each case, this presents an overview of the energy resources and reserves available, and the current and projected future use of these energy sources. There is then a review of national energy policy as well as plans for carbon mitigation and constraints on energy use, followed by information on current and likely CO_2 emissions arising. This is followed with information on any CCS development and deployment initiatives, which are compared subsequently with the implementation of alternative carbon mitigation actions. The final chapter provides an assessment of the relevance of CCS for each of the designated countries, within the context of their respective carbon mitigation approaches, together with the challenges and opportunities to ensure adequate implementation.

2 Carbon mitigation options for the power generation sector

Coal-fired power generation emits high levels of CO_2 for each unit of power generated. In order to counter this potentially adverse impact, there are several options, which include:

- reducing the demand for electricity so that less power needs to be generated, which means less coal needs to be burned;
- improving the efficiency of electricity generation so more power is generated for each unit of coal that is burned;
- making better overall use of the energy released through provision of the lower grade energy as heat to end-users;
- applying CCS so that the CO_2 is captured and stored rather than released to atmosphere;
- switching to a fossil fuel with a lower carbon content such as natural gas;
- switching to an alternative power generation process with near to zero carbon emissions.

While each of these options is potentially attractive, all have some issues that must be taken into account. Key points are discussed below.

2.1 Demand-side energy efficiency improvements

Demand-side management comprises various actions to reduce the amount of energy used by customers and to change the pattern of that usage. The aim is to smooth out peaks and troughs in energy demand either by reducing consumption at peak times, increasing it during off-peak times or shifting load from peak to off-peak periods to maximise the use of efficient base load generation. Alongside this, there are energy-efficiency programmes to reduce the energy used in appliances through the use of advanced equipment to produce at least the same level of lighting, heating and cooling, with less electricity.

2.2 Coal-fired power generation

The most common technology used is pulverised coal (pc) combustion, which accounts for some 97% of coal-fired capacity worldwide (Nalbandian, 2008). Coal is first milled (pulverised) to a fine powder, which increases the surface area and allows it to burn more quickly. This is then blown with part of the combustion air through a series of burner nozzles into the combustion chamber of a boiler. Secondary and tertiary air may also be added. Combustion takes place at temperatures between 1300°C and 1700°C depending largely on the type of coal used. The energy that is released heats the water in the tubes lining the boiler to produce steam. The high pressure steam is passed into a turbine-generator, where electricity is produced and the steam is subsequently condensed before being returned to the boiler to be heated once again (World Coal Association, 2011).

2.2.1 Options for increased efficiency

A conventional (subcritical) plant typically operates with steam temperatures up to 540°C and has a thermal efficiency of between 30% and 39% (net LHV basis), depending on the unit size, coal quality and local conditions.

In recent years, the major way of achieving higher efficiencies has been the introduction of supercritical (SC) and ultra-supercritical (USC) steam conditions, which raise steam at higher temperatures and under a higher pressure to give a thermal efficiency level of 45% to 46%, depending on the exact conditions. Such SC and USC plants have higher capital costs than the conventional (subcritical) units because of the higher requirements of the steel needed to withstand the higher pressure and temperature. However, this is offset by operational costs savings due to the higher efficiency of the process (Nalbandian, 2008).

It is possible to increase further the mean temperature of heat addition, by taking back partially expanded and reduced temperature steam from the turbine to the boiler, reheating it, and re-introducing it to the turbine. This can be done either once or twice, which is known as single and double reheat respectively. The improvement in thermal efficiency can be one percentage point with the addition of the second reheat stage (NETL, 2008).

Decreasing the condenser pressure from, say, 0.0065 MPa to 0.0030 MPa, can further increase the thermal efficiency by up to 1.5 percentage points (CIAB, 2010).

Reducing the excess air ratio from 25% to 15% can result in a small increase in thermal efficiency of 0.3 percentage points. Boilers are normally operated at the minimum practicable excess air amount, while ensuring that sufficient air is available to burn virtually all the carbon present in the coal. At the same time, modern design and practice is to control and stage the addition of air in order to minimise the formation of NOx. Consequently, controlling the excess air is an important function in boiler operation, which requires a careful balance between these conflicting requirements (Schilling 1993).

In addition, reducing the stack gas exit temperature by 10°C, while recovering the heat involved, can also bring about a similar small increase in thermal efficiency of 0.3 percentage points.

2.2.2 Cofiring of biomass with coal

Cofiring biomass with coal in existing power plants can also significantly lower the CO_2 emissions, because some of the coal is replaced by 'carbon neutral' biomass (European Commission, 2008). This technique, with up to 10–15% of the energy being provided by biomass, has been established for many years in the UK and other northern European countries, with financial incentives being provided as biomass is classed as a renewable feedstock.

2.2.3 Use of CCS

The CCS process comprises three integrated stages, namely:
- capture and subsequent compression of the CO_2;
- the transport of the CO_2 in a supercritical/dense phase;
- its subsequent injection into the selected geological formation.

The choice of capture technique depends on the type of industrial process, from which the downstream transport and storage stages are essentially independent. All CCS options incur costs and reduce the efficiency of the plant. Fitting CCS to a power plant requires additional capital investment for the CO_2 capture and compression equipment, the transport infrastructure as well as the equipment associated with the storage activities. In all cases, CO_2 capture will use additional energy for the capture and subsequent compression of the CO_2 that will reduce the overall process efficiency and also increase the amount of fuel used to achieve a given power generation output.

Capital costs are expected to reduce once this technology is demonstrated and then deployed on a significant scale. Improvements in the efficiency of the capture technologies and effective integration with the other process components will lead to reductions in the energy penalty. At the same time, other aspects such as the reliability of the plant, scalability of the equipment, maintainability, as well as consumption of water will need to be considered. The cost of CCS will also be affected by the length of pipeline between the power plant and the storage site, as well as the type and depth of storage. For example, offshore storage would be more expensive than onshore storage (Freund, 2009).

2.3 Natural gas fired units

The newer natural gas fired power plants are 'combined-cycle' units, which include both a gas turbine and a steam turbine. The hot gases released from burning natural gas are used to drive the gas turbine while the waste heat from this process is passed through a heat exchanger to raise steam, which is then used to generate electricity in a steam turbine. This efficient use of the heat energy released from the natural gas means that these combined-cycle plants can achieve thermal efficiencies of around 60% (NaturalGas, 2011).

2.4 Nuclear power

This is a nominal zero emissions technology, in that operation of the power plant does not produce CO_2 unlike the fossil fuel fired systems. However, there are some CO_2 emissions arising from the construction of the plant and the fuel preparation process, the magnitude of which is considered in Section 2.7.

Nuclear power stations operate in the same way as a coal-fired power plant in that heat is released, in this case from a continuous nuclear fission reaction, and then used to raise steam to drive a steam turbine to generate power. As such, modern nuclear power stations use the same type of steam turbines and generators as conventional fossil fuel fired power stations (World Nuclear Association, 2011).

2.5 Renewable energy

These technologies are also classed as having near-zero emissions but, unlike nuclear, do not depend on a finite energy source.

2.5.1 Biomass

Biomass resources include agricultural residues; animal manure; wood wastes from forestry and industry; residues from food and paper industries; municipal green wastes; sewage sludge; dedicated energy crops such as short-rotation (3–15 years) coppice, sugar crops and starch crops. Wastes and residues have been the major biomass sources used to date. For energy applications, biomass is nominally classed as carbon neutral because the CO_2 released by burning is equivalent to the CO_2 absorbed by the plants during their growth.

Biomass fuels are much lower in energy and density than fossil fuels (NREL, 2000), which means that the size of unit is determined by the amount of biomass that can be economically supplied for combustion in a power station. The typical capacity of a biomass-fired power plant is 10–25 MWe, which means that the thermal efficiency is low and conventional emissions can be problematic (Minchener, 2010). In contrast, cofiring the same quantity of biomass with coal in large-scale conventional power stations overcomes the disadvantages of biomass-only firing.

2.5.2 Geothermal power systems

The technology has been established in 24 countries but, in each case, capacity is typically less than 100 MWe (Geothermal Energy Association, 2010).

Interlinked boreholes are drilled to a depth of at least 5 km into hot rocks. Water is injected down one borehole, which is turned into steam or hot water and travels up another borehole to the surface, where it can be used to turn the turbine of a generator, thereby producing electricity (US DOE, 2011). The fluid is then cooled and returned to the heat source.

There are three variants. Thus:
- the steam from the boreholes is used directly to drive a turbine;
- the hot water, usually at temperatures over 200ºC, is allowed it to boil as it rises to the surface, from which the steam is separated and used to drive the turbine;
- the hot water is passed through heat exchangers, in order to boil an organic fluid that is used to drive the turbine.

2.5.3 Hydropower

Hydropower is a means of generating electricity from the energy of moving water (Renewables Info, 2010). There are two main types of hydroelectric schemes; storage and run-of-river. Storage schemes require dams to build up a head of water that then passes through the dam to turn a turbine. In the much smaller capacity run-of-river schemes, turbines are placed in the natural flow of a river. The storage systems offer a more stable (constant) source of energy compared to other renewable sources because electricity can be produced at a steady rate although there is generation flexibility to meet sudden fluctuations in demand (Pew Centre, 2009). There is one operational disadvantage in that, in times of droughts when there is not enough available water, hydropower cannot produce electricity.

2.5.4 Solar power

Solar power is the conversion of sunlight into electricity. This can be achieved either directly using photovoltaics (pv) or indirectly with a concentrating solar power (CSP) system. The pv cells, which are also known as solar cells, are made of crystalline silicon, a semi-conducting material which converts sunlight into electricity (PV resources, 2012). CSP systems use either lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated energy is then used as a source to heat a working fluid, which can then be used to generate power via a turbine in a conventional type of power plant (Solar Paces, 2011). Both technology variants need large arrays to ensure sufficient access to sunlight. To date, the larger pv power plants in operation are <100 MWe, while construction of a 200 MWe plant has just been completed, and plans for larger plants are in preparation (PV power plants, 2011). For CSP, the largest power plant has a capacity of 354 MWe, which comprises nine units (Solar Paces, 2011).

2.5.5 Wave and tidal power

There are two types of marine energy devices, wave energy converters and tidal (stream and barrage) devices, both of which are still under development and not yet operating at close to commercial scale.

2.5.6 Wind power

A wind turbine is a device that converts the kinetic energy from the wind into mechanical energy, which is used to produce electricity. Increasingly, wind farms, which can consist of large grid-connected arrays of several hundred individual wind turbines, are becoming a large source of commercial electric power (GWEC, 2010a). These farms can be located either onshore or offshore. The onshore units are less expensive to construct than those offshore, although the latter can harness the better wind speeds that are available (World Wind Energy Association, 2011). Wind power is a very low carbon technology; however, it is a very intermittent source of power and requires back-up in order to ensure continuity of power generation.

2.6 Carbon footprints

All electricity generation technologies emit CO_2 at some point during their life cycle, which is referred to as the carbon footprint of electricity generation, that is the CO_2 emitted for each unit of electricity generated, including resource extraction, power plant and equipment manufacturing and construction, and power production operations (Postnote, 2006). There is some debate about how large these footprints are, especially for 'very low carbon' technologies such as wind and nuclear, in part due to the use of various methods of calculation. The results from a UK study are presented in Figure 1. This compared the various technologies on a reasonably consistent basis, although inputs were gathered from separate sources for each technology, both under recent conditions and taking account of possible advances.

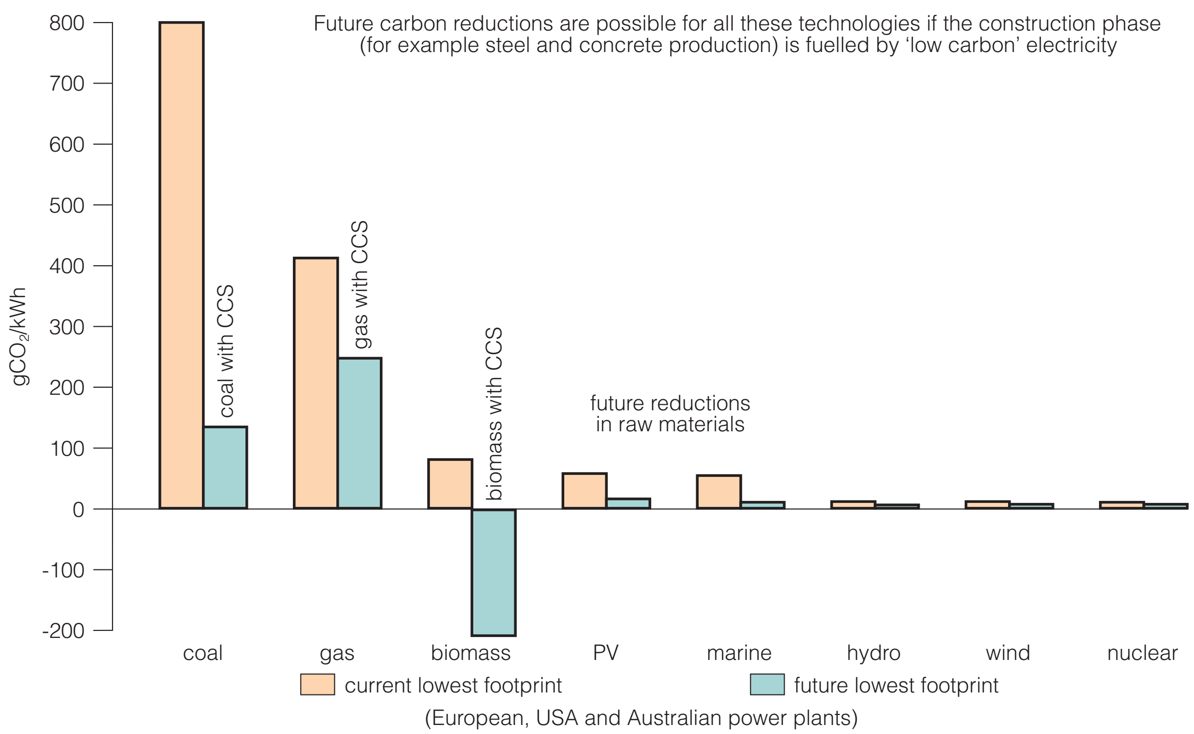

Figure 1 Current and future carbon footprints (Postnote, 2006)

This showed that coal-burning power systems have the largest carbon footprint of all the electricity generation systems analysed, of the order of >1000 gCO_2-e/kWh for a UK 500 MWe subcritical unit. In contrast, a modern high-efficiency unit with advanced steam conditions, such as found in parts of Europe and especially in Asia, would achieve some 40% lower emissions. However, this would still be higher than a gas-fired unit and considerably higher than the low carbon technologies. With regard to the latter options, in overall terms, there is no significant difference between the life-cycle carbon footprint of hydro, nuclear, and wind. While wave/tidal power, pv and biomass have absolute CO_2 emission footprints that may be three times those of hydro, nuclear, and wind they are still far lower than those of coal and natural gas (Sustainable Energy Today, 2010).

The carbon footprint of fossil-fuelled power plants is dominated by emissions during their operation. In contrast, the common feature of nuclear and most renewable energy systems is that emissions of greenhouse gases (GHG) and other atmospheric pollutants are 'indirect', that is, they arise from stages of the life cycle other than power generation.

Figure 1 also shows the impact of including CCS on coal- and gas-fired power plants. This indicates that CO_2 emissions can be reduced significantly to within an order of magnitude of the low carbon technologies. However, these assessments do not take account of the need with some renewable power sources for back-up power supplies, which are required to counter the intermittent nature of solar and wind power. At the same time, the capacity of hydropower is vulnerable to low water levels while there is no flexibility in operation with nuclear power. In contrast fossil fuel fired plants, either with or without CCS, offer a flexible operational approach.

2.7 Costs comparison

With regard to comparative costs between various technologies, these will vary to some extent on a geographical basis and depending on the assumptions made. However, studies by the UK Department of Energy & Climate Change (DECC), the IEA and the USA Energy Information Administration (EIA) broadly agree that coal- and gas-fired plants with CCS deliver electricity at comparable costs to nuclear and onshore wind, while offshore wind and solar power are more expensive (European Energy Review, 2011).

More recently, Alstom published the findings of their own study, which examined the costs of decarbonised power for the range of technologies outlined above, Figure 2. This focused on the application of such technologies in the period 2011-16 and again suggested that coal- and gas-fired power plants would be competitive with the alternatives (MacNaughton, 2011), even without taking into account the system costs necessary to provide back-up for those technologies that can only manage intermittent generation.

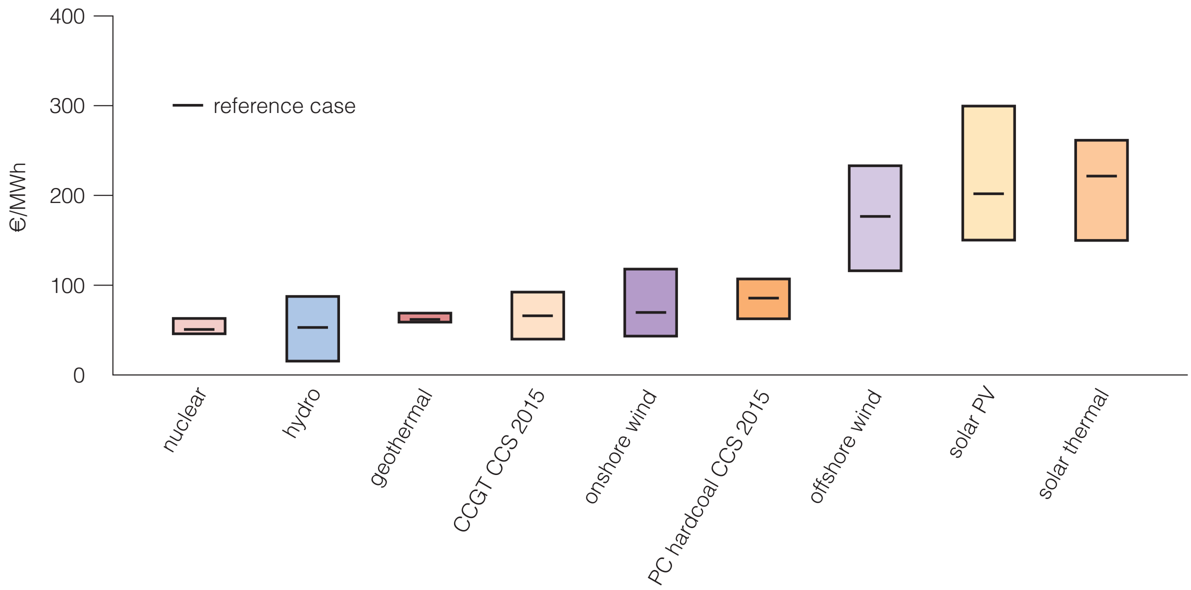

Figure 2 Comparison of the costs for decarbonised power for Europe in the 2011-16 period (MacNaughton, 2011)

3 Brazil

Brazil is the fifth largest country in the world on a geographical basis, with a population of around 200 million (BBC News, 2012). Unlike most developing countries, its economic growth has been achieved largely through the use of the large hydropower resources that are available, rather than by the use of fossil fuel based power.

3.1 Energy resources and reserves

Brazil has extensive fossil fuel reserves and resources, *see* Table 1, of which oil is exploited to meet current internal demand, much of the natural gas is exported, while coal is hardly used (EIA, 2011a). Brazil has between 6 and 7 Gt of proven hard coal and lignite reserves, with annual production close to 10 Mt, most of which is used for electricity generation.

Table 1 National fossil energy sources and demand for Brazil (BGR, 2010)

Fossil Energy 2009	Resources	Reserves*	Production	Demand
Oil	5000 Mt	2450 Mt	100 Mt	104 Mt
Natural gas	2000 billion m^3	365 billion m^3	12 billion m^3	~6 billion m^3
Hard coal	4665 Mt	1547 Mt	~4 Mt	~17 Mt
Lignite	12,587 Mt	5049 Mt	6 Mt	6 Mt

* Based on exploration and field discovery to date. These estimates do not include allowance for unconventional natural gas, such as shale gas.

3.2 Current energy mix and likely future changes

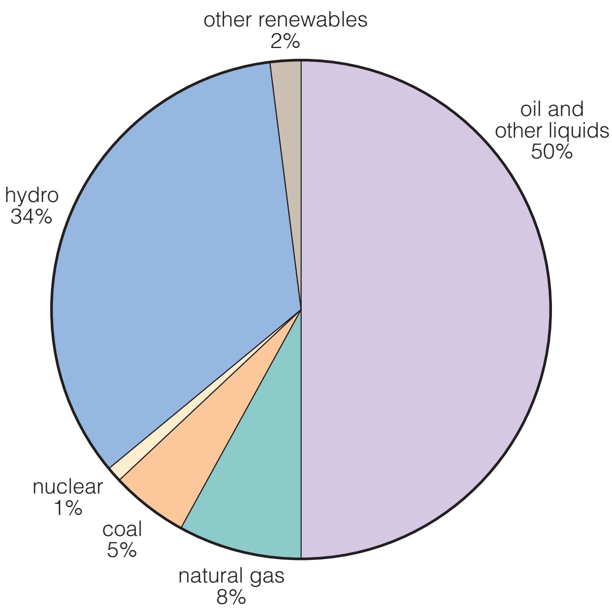

Figure 3 Total energy consumption by type in Brazil for 2008 (EIA, 2011a)

Brazil is the ninth largest energy user in the world, with total primary energy consumption of 11.2 x 10^{12} MJ (250 x 10^6 Mtoe) in 2008, which has increased by close to a third since 2000 due to sustained economic growth. The largest share comes from oil and other liquids (50%, including ethanol), followed by hydroelectricity (34%) and natural gas (8%) as shown in Figure 3.

Brazil had over 113 GWe installed generating capacity at the end of 2010, with the mix being dominated by renewable energy sources, especially hydropower, as shown in Table 2. In 2009, the country generated 461 GWh of electric power, of which hydropower accounted for 84%, with smaller amounts coming from conventional thermal, nuclear, and other renewable sources. Although hydroelectricity remains the dominant generation source (Power, 2012), the latter options have significant potential.

Table 2 Installed power plant capacity in Brazil at end 2010 (Carvalho, 2011)

Type			Capacity, GWe	Proportion	Average power price as of October 2010, US$/MWh
Hydro			80.7	71.2	55.8
Thermal	Gas	13.0	29.7	26.2	84.3
	Diesel	6.9			94.9
	Biomass	7.8			92.3
	Coal	1.9			88.0
Nuclear			2	1.8	–
Wind			0.9	0.8	81.1

For the future, in 2030, although there will be increases in domestic consumption driven by rapid economic growth, crude oil supply will be in excess of demand due to exploitation of major new deposits and so significant exports will be expected. With regard to natural gas, production has grown slowly in recent years, mainly due to a lack of domestic transportation capacity and low domestic prices. While there has been some expectation that its use in the power sector would increase as greater quantities become available from the new deposits, this is now seen as less likely since power production from wind energy appears to be less expensive in the Brazilian context, as discussed in Section 3.6. Growth in overall coal demand is expected to be modest, since the high ash and sulphur contents of the domestic supplies make them unsuitable for export, with internal use limited to power generation. Total annual demand might reach 30–35 Mt by 2030, with imports, currently about 13 Mt, continuing to increase in proportion as demand for coking coal continues to rise while for power production the impact will be far lower (Minchener, 2009).

3.3 National policies for energy and carbon mitigation

In December 2008, Brazil established its National Climate Change Plan (Elaw, 2008), which was quantified in December 2009 with the announcement that Brazil would decrease its total GHG emissions by 36.1–38.9% by 2020 compared with a business-as-usual scenario. The great majority of this change is expected to be achieved through a reduction in deforestation and land use changes. However, the plan also contains provisions for between 6.1 and 7.7 percentage points of the reduction to come from changes in energy usage, with the need to improve energy efficiency across various sectors of the economy (ABB, 2011).

Brazil is committed to maintaining the high renewable energy mix in its transport and electricity sectors. Although the government has declared that hydropower has the potential to provide up to 260 GWe of power generation capacity, in recent years certain plants have suffered from water shortages while the lack of a reliable grid system has meant that it has proved impossible to re-route power from other parts of the country. This has led to significant power outages in those locations where the hydropower has been inadequate. Consequently, while there are plans to increase hydropower, which will continue to play the major role in the electricity sector, there are also significant measures to introduce alternative renewable energy options, due to the need to ensure reliable power production, while using as far as is practicable the lower cost generation sources.

Back in 2002, the government created the 'Programme to Foster Alternative Sources of Electric Power (PROINFA)', with the aim to diversify from large-scale hydropower by increasing the use of wind power sources, biomass sources and small hydropower systems for power generation via independent producers. This programme has been renewed at least twice since its start, with changing targets, and the focus has been on using financial incentives to encourage the implementation of these renewable alternatives to large-scale hydropower (ABB, 2011). The medium- to long-term objective is that at least 15% of the annual market growth will be supplied by these alternative sources until they can provide 10% of the nation's annual electric power demand/total consumption.

PROINFA has now concluded and the government has subsequently introduced the concept of power contract auctions, in which various companies bid to obtain twenty-year set price power contracts. The first was held in mid-2009, with subsequent auctions later that year plus several in 2010 and 2011. The very great majority of contracts were for wind power (Clean Technica, 2011).

3.4 Current and projected future CO_2 emissions

At the end of 2009, energy-based CO_2 emissions in Brazil were about 340 Mt, of which the largest sector was transport, with less than 80 Mt from the power sector (IEA, 2011b). For the future, emission levels will increase as some additional coal power plant is introduced and the use of oil and coal in industry continues to grow. The likely level in 2030 from energy sources is 445 Mt, even if plans to implement better energy efficiency in industry and regional integration are implemented (BP, 2012).

3.5 National initiatives for CCS development and deployment

The National Plan has identified climate change as a strategic issue for both the present and future national development (GCCSI, 2009a). Currently, Brazil does not have any integrated policies or legislation dedicated to either encouraging the development of CCS technologies or regulating the implementation of CCS projects in Brazil. However, there are some ongoing activities. Thus, Brazil is a member of the Carbon Sequestration Leadership Forum (CSLF), which is an international climate change initiative that is focused on the development of improved cost-effective technologies for the separation and capture of CO_2 for its transport and long-term safe storage (CSLF, 2011). This includes addressing key technical, economic, and environmental obstacles through promotion of awareness and the championing of legal, regulatory, financial, and institutional environments conducive to such technologies.

The need for CCS in relation to coal-fired power plants is not of significant importance to Brazil because of the characteristics of its power generation sector. However, there is the commitment to make future reductions in CO_2 emissions arising from energy use, for which the focus is on the oil and gas sectors. In particular, there is a need for the oil industry to limit such emissions, especially as there is expected to be a surge in production due to recent discoveries of new deep pre-salt oil and gas deposits.

The pre-salt crust above certain deep oil fields is a corrosive environment beneath which there are considerable amounts of natural gas contaminated with CO_2 in association with the oil. Petrobras, the major state-owned oil and gas company, has proactively agreed not to release to the atmosphere the CO_2 associated with the natural gas. Consequently, it is examining CO_2 storage options, which include injecting around 400 tCO_2/d into a saline formation as a baseline CO_2 storage demonstration project. However, the main driver is CO_2-based EOR, with the intention to separate the CO_2 and the natural gas from the oil, and to compress and transport the CO_2 recovered for reinjection into the reservoirs to boost the oil recovery. There is believed to be scope to develop new CO_2 separation and capture options that will be more appropriate to the pre-salt situation. Therefore, in March 2011, Petrobras also started injecting high-pressure CO_2 into the Lula oil field within the Santos Basin pre-salt fairway, following onshore pilot testing that took place in 2009 (Reuters, 2011a). This is seen as a precursor for future development projects to support oil extraction from the offshore deep pre-salt fields (Offshore, 2010).

Petrobras is required by the government to invest 0.5% of its revenue arising from the major oil fields on R&D, to be undertaken by national institutions. This can include support for Brazilian scientific institutions and universities, as well as for participation in International Cooperation Agreements and Joint Implementation Projects. Thus, in October 2008, the Carbon Storage Research Centre (CEPAC) was created to undertake research into storing CO_2 in depleted coal mines, oil and gas fields and saline aquifers. Also in 2008, Petrobras established the Carbon Sequestration and Climate Change Thematic Network, which comprises 13 universities with some US$30 million financial support. As well as EOR related activities, Petrobras is also supporting R&D covering all aspects of the CCS chain, including regulation. It has also held a number of international CCS conferences within Brazil (zeroco2, 2011).

One of the major contributions that CEPAC has made to CCS in Brazil is a project to identify appropriate sites for long-term CO_2 storage in oil fields, saline aquifers and coal seams, including matching sources and sinks throughout the country, with the intention to produce a CO_2 storage atlas by early 2012. Some 361 large stationary sources of CO_2 were mapped, with an annual emissions level of 204 $MtCO_2$, including cement production, power production, refineries, ethylene production, iron and steel plants, biomass, ethanol production and one ammonia production plant (Ketzer and others, 2007). Regarding sinks, Brazil has extensive areas with potential geological reservoirs, consisting of 32 onshore and offshore sedimentary basins. The results suggest adequate storage capacity, for the current and projected future fossil fuel fired operations, of the order of 2000 Gt. There is reasonable source-storage mapping, especially in the south eastern part of the country where most of the oil fields and saline aquifers are located (Rockett and others, 2011).

The Brazilian Coal Association (BCA) is also looking at CCS, as part of a joint venture with the Ministry of Science and Technology to build a clean coal centre in Brazil. It is also working with Petrobras and NETL in the USA to develop a coal gasification programme, which includes the training of over 50 people, and with Germany to train people in conventional combustion. It is also seeking to engage the Brazilian Ministry of Mines and Energy about CCS regulation (IEA, 2009d).

As part of an International Cooperation Programme, Petrobras and other major energy companies have been undertaking the CO_2 Capture Project, which aims to develop the technologies necessary for the deployment of industrial-scale CCS. The scope of work is broad, covering the science, economic feasibility and technological requirements of CCS. There is co-operation with the US Department of Energy, the European Commission and more than 60 academic bodies and global research institutes. As part of the third phase, Petrobras has initiated an oxy-combustion capture pilot trial on a fluid catalytic cracking unit at its research complex. The trial aims to confirm the technical and economic viability of retrofitting an FCC unit with carbon capture through oxy-combustion (Crombie and others, 2011).

3.6 Development of alternative carbon mitigation actions

As noted above, while there are major plans to increase large-scale hydropower, there are also significant measures to encourage alternative renewable energy options. There are also some plans to introduce additional nuclear power and to achieve significant energy savings through efficiency measures.

3.6.1 Energy efficiency

In 2010, the Brazilian government announced a National Plan for Energy Efficiency, with the aim of achieving 109 TWh of electricity savings by 2030, which would be equivalent to a 10% saving of expected energy consumption at that time under a business-as-usual scenario (Inter-ministerial Committee on Climate Change, 2008). This plan would also be expected to result in cumulative CO_2

emissions savings of 30 Mt. The intended approach is to provide tax incentives for all parts of the energy chain as part of a strategy to encourage industrial, building and transport energy efficiency (ABB, 2011).

3.6.2 Nuclear power

The current 2 GWe of nuclear power capacity will be increased by 1.4 GWe when a third plant is completed in 2015 and there are tentative plans to further increase this to 6 GWe by 2030 (EIA, 2011a).

3.6.3 Biomass power

Biomass has traditionally been used in rural locations for heating and cooking, and the government used tax incentives to initiate a reforestation programme to provide for industrial wood energy and wood product needs (ORNL, 1995). Currently, there is interest in establishing the production of electric power from short rotation plantation grown wood.

3.6.4 Hydropower

The national plan is to increase hydropower capacity from 81 GWe to 117 GWe by 2020. However, there are concerns about this approach due to the adverse environmental impacts caused by the need for large-scale flooding upstream of the dam (Guardian, 2011).

3.6.5 Solar power

Brazil currently has a 1 MWe capacity solar pv power plant and the technology is viewed as expensive. There is some discussion about using the auction approach to encourage additional solar power projects and to bring down the price but this approach has not been confirmed by the government (Bloomberg, 2012).

3.6.6 Wind power

Brazil's wind power potential is thought to be at least 140 GWe, with some estimates suggesting up to 350 GWe (GWEC, 2011a), with the more suitable locations conveniently close to the electricity grid and to demand centres. The installed capacity target for 2020 has been set at 10 GWe by the Brazilian Wind Energy Association and the government. There has been a steady introduction of units, due to the major subsidies and incentives provided through the PROINFA scheme, which has supported over 95% of all installations to date. As a result, Brazil is the largest wind power producer in South America and it is on target to reach 1.5 GWe of capacity by 2012 (ABB, 2011), as shown in Table 3.

Table 3 Total cumulative installed wind power capacity in Brazil (GWEC, 2011a)

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010
MWe	22	29	29	29	237	247	341	606	931

Subsequent to PROINFA, by the end of December 2011, the various auctions resulted in twenty-year power production contracts being put in place for an additional 6 GWe, with the first units required to be on line by mid-2012 (Ecoseed, 2011). The expectation is that the capacity will be over 7 GWe by 2015, which is on course to meet the 2020 target.

Many of the international companies that have been successful in the auctions are building production facilities in Brazil, with government support, in line with the national plan to ensure that the local content share of any wind power order reaches 60% (Clean Technica, 2011). This is helping to bring down costs and, as a result of the auction process, the contracted prices for wind power have been steadily falling to about 55 US$/MWh at the end of 2011 (compared to 86 US$/MWh in 2009), which is lower than the price of natural gas fired power generation under Brazilian conditions.

4 China

China has a population of over 1.3 billion, with a rapid and consistently growing economy that is the second largest in the world. This growth has been underpinned by coal use although steps are now being taken to change the primary energy capacity mix by introducing low and zero carbon alternatives, while also continuing to improve the efficiency of energy usage.

4.1 Energy resources and reserves

China has very extensive reserves of coal, but limited supplies of oil and natural gas compared in each case to national demand, as shown in Table 4 (BGR, 2010). At the same time, it imports significant quantities of all three fossil fuels, with coal being included because it is more economic to source supplies for the coastal regions in the south of the country from external suppliers due to the limitations and costs for transport from the major supply regions in the north and north-west of the country (Minchener, 2009).

China's currently recoverable coal reserves appear low when the rate of production to meet a significant part of the country's primary energy needs is considered (BP, 2011). However, as with many developing countries, the national methods of assessing coal deposits do not necessarily align with international procedures. According to Chinese sources, the country appears to have about 557 Gt of recoverable reserves and a very strong likelihood of up to a further 314 Gt being available, subject to full geological surveys. After this, there is the strong prospect of developing further reserves from the very extensive resources identified so far, again subject to full geological surveys (Minchener, 2009).

Table 4 National fossil energy sources and demand for China (BGR. 2010)

Fossil Energy 2009	Resources	Reserves*	Production	Demand
Oil	2300 Mt	2018 Mt	189 Mt	390 Mt
Natural gas	10,000 billion m^3	2455 billion m^3	82 billion m^3	89 billion m^3
Hard coal	5,010,000 Mt	180.600 Mt	2930 Mt	3034 Mt
Lignite	307 Mt	11,000 Mt	120 Mt	120 Mt

* Based on exploration and field discovery to date. These estimates do not include allowance for unconventional natural gas, such as shale gas.

4.2 Current energy mix and likely future changes

China is the second largest energy user in the world, with total primary energy consumption of 89.7×10^{12} MJ (2003×10^6 Mtoe) in 2008, and, as shown in Figure 4, the energy mix was dominated by coal. Indeed, over the last decade especially, the rapid and sustained economic growth has been underpinned by coal use, especially through the continuing expansion of the electricity, steel and construction materials sectors. In terms of utilisation, in 2010, coal production reached 3.2 Gt, with 55% used for power generation and about 16% each for steel and cement respectively (Minchener, 2011b). Further coal-fired power plants are scheduled to come on line and annual coal use could reach about 4 Gt by 2015. However, it has been stated that China will limit annual coal utilisation to between 3.6 and 3.8 Gt for the period 2011-15 although how that might be achieved has not been defined (Minchener, 2011b)

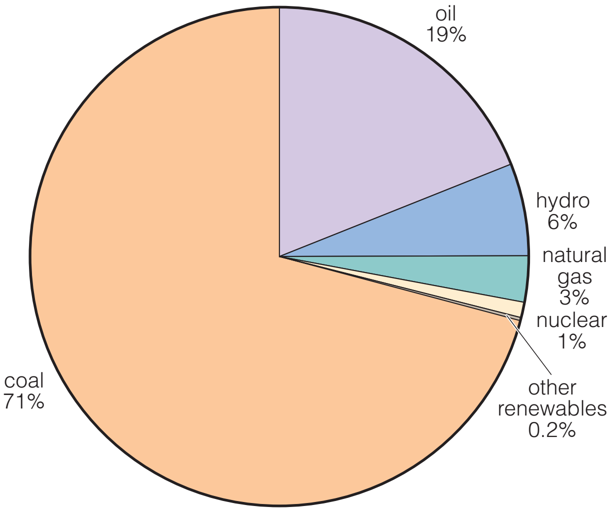

Figure 4 Total energy consumption by type in China for 2008 (EIA, 2011a)

Table 5 provides a preliminary estimate of the power sector energy mix for the period to 2050. This provides firm data on the situation at the end of 2010, the official plan for the 12th Five-Year Plan (FYP) together with some indicative estimates of likely coal power capacity for 2020 and 2050. It indicates that in relative terms the proportion of coal based power will decrease although in absolute terms there will be a considerable increase in coal use.

Outside of the coal sector, in 2010, China's annual oil production level was about 200 Mt compared to a total demand of 454 Mt (Oil voice, 2011). The latter is projected to rise to 540 Mt in 2015 on the back of the country's rapid economic expansion, which could result in the nation's overseas oil dependence ratio climbing significantly as it is proving difficult to maintain domestic production above 180 Mt. In order to address this expected ongoing and increasing shortfall, the government is undertaking a rigorous programme of establishing long-term supply agreements with a very wide range of suppliers, to ensure security of supply via diversified import sources (Minchener, 2011a).

With regard to natural gas, although this currently accounts for about 4% of China's primary energy consumption, demand is growing far quicker than domestic supplies are becoming available, with ever greater shortfalls projected in the period to 2020. In 2010, China's natural gas consumption was about 106 billion m^3, of which some 85 billion m^3 were produced domestically. However, by 2011, demand had surged to around 130 billion m^3, due in part for the need to increase low carbon energy use in

Table 5 Projection for China's total installed electric power generation capacity from 2015-2050 (Mao, 2011)

<table>
<tr><th colspan="2"></th><th>2010</th><th>2015</th><th>2020</th><th>2050</th></tr>
<tr><td colspan="2">Total installed net power plant capacity, GWe</td><td>963</td><td>1437</td><td>1730</td><td>2900</td></tr>
<tr><td colspan="2">Coal, GWe (%)</td><td>687 (71.4)</td><td>933 (65.3)</td><td>960 (55.5)</td><td>1400 (48.3)</td></tr>
<tr><td colspan="2">Natural gas, GWe (%)</td><td>20 (2.0)</td><td>40 (2.7)</td><td>60 (3.5)</td><td>100 (3.5)</td></tr>
<tr><td colspan="2">Hydro, GWe (%)</td><td>213 (22.1)</td><td>324 (22.0)</td><td>350 (20.3)</td><td>400 (13.8)</td></tr>
<tr><td colspan="2">Nuclear, GWe (%)</td><td>11 (1.1)</td><td>43 (2.9)</td><td>70 (4.0)</td><td>300 (10.3)</td></tr>
<tr><td rowspan="3">Renewables</td><td>Wind, GWe (%)</td><td>30 (3.1)</td><td>70 (4.8)</td><td>250 (14.4)</td><td>400 (13.8)</td></tr>
<tr><td>Biomass, GWe (%)</td><td rowspan="2">2 (0.2)</td><td rowspan="2">27 (1.8)</td><td>20 (1.1)</td><td>100 (3.5)</td></tr>
<tr><td>Solar, GWe (%)</td><td>20 (1.1)</td><td>200 (6.8)</td></tr>
</table>

Notes:
(1) The projection of China's total installed power capacity is based on information collected from representatives of the China Electricity Council (CEC), the NDRC and Tsinghua University.
(2) The data for 2010 were issued officially by the CEC, early in 2011.
(3) The data for 2015 represent the official goal of the 12th Five-Year Plan (2011-2015)
(4) The projections of China's total installed power capacity for both the medium term (2020) and the long term (2050) are at best indicative with many assumed conditions. As such they should not be in any way considered as official projections by the Chinese Government.

order to reduce CO_2 emissions. According to government forecasts, the demand for natural gas may reach 230 billion m^3 by 2015, which could require imports of over 80 billion m^3 as domestic supplies are not projected to increase sufficiently (Oil voice, 2011). It has been suggested by PetroChina that demand may reach 300 billion m^3 by 2020 (China Knowledge, 2010). Again, as with oil, while the government is taking steps to implement further production opportunities, it is also seeking to ensure security of supply via diversified import sources.

4.3 National policies for energy and carbon mitigation

Climate change has been increasingly highlighted within China, as seen with the major energy saving initiatives implemented within the Government's national 11th FYP and especially with the early announcements of the 12th FYP. The vision for 2020 includes reducing carbon intensity (CO_2 emissions per unit of GDP) by 40–45% from 2005 levels, and meeting 15% of the total energy demand with non-fossil fuel, with much of the focus on the power sector.

Several important energy and environment specific targets have been set for the period to 2015 (China Daily, 2011a,b; RAP, 2011) including:

- energy intensity (consumption per unit of GDP) to be cut by 16% from 2010 levels;
- carbon intensity to be cut by 17% from 2010 levels;
- non-fossil fuel use to account for 11.4% of primary energy consumption.

The NDRC is expected to introduce new environmental taxes covering SO_2 and wastewater in the near future, with the expectation of some form of carbon tax within the next three years to be levied on producers and wholesalers of fossil fuel based energy such as power companies. Other new market mechanisms, such as tiered energy pricing and pilot carbon emissions trading programmes, will also be explored, with selected provinces and specific sectors such as the power sector being the focus of the initial experiments in cap-and-trade (China Daily, 2011c).

The Renewable Energy Law, which was enacted in 2005, provided a framework for national, regional and local policies, and targeted various sectors and types of renewable energy (Renewable Energy World, 2010). This provided for renewable portfolio standards (also called 'mandated market shares') together with feed-in tariffs for biomass, 'government-guided' prices for wind power, an obligation for utilities to purchase all renewable power generated, together with new financing mechanisms and guarantees. The 'Medium and Long-Term Development Plan for Renewable Energy in China' of 2007, updated in 2009, set an overall renewable power sector installation target for 2020. This suggested 300 GWe of hydropower, 150 GWe of wind power, 30 GWe of biomass power, and 20 GWe of solar pv. In addition, the renewable energy portfolio standards for major utilities require them to achieve 8% of capacity and 3% of power generation from non-hydro renewables by 2020.

Since 2010, the 2020 renewable energy target has been defined as a 15% share of final energy consumption rather than a 15% share of primary energy, which implies a larger quantity of renewables. However, at the same time, the scope of the target has been changed from 'renewables' to 'non-fossil fuel sources', which includes nuclear. Nuclear power currently provides less than 0.3% of final energy supply in China, but will possibly increase to 60–70 GWe by 2020. As such, the net impact on total renewables by 2020 of the target change is complicated to assess (Renewable Energy World, 2010), more so as likely adjustments are already being considered due to external events as discussed in Section 4.6.

Within the 12th FYP, in the power generation sector, the Chinese Government has announced plans to build 235 GWe of capacity for non-fossil energy sources by end 2015 (People's Daily Online, 2010). This will include:

- starting 40 GWe of nuclear power projects in the coastal areas and central regions;
- 120 GWe of hydropower stations;

- at least 70 GWe of wind power capacity with six large power bases to be located on land and another two in coastal areas;
- 5 GWe of solar power capacity, to be located in Tibet, Inner Mongolia, Ningxia, Gansu, Qinghai, Xinjiang and Yunnan (Figure 5).

Figure 5 Map of the provinces of China (Muztagh, 2011)

Alongside the continuing investment in new capacity, a key government priority is the further development of the country's power transmission system, including better links between the provincial systems, with plans for the large-scale construction of a smart grid to begin during the 12th FYP period. The reform of electricity prices and systems is also included in the plan, which advocates making full use of the market in setting prices and implementing independent transmission prices.

For coal-fired power generation, the current initiatives to improve overall energy efficiency will be continued while the expectation remains that coal-fired power will continue to show significant growth with an annual increase in capacity of some 50 GWe, all of which except for CHP schemes will be either 600/660 or 1000 MWe high efficiency SC and USC units. There will also be a continuation of the closure of small obsolete coal power units, with some 50 GWe of capacity scheduled to be permanently closed in the period from 2011 to the end of 2015.

Despite these very promising energy and environmental initiatives, there is no provision for CCS in the 12th FYP and the official position remains that CCS technology is as yet unproven and too expensive for current deployment. However, it remains a development priority in energy R&D, as is considered below. In part this is driven by the recognition that as many CCS systems are based on the application of known techniques, China is becoming well placed to become a serious supplier of CO_2 capture technology alongside its initiatives to export advanced SC coal-fired boilers within the Asian region and elsewhere, where it has a significant cost advantage compared to OECD suppliers (Minchener, 2011b).

4.4 Current and projected future CO_2 emissions

For 2010, the total CO_2 emissions in China were 8.3 Gt (Reuters, 2011b), with coal thought to account for over 6 Gt, up from ~5.8 Gt in 2009 (IEA, 2011b). Although the majority (55%) of coal use was for power generation, there was significant use in a number of industrial processes, particularly iron and steel, building materials and chemicals (37%). In all these cases, although in absolute terms CO_2 emissions have risen strongly in recent years, carbon intensities have reduced (Climate Policy Initiative, 2010) as a result of technology improvements and the closing of old, obsolete capacity (Minchener, 2010; UNDP, 2010).

With regard to future emissions levels, there have been various projections, taking into account the State Government's initiatives to cut both energy intensity and carbon intensity through to 2020 compared to 2005 levels. Various modelling studies have been undertaken by Chinese and international organisations, to develop possible energy growth scenarios for China, including the impact of various policy measures on the timing of possible large-scale deployment of mitigation measures. All of these studies indicate that, under the current policies, while levels per unit of GDP should fall, absolute energy demand and CO_2 emissions will continue to rise, but at decreasing rates.

It seems possible that, with the continued application of these initiatives to meet announced targets and goals for energy efficiency improvements together with the further introduction of low and zero carbon technologies, a very broad plateau in annual CO_2 emissions may be reached by about 2030. If it is assumed that there will not be any premature retirement of advanced coal-fired plant with replacement by, say, nuclear units, then it would almost certainly require the introduction of CCS to ensure that this expected plateau would decline in the period to 2050. This effect is shown in Figure 6, based on a United Nations Development Programme (UNDP) study (UNDP, 2010).

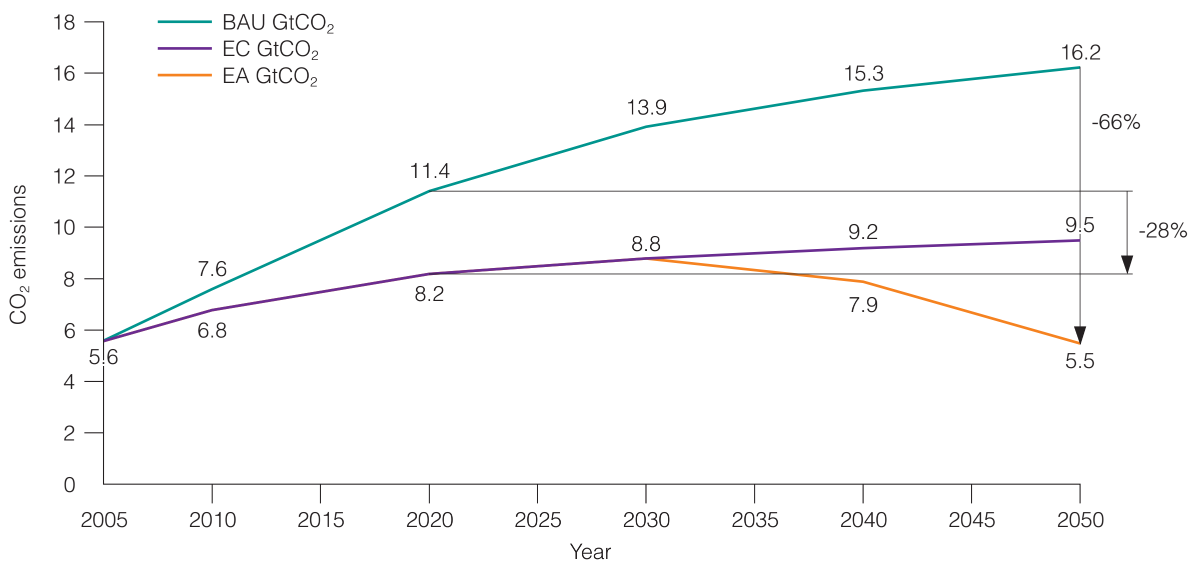

Figure 6 Future CO_2 emissions scenarios for China (UNDP, 2010)

4.5 National initiatives for CCS development and deployment

There are conflicting signals regarding development and deployment of CCS. The Ministry of Science and Technology (MOST) and the state-owned Energy Enterprises are interested in the technology from R&D and commercial perspectives, and see a potentially significant benefit for China of positioning itself at the forefront of the technology development curve. At the same time, the key Government decision makers in the NDRC and NEA are currently not convinced that CCS is appropriate for China because of the increased capital cost implications and the high operational energy penalty, which leads to a significant increase in coal demand (IEA, 2009c). This means that the development work is not supported within a domestic policy framework that will enable China build on its impressive R&D progress to deliver full chain CCS technologies, at least in the near term.

China is involved in many international CCS related organisations. Thus:
- MOST is the Chinese Government representative for the GCCSI, which aims to help deliver the G8's goal, agreed in July 2008, of developing at least 20 fully-integrated industrial-scale demonstration projects around the world, in order to accelerate the broad deployment of CCS technology by 2020 (GCCSI, 2012a). The Huaneng Group has signed up as the representative of the Chinese power industry and the China Steel Corporation is also a member with a focus on non-power CCS applications.
- MOST is also the Chinese representative for the CSLF.
- The Chinese Government was part of the Asia-Pacific Partnership on Clean Development and Climate (APP), which was a voluntary partnership among seven major Asia-Pacific countries, namely Australia, Canada, China, India, Japan, Korea, and the USA. These countries worked together to address increased energy needs and the associated issues of air pollution, energy security, and climate change. While the APP has now formally ended, some of these projects are continuing via various bilateral arrangements.
- The Huaneng Group is a shareholder and partner of the FutureGen Alliance, which is a public-private partnership to build a first-of-its-kind coal-fuelled, near-zero emissions demonstration power plant.

China's R&D programme covers all capture, transport, utilisation and storage options, with a near-term emphasis on CO_2-driven EOR to help limit China's growing oil imports (Minchener, 2011b). Many of these activities include a high level of international co-operation, through capacity building programmes with, amongst others, Australia, Canada, European Union, Italy, Japan, Norway, UK and USA. For CO_2 capture, the drivers are to reduce the energy penalties and high costs for the first generation technologies while also seeking to develop improved second generation systems. There has been an extensive programme examining CO_2 storage and, alongside this, there is a plan to produce a comprehensive CO_2 storage atlas for China, covering EOR applications as well as storage in oil and gas fields, unmineable coal seams and saline aquifers (IEA, 2009a). In addition, there continues to be a desire to develop innovative and cost-effective CO_2 utilisation technologies since China's official position is that their aim is to utilise CO_2 wherever possible rather than just store it (CCUS). Beyond EOR, this is considered an unrealistic aspiration by most external experts given the limited markets for the potential products and the increased energy usage needed in many cases for their production.

A CCUS roadmap has been prepared by MOST, which suggests that the first full chain technology demonstration should be established on a non-power gasification application, namely a coal-to-chemicals plant since this offers a source of low cost high concentration CO_2 that is produced as part of the overall process (Zhang, 2010). The intention would be to use the CO_2 for an EOR application. The roadmap also indicates that China would wish to progress the demonstration of CCUS on coal-fired power plant, with an equal interest at this stage in post-combustion, pre-combustion and oxyfuel applications. While EOR is favoured in the near term, there is some recognition of the importance of storage in saline aquifers if large-scale CCUS deployment should be implemented. The timescale of the Chinese target for large-scale demonstration is modest, with an apparent target of a 1 $MtCO_2$/y capture and storage (non-EOR) project by 2030.

With regard to progression beyond research, it is very significant that various power generation, coal and oil companies, such as Huaneng, Shenhua and PetroChina, are becoming involved in major CCS projects, including funding and implementing large industrial pilot-scale trials (Minchener 2011b). Huaneng has established a 100,000 t/y post-combustion CO_2 capture unit on an advanced supercritical coal-fired power plant, with the CO_2 being sold into the food and beverage industries, Figure 7. Shenhua has established a similar scale of operation pre-combustion capture process on the gasification stream of its coal to oil demonstration process, with the CO_2 being transported and stored in a saline aquifer. PetroChina is processing natural gas to remove the CO_2 impurity, which is then used for EOR in a nearby oil field. Complementary activities are under way by other major state-owned enterprises (for example CPIC, Guodian and Sinopec), with the intention to scale-up at least to the level achieved by the above mentioned first movers. All these projects have been undertaken and funded by China, although much of the early investigative work was supported via bilateral arrangements.

Figure 7 The CO_2 stripper, absorber and spherical storage tanks on the sidestream from one of the 660 MWe ultra-supercritical units of the Shidongkou No 2 PC Power Plant in Shanghai (Liu, 2011)

There are other larger-scale prospects being developed, covering each first generation capture technique, with ultimate implementation being dependent on funding support being ensured, which will not necessarily be from China. Thus Huaneng is working on a 1 $MtCO_2$/y post-combustion capture and EOR project for implementation on an advanced supercritical PC plant. For pre-combustion applications, Huaneng is to undertake a feasibility study to establish a 100,000 tCO_2/y capture and EOR project at a gasification based coal to chemicals plant, which would be a low cost near-term opportunity in line with the MOST CCUS roadmap. It is also progressing the intended Phase 2 of the GreenGen project, which will be to establish a 60,000–100,000 tCO_2/y capture and EOR sidestream on the 250 MWe IGCC now being commissioned at Tianjin. Shenhua is conducting a feasibility study into a second facility at its coal-to-oil plant that will be capable of handling 1 $MtCO_2$ annually and there are plans to develop a larger facility capable of handling 3 Mt annually. However, in both cases, no schedule for construction has been set. For oxyfuel, Huazhong University of Science and Technology in Wuhan is involved in plans to build a 35 MWth industrial pilot unit, with up to 100,000 t/y of captured CO_2 being stored in nearby deep salt mines. This project is at the engineering design stage. At the same time, Shenhua, via its subsidiary Shenhua Guohua (Beijing) Power has announced plans to build a 100 MWe demonstration project by the end of China's 12th FYP.

4.6 Development of alternative carbon mitigation actions

As noted above, China has ambitious plans to achieve some 15% of energy consumption from non-fossil fuel sources by 2020, which is driven by the need to meet their declared targets for reductions of energy and carbon intensities. Alongside this, there are major actions to ensure significant energy efficiency savings.

4.6.1 Energy efficiency

China had been achieving significant energy savings since 1980 although this lost momentum in 2000 as a result of a surge in coal-based industrialisation. As outlined above, in the 11th and 12th FYP, the government has stressed that unchecked demand growth would impede economic development and therefore has set definitive targets to reduce energy intensity (cut energy consumption per unit of gross domestic product), with national reduction targets of 20% from 2005 levels by end 2010 and 16% from 2010 levels by end 2015 (Minchener, 2011b).

The NDRC was authorised to design and carry out programmes to meet these goals. Reforms have taken place at all levels of government, with programmes created and implemented in all provinces. A key aspect has been the ‘Top-1000 Energy-Consuming Enterprises Programme’, which was established to set targets for and monitor the energy efficiency improvements of China’s 1000 largest companies that together account for approximately one-third of national energy use. There has been strong public support by the government for energy efficiency, the creation of a sizeable fund for energy-efficiency investments, and the linking of individual career advancement for company officials to achieving the energy reduction targets (Zhou and others, 2010).

There has been a considerable focus on supply side savings through the closing of small obsolete coal power plants, steel mills, cement works and other energy-intensive factories. In addition, there have been measures to restrict exports of energy-intensive products, and tax incentives for pollution-reduction projects. For demand side savings, state and provincial government offices have been switched to low-energy lighting, and officials will be compelled to purchase only the most energy efficient and environmentally friendly electrical products (China View, 2007). As an example of a recent initiative, the government has decided to phase out all incandescent light bulbs by 2016. Lighting constitutes 12% of China’s total electricity consumption and this scheme will cut the country’s annual CO_2 emissions by 48 Mt, according to the NDRC (RTCC, 2011).

4.6.2 Nuclear power

China intends to establish a large base load of nuclear power plants in accordance with its energy policies (World Nuclear Association, 2012a) that:

- pressurised water reactors will be the mainstream but not sole reactor type;
- nuclear fuel assemblies will be fabricated and supplied indigenously;
- domestic manufacturing of plant and equipment will be maximised, with self-reliance in design and project management;
- international co-operation will nevertheless be encouraged.

Currently China has 14 nuclear power reactors in operation, with a total capacity of over 11 GWe, and at least 25 under construction, with more at the design stage. Most of these are located in coastal regions towards the south of the country, in regions remote from the coalfields and where the economy is developing rapidly.

As of June 2010, the official installed nuclear capacity projections were 70–80 GWe by 2020 and 200 GWe by 2030. However, in the wake of the Japanese nuclear disaster, China has taken steps to tighten its safety regulations and procedures, which has led to a freeze on approvals for new nuclear projects (Financial Times, 2011). Currently, it is not clear when approvals will recommence although the new nuclear safety regulations are expected to be completed by the end of 2012. This is likely to lead to a slowdown in China’s nuclear development that might last for the subsequent two to three years, with the likely 2020 capacity target being reduced to at best 60–70 GWe, although there are no indications that the medium- and long-term nuclear strategy will be changed (Reuters, 2011c).

4.6.3 Biomass power

In the power sector, there has been interest in biomass firing and, in 2007, the Chinese Government announced that it would construct 30 GWe of biomass-fired power stations by 2020, with the intention that this would be underwritten with CDM credits (Asia Biomass Office, 2008). The government also included this technique as one for which an enhanced price would be paid for renewable power generation. This led to a rush to build small units, typically 12 MWe to 25 MWe capacity (Asia Biomass Office, 2008). However, the eagerness of provincial governments to support a new revenue earning scheme was not overly successful as the economics of the process is critically dependent on the price of biomass. In certain provinces, where a large number of these small power units were built, demand for biomass rapidly led to significant price rises, which led to many power plant owners going bankrupt (Hu, 2011).

Subsequent progress has been more controlled, with 5.5 GWe of capacity installed by end 2010 (Biomass energy, 2012). The Chinese government is continuing with its policy of constructing these small centralised systems, which should be located strategically within rural China to limit transmission losses. However, the small sizes of the plants and the problematic nature of the biomass feedstock (for example, straw) causes severe operational problems. The expected 2015 figure has been downgraded to 13 GWe from the previous 14.5 GWe.

4.6.4 Hydropower

Hydropower is a mature renewable energy technology that gained added prominence following the announcement of the government's carbon emissions reduction targets in 2009 (Guardian, 2009). However, there are growing concerns regarding ecological damage due to large-scale flooding and the social issues due to large-scale relocation of villages when dams are built. Indeed, following completion of the Three Gorges Dam in 2005, hydropower construction and installation slowed considerably with regulators unwilling to approve new construction plans amid concerns about environmental risks and massive relocation costs. Over the 2006-10 period, this resulted in around 50 GWe of capacity being put into operation compared to the 77 GWe originally intended (Reuters, 2012).

In 2010, Chinese hydropower installed capacity reached 213 GWe, while a further 70 GWe of plant was under construction with another 12 GWe at the approval stage (Research and markets, 2011). Original government plans for 2020 suggested that hydropower installed capacity should reach about 380 GWe comprising 330 GWe of conventional hydropower stations and 50 GWe of pumped storage hydropower stations. However, these numbers may now be increased as an alternative approach to meeting the 2020 target for non-fossil fuel energy should the government significantly delay the approval of new nuclear plants. For the period to 2020, 120 GWe of new hydropower capacity may now be built, which would raise the total capacity (excluding pumped storage) to about 420 GWe (Reuters, 2012). However, this appears to be at the limit of the national total exploitable capacity.

4.6.5 Others

Although not a priority development, China has established some 34 MWe geothermal and 4 MWe marine energy power generation capacity (Renewable Energy World, 2010).

4.6.6 Solar power

Previously, China had a steady interest in pv solar power, with an established industrial chain comprising more than 50 solar cell and over 300 solar module companies, including world ranked organisations such as Trina Solar, JA Solar, Suntech Power and LDK Solar (Reuters, 2011d). Although it is the world's largest exporter of pv solar products, its domestic installed capacity in the power sector was 1 GWe at end 2010, with a target of 5 GWe by end 2015 and 20 GWe by 2020. This modest level compared to other renewable alternatives was, in part, due to the comparatively high costs.

This 2015 target was raised to 10 GWe after the Japanese nuclear power crisis, to counter possible delays should the nuclear programme be held back on safety grounds. During July 2011, the government unified grid feed-in tariffs for solar and offered a higher price for projects that would be put into operation before the year end. This led to an acceleration of various installations, which has encouraged the government to further raise the 2015 capacity target to 15 GWe (Reuters, 2011d). It is not yet known if the 2020 target will be raised.

4.6.7 Wind power

China's potential capacity for both land-based and offshore wind power is estimated to be in the range 700–1200 GWe. Developments to date have been focused on Inner Mongolia, the Northwest, the Northeast, Hebei Province, the Southeast coast and offshore islands (GWEC, 2010b). Table 6 shows the total cumulative installed capacity, which has doubled each year between 2006 and 2009 to reach over 42 GWe by end 2010. The State Government expects that cumulative installed wind power capacity will reach 200 GWe by 2020 (GWEC, 2010b). The intermediate target for 2015 is an installed capacity of 100 GWe.

Table 6 Total cumulative installed wind power capacity in China (GWEC, 2010b)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
MWe	346	402	469	567	764	1260	2599	5910	12,020	25,805	42,287

Almost all units are built by Chinese wind turbine manufacturers, four of which, including Sinovel, Goldwind, United Power and Dongfang Electric, are part of the world's top ten wind turbine companies and are beginning to expand into overseas markets.

The positive financial support for wind power has included halving VAT for wind and levying a low duty rate for domestic investment in wind power. In 2009, this was supplemented when the Renewable Energy Law was amended to introduce a requirement for grid operators to purchase a certain fixed amount of renewable power. The amendment required grid companies to absorb the full amount of renewable power produced, while giving them the option of applying for subsidies from a new 'Renewable Energy Fund' to cover the extra cost related to integrating that power. Also in 2009, China introduced a feed-in tariff for wind power generation, which applies for 20 years of a wind farm's operation (GWEC, 2010b). Even so, a very large number of wind power projects have gained additional income from CDM credits. As of June 2010, there were 481 wind power CDM projects in China that were either at the public validation stage or beyond, representing a total expected installed capacity of 27.5 GWe (Junfreng and others, 2010). For the near future, China has plans to develop seven major wind power bases on a 10 GWe scale in Gansu, Xinjiang, Hebei, the eastern and western part of Inner Mongolia, Jilin and the coastal area of Jiangsu (*see* Figure 5, page 24).

However, the rapid development of wind power in China has put an unprecedented strain on the country's electricity grid infrastructure. This has become the biggest problem for the future development of wind power in the country, as some projects have to wait for several months before being connected to the national grid. Indeed, the provincial grid companies have been reluctant to accept large amounts of wind power into their systems. However, they have reached an agreement to connect 80 GWe of new wind power by 2015 and 150 GWe by 2020. These levels are rather lower than the national wind energy targets of 90 GWe for 2015 and 200 GWe for 2020 and it remains to be seen how this discrepancy will be addressed.

5 India

India has a population of around 1.1 billion, is the fourth largest energy consumer in the world, with a continuing growing economy.

5.1 Energy resources and reserves

India only has extensive coal resources and, for all fossil fuels, demand exceeds domestic supply, with the country increasingly becoming a major importer, *see* Table 7.

Coal is plentiful but of low quality, mostly being bituminous with a high inherent ash content and low heating value while relatively low in sulphur content (Chikkatur, 2008; World Coal Institute, 2009). As well as hard coal, there are also reasonable lignite deposits available.

Table 7 National fossil energy sources and demand for India (BGR, 2010)

Fossil Energy 2009	Resources	Reserves*	Production	Demand
Oil	400 Mt	792 Mt	35 Mt	149 Mt
Natural gas	900 billion m^3	1115 billion m^3	39 billion m^3	52 billion m^3
Hard coal	167,012 Mt	72,009 Mt	532 Mt	598 Mt
Lignite	33,752 Mt	4,895 Mt	34 Mt	34 Mt

* Based on exploration and field discovery to date. These estimates do not include allowance for unconventional natural gas, such as shale gas.

5.2 Current energy mix and likely future changes

Total energy consumption in 2008 was some 21.1 x 10^{12} MJ (471 x 10^6 Mtoe), for which the energy mix is shown in Figure 8. While 73% is provided by fossil fuels, some 24% is from the combustion of biomass and waste, which are used by more than 800 million Indian households for cooking. Other renewables such as wind, geothermal, solar, and hydropower represent 2% of the Indian fuel mix, while nuclear provides 1% (EIA, 2011d).

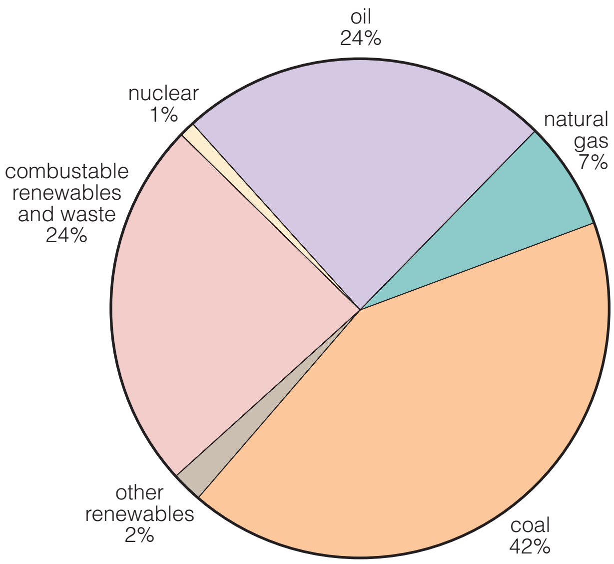

Figure 8 Total energy consumption by type in India for 2008 (EIA, 2011d)

The power generation sector in India is a major energy user, with an installed capacity of close to 186 GWe as of end 2011, which was the fifth largest in the world (Government of India, 2011). Coal-fired plants account for 55% of capacity, oil and gas 10%, hydroelectric about 21% with the rest being a combination of wind, small hydro, biomass, waste-to-electricity, and nuclear (IEA, 2011a). However, currently some 300 million Indian citizens have no access to electricity (IEA, 2011c) and, for those who do have access, the supply can be intermittent and unreliable. Under current conditions, it would need an investment of at least US$135 billion to provide universal access of electricity for India's population (IEA, 2011c).

Coal use both for power generation and industry has been increasing in order to underpin the rapid growth of the economy (Mills, 2007). Total coal demand has increased by about 80% between 2000 and 2010, reaching 420 Mtce, with growth accelerating to more than 7% per year on average since 2005, compared with 5% in the first half of the decade (IEA, 2011c).

With regard to the future, total primary energy consumption for 2030 is expected to be almost double compared to 2010. India is expected to become the world's second-largest consumer of coal by around 2025, with demand more than doubling to 880 Mtce by 2035. Increasingly, rapid demand in growth will outstrip domestic supply, especially for use in the advanced coal-fired power plants that have begun to be introduced. In 2010, India needed to import 83 Mt of coal and this level is expected to increase rapidly, with the country poised to become the world's biggest importer of coal soon after 2020.

Electricity consumption is projected to grow at an average rate of 3.3%/y through 2035 which means that India could well need to add at least 234 GWe of additional capacity (EIA, 2011c). On a longer-term basis, some projections suggest that a further 360 GWe to 960 GWe could be needed by 2050 compared to 2030 (IEA, 2011c). However, a combination of security of supply concerns regarding the increasing importation of fossil fuels, national air quality issues and international climate change issues has resulted in a shift in emphasis as to how best to establish this additional power generation capacity.

5.3 National policies for energy and carbon mitigation

India faces formidable challenges in meeting its energy needs and providing adequate energy to users in a sustainable manner and at reasonable costs. It has stated that it needs to maintain an 8% to 10% economic growth rate to eradicate poverty and meet its economic and human development goals. In order to deliver a sustained growth of 8% through to 2031, on a business-as-usual scenario, power generation capacity would have to increase to 778 GWe and the annual coal requirement would be 2040 Mt. Consequently the government has declared that it must take measures to reduce the energy requirement and improve the quality of energy supply to meet its sustainable economic growth imperatives (Government of India, 2005). There is a focus on building up the use of renewables and, especially, nuclear and, to a lesser extent, natural gas, although coal is still expected to dominate the near- and medium-term energy mix.

Recently, India made a commitment to reduce its GHG emissions intensity by 20–25% by 2020 (from 2005 levels) not including emissions from agriculture (NRDC, 2009). In order to achieve this challenging goal within its overall energy growth plan, India intends to:

- increase fuel efficiency standards by 2011;
- adopt building energy codes by 2012;
- increase forest cover to absorb 10% of its annual emissions;
- increase the fraction of electricity derived from renewable sources from the current 8% to 20% by 2020;
- increase the rate of introduction of nuclear power.

Even so, with the recognition that coal-based power generation will remain the dominant approach within the Indian power sector for many decades, due to its large coal resource base and current overwhelming proportion of the existing capacity mix, the government is taking steps to improve the overall efficiency of coal-fired power plants by deploying higher-efficiency pulverised coal combustion technologies. It has a plan to establish up to nine 'Ultra Mega Power Projects', each of which, will be a 4000 MWe power station comprising several large units with SC steam conditions.

The Indian government aims to have these power plants built by private sector companies before 2017. Much of the financing for this initiative is coming from China with Chinese manufacturers supplying most of the coal power components (Balachandar, 2011).

It also intends to improve the other elements in the existing power system, such as transmission and distribution. Currently, electricity transmission and distribution losses are between 30% and 45%, which is a result of the focus on building new energy generation capacity without a corresponding emphasis on grid improvements (Marcus, 2011). This problem is being exacerbated by the need to accommodate a growing level of renewable energy technology on the grid system.

Although not an efficiency improvement issue, it should be noted that air pollution emissions control is focused mainly on limiting the release of fine particulates. There are no limits for NOx emissions while SO_2 control measures are generally addressed through the provision of stacks of sufficient height to ensure adequate local dispersion.

In 2008, the National Action Plan for Climate Change (NAPCC) was announced, which included several measures to address global warming, including an increase in the share of renewable energy based power generation (MNRE, 2009). The NAPCC also has the ambitious goal of a 1 percentage point annual increase in renewable energy growth compared to the 2010 baseline for ten years so that renewable energy will then constitute about 15% of the energy mix of India (MNRE, 2009).

India's National Mission for Enhanced Energy Efficiency was established as one of India's eight missions under its NAPCC. The aim is to establish a market for some US$16.75 billion worth of demand-side energy efficiency improvements through policy and financial support. The overall target for this market-based approach is by 2014-15 to:

- achieve annual fuel savings in excess of 23 Mtoe;
- avoid cumulative electricity capacity addition of 19 GWe;
- ensure annual CO_2 emission reductions of 98 Mt.

As part of this initiative, the government has amended legislation so that over 710 energy-intensive businesses are required to take part in a scheme to cap energy usage as part of an energy-efficiency certificate trading scheme (Ministry of Environment and Forests, 2010).

With regard to renewable energy, although India has very significant potential, it is recognised that achieving the 2020 target will require an order-of-magnitude increase in renewable energy growth across the country during the next decade. On the basis of the current financial cost of coal-based power generation, renewable capacity is not financially viable as an alternative under Indian conditions (World Bank, 2010). About 5 GWe of such capacity is viable compared to the cost of gas-based generation, while all the intended wind, biomass, and small hydropower capacity would be viable compared to the cost of diesel-based power generation. Solar energy would not be financially viable at any of these opportunity costs. Consequently, there is a need for strong policy measures, a proactive regulatory framework and innovative financing instruments to ensure a realistic enabling environment, if these very ambitious targets are to be achieved (World Bank, 2010). Under current planning and pricing regimes, achieving the government's goal over the next decade will require an annual subsidy of around US$1 billion.

With this in mind, the government has announced a 'coal tax' of 50 rupees (US$1) per tonne (Bloomberg, 2011). The resulting revenues will go to a National Clean Energy Fund, which will finance clean energy research and development. In addition, India has stopped subsidies for petrol and lowered subsidies for diesel and kerosene. The government has also reduced import duties on renewable energy equipment and exempted some renewable energy machinery, such as wind turbine parts, from a domestic production tax on new goods. Most states in India have implemented renewable power obligation schemes that require the electricity distribution companies to source a fixed percentage of their power from renewable sources, or buy renewable energy certificates (The

Times of India, 2012). The Ministry for Renewable Energy is also working with the regulators to determine a suitable framework for tradable renewable energy certificates to provide a mechanism for better returns for renewable energy developers, leading to a boost for further investments in the sector.

In 2009, India unveiled a National Solar Mission. The initial investment was US$1.1 billion, which the government will add to from the revenue raised by a new fossil fuel power generation tax of 0.1 cents for every kWh of electricity produced, up to a level of US$19 billion. The aim is to increase the installed solar generation capacity from the 2009 level of 5 MWe to 20 GWe, by 2022, with tentative targets of 100 GWe and 200 GWe by 2030 and 2050 respectively (India Business Connections, 2011). The intention is to provide financial incentives for leveraging domestic and foreign investments in order to encourage rapid scale-up and to drive down costs, increase and improve domestic manufacturing capability. These incentives include capital subsidies of up to 30%, low-interest loans, and feed-in-tariffs for rooftop solar projects. As a start, under the plan, the use of solar-powered equipment and applications will be made compulsory in all government buildings, as well as hospitals and hotels.

For wind power, currently 18 of the 25 State Electricity Regulatory Commissions (SERCs) have issued feed-in tariffs for wind power. These together with the renewable power purchase obligations have helped to create long-term policy certainty and investor confidence, which have had a positive impact on the wind energy capacity additions in those states (GWEC, 2012).

Finally, India has formed an Expert Group on Low Carbon Strategy for Sustainable Growth, with the group’s recommendations to be adopted in India’s 12th Five-Year Plan in 2012.

5.4 Current and projected future CO_2 emissions

In 2009, annual CO_2 emissions from industrial activities (excluding land use and land use change and forestry) were 1586 Mt, of which about 70% were from coal (IEA, 2011b). Rapid growth in such emissions is expected since the economy continues to grow at a significant rate with additional coal use for power and other energy-intensive sectors still representing the major increase in primary energy consumption. To put that in context, the nine planned ultra-mega power plants alone could add some 257 $MtCO_2$ to annual emissions (Boden and others, 2011). By 2030, India expects to emit between 4 $GtCO_2$ and 7 $GtCO_2$ annually (Master Resource, 2009). However, this situation may ease with greater renewables use and if the projections for a massive increase in nuclear power capacity are realised.

5.5 National initiatives for CCS development and deployment

There are neither policies nor legislation to encourage the development, deployment and regulation of CCS technologies in India. Currently, Indian stakeholders have raised doubts, including safety issues about the potential for leakage from CO_2 transport and injection. There are also major concerns about the energy penalty, as this effectively means a need to increase coal production for no increase in electricity output and makes CCS potentially less attractive than renewable options (GCCSI, 2012b).

As such, the country’s involvement at present is limited to some Government-led public awareness activities together with some CCS technology R&D projects, almost all of which is linked to various international collaboration initiatives.

In 2003, India joined the CSLF, with the Ministry of Power as the lead ministry, and it has been a member of the Asian Pacific Partnership. It signed an agreement with the USA in April 2006 to become a partner in the FutureGen zero emission power plant project. It is also an institutional partner in the Big Sky Carbon Sequestration Partnership, which involves the US DOE National Energy Technology Laboratory (NETL) and seven regional CO_2 partnerships that are designed to determine the best approaches for capturing and permanently storing GHGs (GCCSI, 2009b).

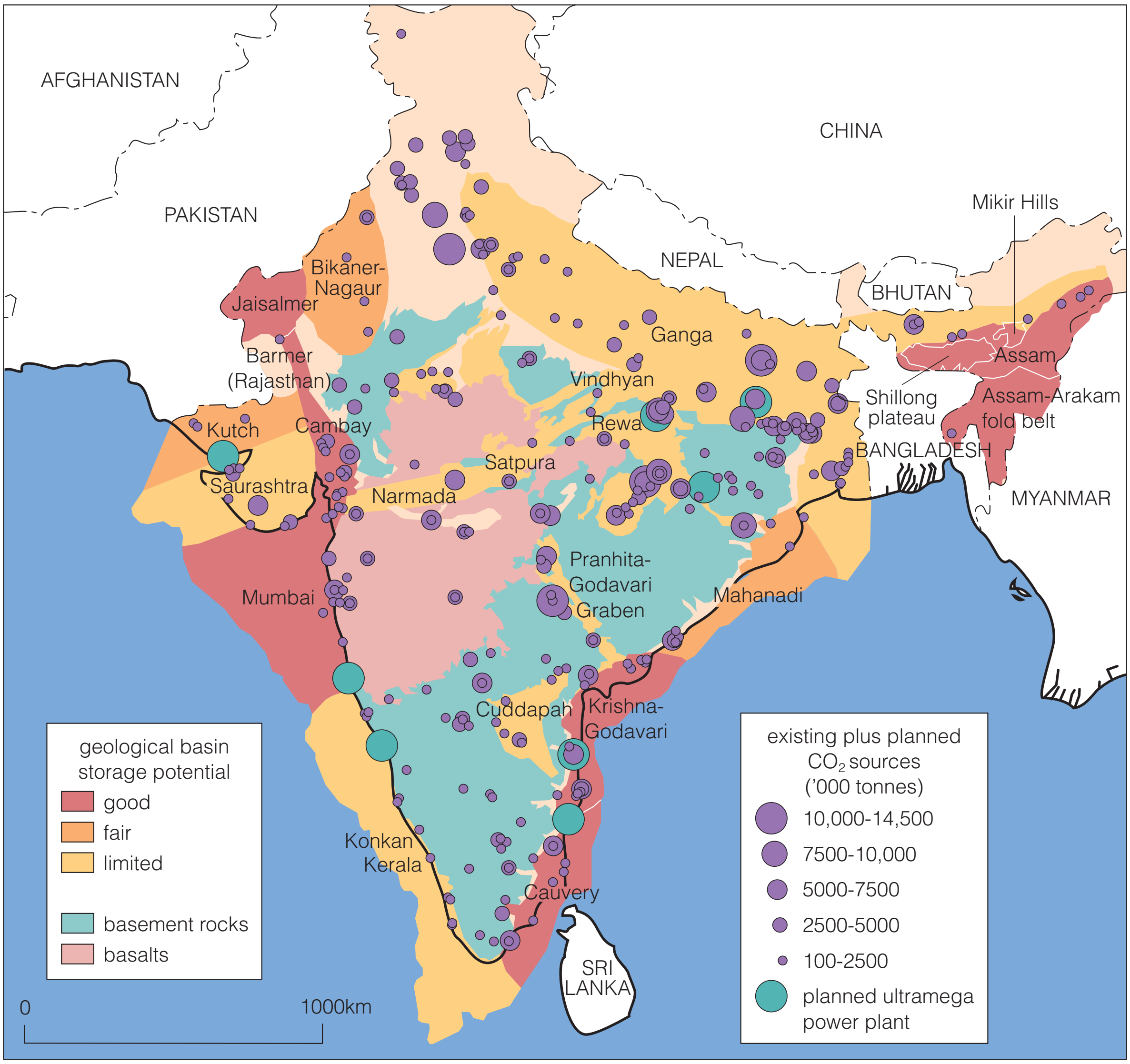

Figure 9 Geographical relationship between existing and planned CO_2 emission sources and sedimentary basins in India (Holloway and others, 2009)

In terms of country-specific R&D, the UK government via DECC has supported several collaborative studies. This has included two projects, one examining the introduction of advanced supercritical coal power plants with the prospect to make these CO_2 capture ready (Mott MacDonald, 2008) and the other providing an initial CO_2 storage assessment (British Geological Survey, 2007).

The latter study was jointly commissioned by the IEA GHG R&D Programme, for which the British Geological Society (BGS) conducted a regional assessment of the Indian subcontinent to gauge the potential for CO_2 storage in geological reservoirs, which included deep saline aquifers, depleted oil and gas fields, and deep unmineable coal fields. In addition, the study undertook some source-store matching, which considered the geographical relationship between the large point source emissions of the Indian power sector and potential geological storage reservoirs (Holloway and others 2009). Figure 9 shows this relationship between the major existing and planned sources of CO_2 emissions and areas containing the sedimentary basins.

Much of the Indian peninsula would be unsuitable for CO_2 storage because either basalt or crystalline basement rocks occur at the surface. It is possible that sedimentary rocks may occur beneath the basalt in some areas but imaging problems would probably prevent effective site characterisation and monitoring. The main potential CO_2 storage sites, which are not too distant from the emissions sources, are located in the saline aquifers and, to a much lesser extent, in the oil and gas fields around the margins of the peninsula, especially offshore in the Mumbai, Krishna-Godavari and Cauvery basins but also onshore in the states of Gujarat and Rajasthan. In order to determine whether there is significant realistic potential for the application of CCS, there is a need to rigorously quantify the storage capacity of the aquifers.

The impact of basalt on limiting potential CO_2 storage opportunities is significant since many of the large CO_2 emissions point sources are located in such regions. Accordingly, the National Geo-physical Research Institute of India is undertaking a co-operative CO_2 Geological Storage Research Project with the Pacific Northwest National Laboratory, USA. The aim is to develop technology for deep bed injection of CO_2 in sedimentary rocks underlying basalt foundations. Some 2000 tCO_2 will be injected at a selected site followed by monitoring and modelling of its behaviour, using a broad range of geo-physical and geo-chemical techniques (GCCSI, 2009b).

On 6 February 2008, the state-owned Oil and Natural Gas Corporation Limited (ONGC) signed a memorandum of understanding with StatoilHydro ASA of Norway to jointly develop CO_2 management projects. This has led to a project where the CO_2 released during the processing of sour gas at the ONGC plant in Gujarat will be captured and transported to a nearby depleted reservoir for EOR (Project Monitor, 2008).

5.6 Development of alternative carbon mitigation actions

As noted above, India has major and ambitious plans to build up its various alternatives to fossil energy use as part of its carbon mitigation initiative. One of the targets for India’s 11th Five-Year Plan was to add 12.4 GWe of grid-connected renewable power by March 2012. The expectation is that this target will be exceeded, with 14.2 GWe capacity installed during the period (Reinforced Plastics, 2012), although most of this is in the wind sector, as outlined below.

5.6.1 Energy efficiency

The Energy Conservation Act provides a legal framework to embark on this national energy efficiency drive, including the setting up of a Bureau of Energy Efficiency (BEE) to co-ordinate and implement the activities. India’s energy-intensive industries will be part of the initiative to streamline their operational efficiency through the use of technologies such as introducing building management systems, low energy lighting, energy optimising technologies, and energy-efficient appliances in order to reduce their emissions to pre-determined levels. The potential annual CO_2 savings through such initiatives have been estimated at 310 $MtCO_2$-e (McKinsey, 2010).

5.6.2 Nuclear power

India’s nuclear power programme has until now largely been developed without assistance from other countries, which has meant a focus on self-sufficiency including uranium exploration and mining, fuel fabrication, heavy water production, reactor design and construction, together with reprocessing and waste management (World Nuclear Association, 2012b). It is also developing technology to utilise its abundant resources of thorium as a nuclear fuel.

There are six nuclear power plants in India, comprising twenty units with a total capacity of 4.7 GWe (Hindustan Times, 2010). The current nuclear power programme aims to have 20 GWe of nuclear capacity online by 2020 and 63 GWe by 2032, with a long-term goal to supply 25% of electricity from nuclear power by 2050. In order to meet these ambitious targets, there will need to be a very significant import of uranium and foreign technology, through international co-operation, although the government intends that all plants will have a high indigenous engineering content.

5.6.3 Biomass power

It has been estimated that the annual amount of surplus biomass materials in India is about 150 Mt, which could be used to generate some 16 GWe of power. However, to date, there is about 900 MWe capacity installed and 1.3 GWe (equivalent) of grid-connected co-generation plant fuelled by bagasse (Dhingra, 2010).

5.6.4 Hydropower

The capacity of established hydropower projects is over 2.7 GWe, with an additional 900 MWe at various stages of implementation. The potential for small hydropower projects, each up to 25 MWe capacity, is some 15 GWe and, at present, about 300 MWe per year is being introduced, with 70% coming through the private sector. The aim is to double the current growth rate in the next two to three years (MNRE, 2011).

5.6.5 Solar power

The focus will be on pv systems while validating the technological and economic viability of various solar applications, for rural, urban and industrial locations, including grid and non-grid systems. In view of the large target for 2022, progress from 2010 onwards has been slow. In 2010, investments were achieved for just 200 MWe of grid-connected solar power plants (MNRE, 2011), and, in terms of deployment, grid-connected solar capacity increased from 18 MWe in 2010 to about 280 MWe by the end of 2011 (Reinforced Plastics, 2012).

On a more positive note, some large applications have been proposed, and a 35 km^2 area of the Thar desert has been set aside for solar power projects, which if taken up completely could accommodate between 700 and 2100 GWe capacity.

5.6.6 Wind power

There has been significant progress with the introduction of wind power to India, with over 13 GWe installed capacity installed during the decade to 2010, as shown in Table 8 (GWEC, 2010b).

Table 8 Total cumulative installed wind power capacity in India (GWEC, 2010b)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GWe	0.2	1.5	1.7	2.1	3.0	4.4	6.3	7.8	9.7	10.9	13.1

A further 2.8 GWe was added in 2011, which continues the rising trend, with an expectation of a further 2.5–3.2 GWe to be added in 2012 (Reinforced Plastics, 2012).

Total wind power potential is estimated at between 50 and 100 GWe by the Centre for Wind Energy Technology and the World Institute for Sustainable Energy respectively. However, it remains to be seen if the recent growth rates will be maintained as the key instrument for boosting wind power development, accelerated depreciation of capital investment, was discontinued from early 2011.

Another limitation to wind power growth in India is the inadequate grid infrastructure, especially in those states with significant wind potential, which are already struggling to integrate the large but variable amounts of wind electricity produced. As a result, the distribution utilities are hesitant to accept more wind power. If this problem is to be resolved, it will require the Government to improve power system planning and to provide better linkage between regional grids. The Ministry of Power has set up a Smart Grid Task Force as a first step to address this issue.

6 Indonesia

Indonesia comprises more than 6000 inhabited islands and is the fourth most populated nation with some 240 million people. It is a developing country, with an annual GDP growth rate of about 5% to 6%, with that growth being underpinned with increasing fossil fuel use.

6.1 Energy resources and reserves

As shown in Table 9, Indonesia has extensive coal, gas and renewable energy resources and reserves. There is also a substantial resource of coalbed methane (CBM) that has yet to be exploited.

Table 9 National fossil and renewable energy sources and demand for Indonesia (BGR, 2010)

Fossil Energy 2009				
	Resources	Reserves*	Production	Demand
Oil	400 Mt	543 Mt	49 Mt	62 Mt
Natural gas	4400 billion m^3	3185 billion m^3	72 billion m^3	39 billion m^3
Hard coal	34,391 Mt	5634 Mt	254 Mt	30 Mt
Lignite	51,586 Mt	10,141 Mt	38 Mt	30 Mt
Coalbed methane	12.8 trillion m^3	–	–	–
Renewable energy 2008				
	Resources, MWe equivalent		Installed capacity, MWe equivalent	
Hydro	75,700		4200	
Mini/micro hydro	500		86	
Geothermal	27,700		1100	
Biomass	49,800		445	
Solar	1,200,000		8	
Wind	9290		1	

* Based on exploration and field discovery to date. These estimates do not include allowance for unconventional natural gas, such as shale gas.

6.2 Current energy mix and likely future changes

Domestic primary energy consumption has increased at about 5.5% year-on-year to reach 6.3×10^{12} MJ (141×10^6 Mtoe) at the end of 2008 (EIA, 2011b). This is a result of the continuing population growth and urban migration, which is leading to higher energy demand in the residential, industrial and transportation sectors. The energy mix, as shown in Figure 10, remains dominated by oil, which has been a major factor in the development of the national economy, while coal and natural gas have been increasing in importance in recent years. At the same time, Indonesia remains a significant consumer of traditional biomass in its residential sector, especially in the more remote areas that lack connection to Indonesia's energy transmission networks. These data are not readily included in the national energy statistics due to the lack of knowledge of exactly what is being used, although the IEA estimates that combustible renewables and waste together may account for about a quarter of total primary energy supply (IEA, 2009b).

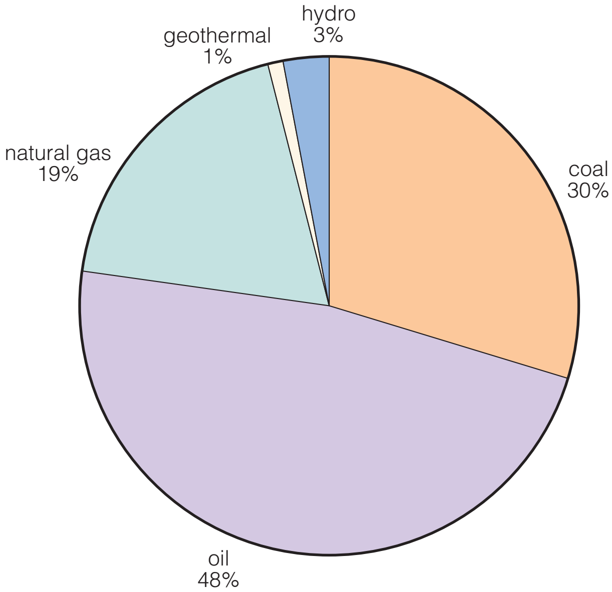

Figure 10 Total energy consumption by type in Indonesia for 2008 (EIA, 2011b)

Readily extractable domestic oil reserves are in serious decline due to the maturity of the country's larger fields and a failure to develop new, comparable resources. Consequently, imports have become a significant requirement. For coal, while domestic consumption has tripled over the last decade to reach 60 Mt in 2009 (BGR, 2010), some 80% of production is exported. Indonesia was once the world's leading exporter of natural gas, but now ranks below 50th because investment restrictions and contract uncertainty meant that the additional production capacity was not developed (International Trade Administration, 2010). That said, production exceeds the supply and there is an increasing market for exports, which can benefit the country, subject to the investment problems being resolved.

For the future, the government faces an interesting balancing act, in trying to at least maintain exports of natural gas and coal while ensuring adequate energy supplies to meet continuing growth in national demand (Minchener, 2009). This will require significant investment, in production, delivery and utilisation infrastructure. For example, more than half of Indonesia's 2009 natural gas production came from offshore fields, and the government estimates that more than 70% of the country's conventional gas reserves may be located offshore, far from the major demand markets.

Indonesia's installed power generation capacity was 27.8 GWe by the end of 2009 (IEA, 2009b), of which 86% comprised conventional thermal sources (oil, natural gas, and coal), 8% hydroelectric, and 6% geothermal and other renewable sources. Of the conventional thermal total, coal accounted for 47%, followed by gas at 33%, and oil at 19%. The state-owned electric utility PT Perusahaan Listrik Negara (PLN) owns and operates 86% of the country's generating capacity through its subsidiaries, and maintains an effective monopoly over distribution activities. Electricity sector demand for coal is expected to more than double by 2014 as a result of coal-fired generation capacity additions. In order to guarantee sufficient domestic supply, the Indonesian government has set a domestic market obligation of 24% for producers.

Indonesia's power sector has suffered from an inadequate supporting infrastructure, difficulty in obtaining land-use permissions, subsidised tariffs, and an uncertain regulatory environment, all of which has led to a lack of the necessary investment. Thus, although the capacity has increased by more than a quarter in the previous ten years, it has lagged behind the pace of electricity demand growth, which has led to the grid-connected areas suffering from power shortages. As of 2009, only 65% of Indonesia's population had access to electricity.

In order to address the capacity shortage, in 2006, the government initiated its 'fast track' plan, which is designed to add an additional 20 GWe of capacity to the grid by 2014 in order to reduce the use of expensive diesel and fuel oil (Baruya, 2009). This is meant to comprise some 10 GWe of coal power by 2010 plus further coal, some natural gas and significant geothermal capacity by 2014. However, the programme has been significantly delayed with a revised completion date for the first tranche of 2013. For the longer term, Indonesia's total installed capacity is forecast to treble to 100 GWe in 2030 (IEA, 2009b), much of which will be coal and natural gas fired, although with increased use of geothermal and some other renewable energy sources.

6.3 National policies for energy and carbon mitigation

As with other developing economies, the Indonesian Government has to balance economic, environmental and social priorities. The Indonesian economy is seen as the third most vulnerable to climate change and the Government has increasingly raised its concerns about the impact on the developing world. The Government has issued the National Action Plan Addressing Climate Change, which set out Indonesia's intention to reduce greenhouse gas emissions from energy sector, land use, land use change and forestry. This included a non-binding commitment to reduce CO_2 emissions in the range 26–41% from business-as-usual levels by 2020, the exact amount depending on the extent of international support (Reuters, 2009)

A major part of this CO_2 saving is expected to come from curbing emissions from deforestation and changes in land use, while in the energy sector the intention is to increase investment in renewable energy, such as geothermal power and biofuels, as well as consider alternatives such as nuclear.

Rural development is a priority for the government, with an electrification target of 90% by 2020, particularly for disadvantaged regions, while also using renewable power to avoid the use of very expensive diesel-based systems. As such, the government plans to increase the use of renewable energy to 15% of the power generation capacity mix by 2025, with the '2005–25 National Energy Blueprint' setting specific sector targets of 9.5 GWe geothermal, 0.5 GWe grid-connected small hydropower, 330 MWe of off-grid mini-hydropower, 80 MWe of solar, 810 MWe of biomass, and 255 MWe of wind (USAID, 2007).

In order to help fund this massive programme, since 2008, the government has offered various incentives for foreign investment. These include a 30% net income tax reduction for six years, free repatriation of investments and profits, and dispute settlement. Geothermal companies are offered additional incentives, including long-term (more than 30 years) licences for land use and a regulated price for geothermal energy (International Trade Administration, 2010).

In 2009, the Government established the Indonesia Climate Change Trust Fund, the aim of which is to assist with some major energy based mitigation and adaption initiatives, namely:

- to encourage greater use of renewable energy, energy efficiency and sustainable management of forest and peat land;
- to reduce the vulnerability of agriculture, water and coastal zones to climate change.

The projected national energy mix for 2025, is given in Table 10.

Although Indonesia's renewable energy resources are substantial and the government has set significant targets to increase renewable energy use, especially in the power sector, there are major issues that need to be addressed if these targets are to be met (International Trade Administration, 2010). The decentralised system of government and the resulting division of control between central and local governments impedes national co-ordination in delivering a realistic policy framework for a partial transition to renewable energy. The financial requirements are very significant and the government wants to encourage independent power producers to establish the necessary projects through foreign investment. However, the government has failed to establish an

Table 10 Indonesia's national energy mix target for 2025 (DECC, 2009)

Source	Proportion, %
Coal	>33
Synthetic fuels from coal	>2
Oil	<20
Natural gas	>30
Geothermal	>5
Biofuel	>5
Other renewables plus nuclear	>5

appropriate enabling environment, through a lack of significant financial incentives, an inadequate regulatory system, together with limitations on foreign direct investment in small-scale power generation schemes that typically might be required. There is also a lack of a strong transmission infrastructure, which makes grid-connected renewable energy projects difficult to implement if they are located far from end users. Consequently, based on progress to date, it is unlikely the country will meet its targets for renewable energy deployment, with its associated internal economic growth, as considered further in Section 6.6.

With regard to CCS, this is a policy objective in the National Energy Plan, with a high-level blueprint for its deployment. There have been, and continue to be, a number of investigative studies undertaken involving various national stakeholders, with some form of international co-operation, as described in the sections below.

6.4 Current and projected future CO_2 emissions

In 2009, annual industrial CO_2 emissions were 376 Mt (IEA, 2011b), while the average annual growth over the previous decade was close to 7%. Should this current growth rate pattern be maintained, on a business-as-usual basis, the emissions from the Indonesian energy sector would reach about 1150 Mt by 2025. Even if the various declared policies are implemented to reduce carbon intensity by reducing oil dependency and increasing the role of renewable energy, annual CO_2 emissions are still expected to reach 950 Mt by 2025 as coal use is expected to increase significantly (DECC, 2009).

6.5 National initiatives for CCS development and deployment

Indonesia's interest in CCS has developed in recent years and it is a founding member of the GCCSI. CCS activities involve several government departments, including the Ministry of Energy and Mineral Resources, the Geology Agency and the Ministry of Environment. To these can be linked PLN and the Agency for Oil and Gas Research & Development (LEMIGAS) of the Ministry of Energy and Mineral Resources.

Between 2003 and 2005, LEMIGAS carried out a study into CCS and incremental oil recovery in East Kalimantan and South Sumatra, Figure 11. In 2009, with funding from DECC, a collaborative study examining the potential for CCS in Indonesia was undertaken by a number of organisations, comprising LEMIGAS, the Indonesian National Committee of the World Energy Council, PLN,

Figure 11 Map of Indonesia (EIA, 2011b)

Ministry of Environment, Royal Dutch Shell and the British Embassy Jakarta. The objective was to develop a better understanding of the requirements associated with deploying CCS in Indonesia by addressing technical, commercial and regulatory aspects of CCS deployment. The work identified major CO_2 sources and potential storage sites, which is an important first step in establishing CCS potential. This was complemented with an assessment of possible demonstration activities in various primary energy sectors (DECC, 2009).

The potential for CCS is the highest in all of South East Asia as the technology offers a means for significant CO_2 removal from the various energy-intensive sources within Indonesia. However, the make-up of the coal power sector, comprising numerous small units in individual locations that are mostly relatively distant from potential CO_2 storage sites means that the likely cost would be disproportionately high. Power tariffs are very low due to subsidies and the Government has no intention to raise them for CCS application as this would undermine economic competitiveness and growth. Thus, as in other south east Asian countries, CCS in the coal-fired power sector is not considered a near-term possibility although this situation might change in the future depending on the size of new coal-fired power plants and how they are deployed (Tharakan, 2012).

A more promising option is the storage of CO_2 arising from various industrial processing systems, which offers a potentially lower cost opportunity. These processes include natural gas plants that have to remove naturally-occurring CO_2 in order to meet purity standards, and refineries where concentrated CO_2 is a by-product (DECC, 2009). The cost of CO_2 capture is comparatively low compared to power plants and there are several, potentially favourable geological storage sinks, namely the South Sumatra, East Kalimantan and Natuna sedimentary basins. These regions are geologically stable, well characterised, and have low population density, with existing infrastructures. In the near term, CO_2 injection for EOR would be favoured by industry while, for the longer term, the options include abandoned oil and gas fields and deep saline aquifers. Consequently, such projects pose lower technical risks and would deliver lower abatement costs.

On this basis, if by 2025 CCS should be applied to the various natural gas deposits that are projected to be exploited at that time, the annual potential reduction in CO_2 emissions would be in the range 285–345 Mt. The demonstration of CCS in this sector could well provide a driver to then introduce it for coal-fired power applications. Assuming that the next generation of coal-fired plants should be larger and grouped nearer to the growing populations, making the technology more viable through economies of scale, the additional potential reduction in CO_2 emissions could be 255–310 Mt. As such, these are significant targets that would make pursuing the introduction of CCS in Indonesia a very worthwhile objective (Tharakan, 2012).

Following this study, in 2010, Indonesia hosted an IEA/APEC CCS roundtable at which key stakeholders discussed the report and possible ways forward were considered (IEA, 2009f). The key recommendations, subject to ascertaining adequate funding mechanisms, included the need for broader capacity building activities, together with the wish to develop a pilot project that would provide a mechanism for developing legislation and technical expertise as well as raising public awareness and confidence in CCS technology.

Currently, the ADB is implementing a Regional Technical Assistance (TA) Programme, which is being financed by the GCCSI, to raise the level of national awareness, technical competence and actual activity on CCS in four selected developing countries, namely Indonesia, Philippines, Thailand and Vietnam (ADB, 2011b). The key objectives are to:

- identify at least two CCS demonstration projects among the four countries, complete with roadmaps and proposed funding sources from the present through full commercial implementation. Such roadmaps would include technical aspects of capture, transport and storage, regulatory requirements, environmental/socio-economic concerns and mitigation, financing, cost estimation, economics and funding sourcing;
- leave each country with an active CCS stakeholders' working group that is capable of bringing

such projects to fruition with minimal external technical support. Alongside the financial, legal and regulatory studies, there has been some useful practical work undertaken. To date, the Indonesian team, which is led by LEMIGAS, has completed an assessment of CO_2 sources and storage locations in South Sumatra, including GIS integration. This has been complemented with some small (50–100 t/d) CO_2 injection trials within some oil wells within the South Sumatra reservoir in order to ascertain that CO_2 EOR should be practicable. Alongside this, the basis for a comprehensive pilot project has been documented.

There are two other ongoing CCS studies in Indonesia, both in the gas processing sector, one of which is a commercial activity being undertaken by Japanese corporations, and as such information is not in the public domain. The other is a joint research activity between various Japanese universities, the Japan Petroleum Exploration Company, and the Institute Teknologi Bandung, which is funded by a Japanese government programme that promotes international joint research targeting global issues. This is a pilot study for the research and development of technologies for assessing deep strata at sites of CO_2 injection. The project outputs have included several symposia on CCS in Indonesia (SATREPS, 2011).

There is also ongoing dialogue with the World Bank and the GEF, and some possible collaboration with Total and Shell.

6.6 Development of alternative carbon mitigation actions

As noted above, Indonesia plans to increase the use of renewable energy to 15% of the power generation capacity mix by 2025, together with establishing energy efficiency initiatives and pursuing the introduction of nuclear power. This plan is dependent on the development of geothermal resources. However, for all these options, there is a lack of positive market drivers and progress is very limited such that the target capacity level appears overly ambitious.

6.6.1 Energy efficiency initiatives

According to the Ministry of Environment, it will implement policies to improve demand-side energy efficiency by 17% in 2020, 20% in 2025 and 24% in 2030 (Ministry of Environment, 2010). The detailed programme is still being developed although there has been a call for large energy consumers to conduct energy audits and to designate an energy manager. Likely target areas include:

- increasing use of energy saving equipment and appliance standards and labelling in households and commercial sectors;
- promoting co-generation and applying demand-side management in industry;
- applying energy efficiency standards to motor vehicles.

However, fossil energy use is heavily subsidised and this acts as a disincentive to make savings (East Asia Forum, 2011).

6.6.2 Nuclear power

Indonesia has been a member of the International Atomic Energy Agency since 1957. In 2002 a study on the potential for use of nuclear power in Indonesia was undertaken, which suggested that it could be possible to establish some 6–7 GWe nuclear capacity by 2025 (IEA, 2008). However, despite plans being announced to start building a 2 GWe unit in 2010 for completion by 2016, no construction activities have begun.

6.6.3 Biofuels

The government has encouraged the development of biofuels, such as biodiesel, for use in the transport and industry sectors. There are several raw material sources, including palm, corn, molasses, cassava, and jatropha. Indonesia is the world's largest producer of crude palm oil (CPO), currently producing approximately 18 Mt/y of CPO from seven million hectares of oil palm plantation, of which some 80% is exported (Jakarta Post, 2010). Besides revenue generation, the oil palm plantations also provide a livelihood for more than three million Indonesian families.

Studies have shown that the total amount of land that is suitable for growing oil palms may be as high as 44 million hectares, which could produce 145 billion litres per year of biodiesel, and provide income to an additional 19 million Indonesian families. However, there is considerable concern that this biodiesel is far from sustainable, when the environmental consequences such as life-cycle CO_2 emissions due to massive deforestation in order to create the plantations are taken into account. Consequently, alternative approaches including the use of marginal land, possibly with alternative crops such as jatropha, are being considered.

The other issues include the production cost of biodiesel and the market potential (Energy Resources Development of Indonesia, 2009). The cost of production is high, and the export markets both for palm oil and biodiesel are limited. Consequently a large proportion of Indonesia's current biodiesel production capacity of nearly 3 billion litres per year is idle and plans to expand the area of Indonesian oil palm to 10 million hectares are currently on hold. It has been suggested that the domestic refineries could be upgraded to produce a so-called 'green diesel' which has superior fuel properties compared to both biodiesel and fossil diesel. Domestically, this means that green diesel could be used in large quantities in place of fossil diesel, thus reducing Indonesia's dependence on fossil diesel imports. However, as yet, this idea has not been taken forward by the government.

6.6.4 Biomass power

Indonesia's potential for biomass power is substantial at 49.8 GWe but as yet less than 0.5 GWe has been realised. The 2025 target is to increase capacity to a modest 0.8 GWe, with the focus on using agricultural residues. However, this would require a significant system to be put in place for gathering and processing the waste material and there is no evidence of progress (International Trade Administration, 2010).

6.6.5 Geothermal power

Current installed capacity is just over 1 GWe, which represents about 3% of the estimated national resource of 28 GWe. The intention, as part of the second phase of the fast track plan, includes establishing an additional 4 GWe geothermal capacity by 2014 while the 2025 target is to achieve a total geothermal capacity of 9.5 GWe, with most of this to be owned by independent power producers (IEA 2010; EIA, 2011b).

If the 2025 target is to be achieved, a further 8.5 GWe is required, which is likely to cost US$30 billion. Although the government wants the private sector to fund this expansion, private power producers are concerned about technical (geological) risks, regulatory risks stemming from uncertain government policy, and the lack of an adequate financial incentive due to the pricing policies of the Indonesian Government (Jakarta Post, 2011a). In mid-2011, the government issued a regulation that was intended to provide guarantees that PLN would meet its financial obligations to IPPs, who invested in the geothermal sector, of purchasing power from geothermal projects at various designated rates. However, this was widely seen as being too limited and failing to clarify important concerns

(Jakarta Post, 2011b). Consequently, there is little likelihood of the additional power being achieved by 2014 with concerns that the 2025 target will also not be met.

6.6.6 Hydropower

The hydropower potential is in excess of 75 GWe, including 500 MWe of mini- or micro-hydropower, but this is not being significantly realised. There is 4.3 GWe large, hydropower and 85 MWe small hydropower installed capacity, with much of the latter unconnected to the grid, despite UNDP support to remove investment barriers (International Trade Administration, 2010).

6.6.7 Solar power

Indonesia has significant solar power resources but installed capacity is currently limited to about 12 MWe, which is from off-grid solar pv systems in urban areas, comprising around 100,000 home-based systems for lighting, television, communication, battery charging and refrigeration. The high investment and operational costs, together with the lack of interconnection standards that allow consumers to sell excess electricity back to PLN, represent major hurdles to the technology being established (International Trade Administration, 2010).

6.6.8 Wind power

Indonesia’s potential for wind energy is very limited because the windier regions are the less populated, eastern islands, which lack a transmission infrastructure capable of sustaining large wind farms. To date, installed capacity is about 1 MWe, comprising small stand-alone systems in rural and remote areas that are used for local electricity production, water pumping (irrigation) and battery charging. It is possible that offshore wind power may prove more attractive due to consistent ocean breezes (International Trade Administration, 2010).

7 South Africa

South Africa is the 25th-largest country in the world; its economy is ranked as the 28th-largest by the World Bank, although this is mixed, with about a quarter of the population receiving social grants and a low GDP per capita (CIA, 2011).

7.1 Energy resources and reserves

South Africa's energy sector is critical to the economy as the country relies heavily on its large-scale, energy-intensive mining industry. The major energy resource is coal, which is plentiful and currently inexpensive to exploit (Minchener, 2009), while there are limited indigenous supplies of conventional oil and natural gas to the extent that imports are required to meet demand, especially of oil, as indicated in Table 11. The other point to note is that South Africa is classified as a 'water stressed' country and so the conversion of coal/oil/gas to other products including electricity may be limited by the availability of process water.

Natural gas currently is used only as a feedstock for synthetic fuel. The likely recoverable reserves are not sufficient in themselves to make a major difference to the energy mix. There are supplies available in neighbouring countries, such as Mozambique and Namibia, which are being imported at present. In addition, South Africa could hold significant shale gas resources, although the sector is at the early stages of development, and exploration plans have been put on hold as a result of environmental concerns that led to a 2011 moratorium on licensing and exploration (EIA, 2011c). Both of these options could be sufficient to influence energy choices in the future.

Currently, only some 5% of crude oil is supplied from indigenous reserves, the remainder is imported and supplemented with the coal to synthetic oil products. As well as fossil fuels, indigenous uranium is used to fuel two nuclear power reactors. While the reserves are significant, the ore must be processed overseas into usable fuel. With regards to renewable energy, there are very limited unused hydro reserves in South Africa. The more promising options are solar energy, especially in the central regions, and wind power, mainly on the coast.

Table 11 National fossil energy sources and demand for South Africa (BGR, 2010)

Fossil Energy 2009	Resources	Reserves*	Production	Demand
Oil	20 Mt	2 Mt	0.7 Mt	27.5 Mt
Natural gas	50 billion m^3	10 billion m^3	3.6 billion m^3	5.4 billion m^3
Hard coal	115,000 Mt	28,000 Mt	251 Mt	183 Mt

* Based on exploration and field discovery to date. These estimates do not include allowance for unconventional natural gas, such as shale gas.

7.2 Current and projected future energy demand

Because of the limited energy mix available, South Africa uses its large coal deposits for most of its energy needs (Stanford, 2011). As a result, carbon emissions and intensity levels are relatively high. In 2008, South African total energy consumption was 5.6 x 10^{12} MJ (125 x 10^6 Mtoe), of which coal/peat accounted for 71.1%, followed by oil (12.8%), renewables and waste (10.4%), together with relatively small shares of natural gas, nuclear, and hydroelectricity, *see* Figure 12 (EIA, 2011c).

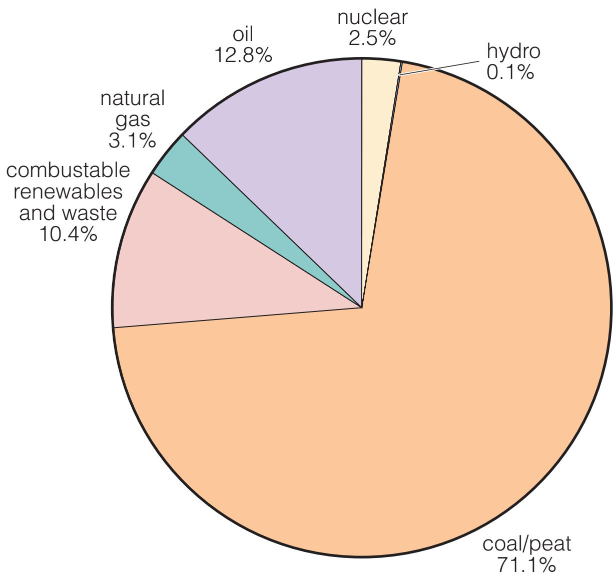

Figure 12 Total energy consumption by type in South Africa for 2008 (EIA, 2011c)

Production and consumption of coal has remained relatively stable over the past decade. In 2010, the country produced some 250 Mt of which it used 182 Mt, with the remainder being exported to China, India, and Europe. Of the coal used domestically, about 53% is used for electricity generation, 33% for the synthetic fuels industry (Sasol), 12% for metallurgical industries and 2% for domestic heating and cooking.

There is a need to consider both short-term needs and longer-term aspirations when considering future energy demand in South Africa, particularly in the power sector. The electricity market is dominated by Eskom, which is currently responsible for 95% of the country's generation as well as owning and operating the country's national transmission system. Generation is primarily coal fired, but also includes a nuclear power station, two gas turbine facilities, two conventional hydroelectric plants, and two hydroelectric pumped-storage stations.

The net maximum generation capacity is some 41 GWe, which includes a 15% reserve margin and an operating reserve margin between 5% and 10% (Mills, 2010). This margin is very tight and in 2008, due to the drive to ensure a massive increase in the national population electrification rate, demand outstripped the available supply, leading to rolling blackouts. This was overcome by encouraging consumers to conserve power during peak periods, a voluntary energy conservation scheme targeting industry to reduce electricity consumption by 10%, and the return to service of three previously mothballed power stations (Power, 2011).

Power demand is expected to grow significantly to about 85 GWe by 2030, driven both by increasing industry demand and particularly by important changes in livelihood patterns of the millions of people who live at or below the poverty line. While Eskom will provide a very significant proportion of the additional capacity, including any nuclear units and several large coal-fired units already either under design or construction, there is a government desire to see independent power producers become involved, particularly in the relatively smaller-scale opportunities to provide renewable power systems.

7.3 National policies and initiatives for energy and carbon mitigation

The South African government's near-term focus is on GDP growth and job creation, and in particular low skilled job creation. At the same time, in 2009, it committed the country to reduce CO_2 emissions and set a reduction target of 34% by 2020 and 42% by 2025 from business as usual levels (KPMG, 2011).

In October 2011, following a consultation process, the government issued its final version of the Integrated Resource Plan (IRP), the objective of which is to develop a sustainable electricity investment strategy for generation capacity and transmission infrastructure for South Africa over the next 25 years (South Africa, 2010). It is intended to:

- improve the long-term reliability of electricity supply in line with economic growth and development;
- ascertain South Africa's capacity investment needs for the medium-term business plan;
- consider environmental and other externality impacts, including the effect of renewable energy technologies;
- provide the framework for ministerial determination of new generation capacity as envisaged in the new generation capacity regulations.

According to the plan, South Africa's 85 GWe power generation capacity target for 2030 will broadly comprise 48% baseload coal, 14% baseload nuclear, 16% renewable energy (wind, solar, biomass, biogas, landfill gas, small hydro), 9% peaking open cycle gas turbine, 6% peaking pump storage, 5% mid-merit gas and 2% baseload import hydropower (Department of Energy, 2011). This assumes that the older Eskom coal-fired power stations, recently returned to service, are decommissioned at the end of their 50-year lifespan, which is scheduled for 2025 to 2030. However, it is possible that these power stations could have their economic life extended with some capital investment and continue to operate for another 10 years should either the proposed new-build options be delayed or demand projections prove insufficient.

In terms of carbon mitigation, the government's rationale is that a two-pronged approach is necessary to achieve this, namely improving energy efficiency and switching to non-fossil fuel based power generation, and that these will have different but complementary timelines. Thus while improving energy efficiency can be an early and ongoing enabling activity, it is not economically viable to replace the fossil fuel based infrastructure prematurely. Consequently, the use of CCS will allow continued use of fossil fuels while achieving deep reductions in CO_2 emissions such that the technology will bridge the gap until such time that the existing energy infrastructure is replaced with non fossil fuel based power generation (IEA, 2009e). Recently, the government published a White Paper on Climate Change Strategy, in which CCS has been designated a National Flagship Programme. In order to take this forward, the Department of Energy has established an interdepartmental CCS committee that will meet from January 2012 to determine the appropriate strategic way forward. The other key departments that will be engaged in CCS policy development are Environment and Mineral Resources.

South Africa's energy plans also include a major objective to build a sustainable renewable industry that can meet a significant proportion of the national generating capacity from 2020 onwards. It already has a longstanding target for 2013 of achieving an annual 10,000 GWh renewable energy contribution to final energy consumption although a very large proportion of this would be expected to comprise solar water heating.

In terms of renewable power deployment, the IRP 2030 target for electricity production from renewable energy sources is 17.8 GWe, of which the major contribution is likely to be wind power at 8.4 GWe (GWEC, 2011b). Since this was announced in 2010, for two years there was little noticeable progress in establishing a feed-in tariff that would pay a guaranteed fixed rate for a prescribed number of years to renewable energy generators for supplying electricity to the power grid (WRI, 2011). This was due to concerns by potential IPP that they would not receive fair treatment from Eskom who in effect currently have a monopoly on electricity generation and distribution. The potential suppliers feared a conflict of interest with Eskom's position as the national utility and its role as buyer of electricity from IPP.

Things have since improved with the Department of Energy taking positive steps to procure 3725 MWe of renewables capacity from IPPs for operation before 2016, to include 1850 MWe of onshore wind, 1450 MWe of solar pv, 200 MWe of CSP, 75 MWe of small hydro, 25 MWe of landfill gas and 12.5 MWe each of biomass and biogas capacity. These allocations might change depending on how technology selection proceeds. The Renewable Energy Feed-In Tariff approach was changed and a competitive tender process was introduced in order to better ensure independent power producers' participation, with the expectation of a combination of foreign and domestic investment being used to establish this new aspect of the power sector. The first call for bids from IPP was in 2011, which led to 28 being accepted with a capacity of just under 1416 MWe (Engineering News, 2011). There is expected to be two further bidding rounds each in 2012 and 2013.

The government has also established a fund to promote renewable energy projects in South Africa, with an intended value of rand 800 million (US$101 million), to be raised from donors and commercial sources (Businessweek, 2011).

The growing importance of nuclear power is a further reflection of the need to balance the interest in renewable energies with the need for energy security as the latter is the only large-scale option for zero CO_2 emissions power. The plan is that 1.6 GWe of new nuclear capacity will be brought online in 2023, followed by five further 1.6 GWe units before 2030.

In addition, the South African government intends to set emissions reduction goals and overall limits for the key companies in the nation's electricity, fuels, mining and transport industries as a driver to ensure that it meets its national CO_2 emissions targets.

7.4 Current and projected future CO_2 emissions

CO_2 emissions and intensity levels are relatively high (IEA, 2011b) and will increase very rapidly under a business-as-usual scenario, reflecting the dominant role of coal as a national energy source and the relatively slow introduction to date of low carbon alternatives. The government's vision is for GHG emissions to peak and plateau by 2025-30 before declining over the period to 2050 (Department of Environment, 2011). Figure 13 indicates the business-as-usual approach, compared to the possible range for the 'peak, plateau and decline' scenario. There is a considerable level of uncertainty in both trajectories.

These targets are challenging. The expected increase in power generation capacity by 2030 is some 54 GWe, of which some 80% is expected to be provided by Eskom and the remainder by independent

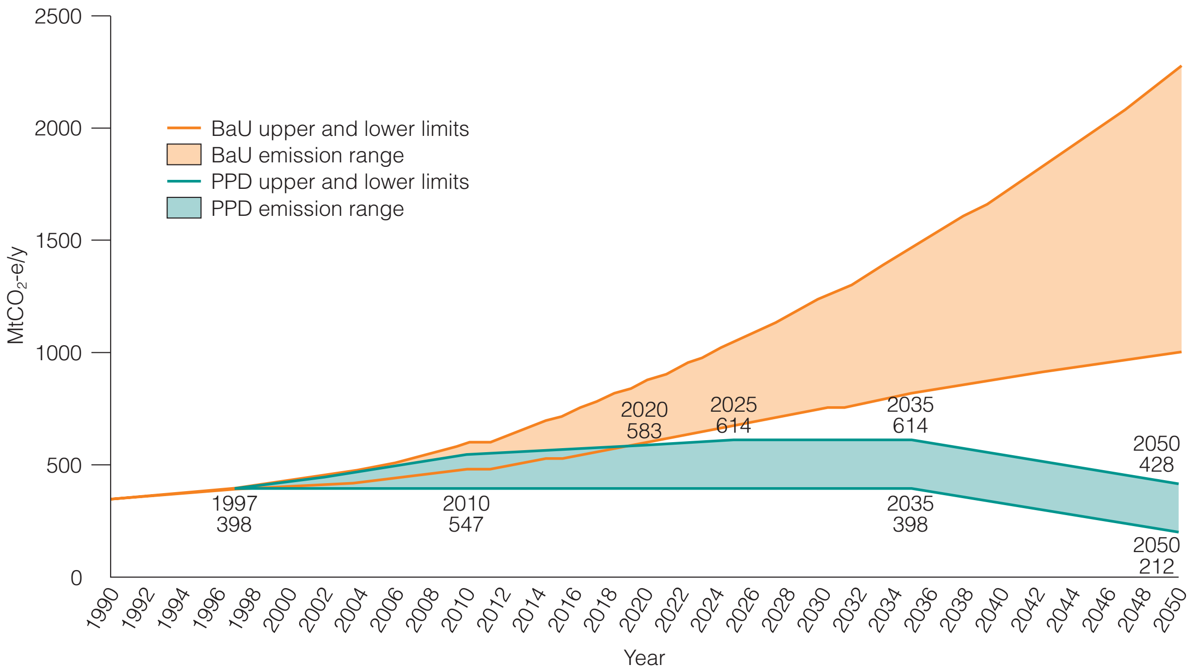

Figure 13 The intended 'peak, plateau and decline' GHG emissions scenario for South Africa (Department of Environment, 2011)

power producers. The plan for over 9 GWe of new nuclear power plant before 2030 is ambitious and needs to get under way if the schedule is to be maintained. With regard to renewables, it remains to be seen if the new tendering approach will have the desired effect of a build-up of capacity and an influx of independent suppliers. There also remain major doubts about the potential conflict with higher priority issues, such as poverty reduction since high electricity prices from renewable power projects could have significant negative socio-economic impacts both for industry but also for the country's poor (Energy Research Centre, 2010). This leaves the significant increase in coal use for power generation by Eskom, which can readily be achieved in line with previous experience. However, the introduction of CCS for use with the new coal-fired plants that would be introduced from 2027 onwards has still to be proved as technically viable in the South African context, as considered below.

7.5 National initiatives for CCS development and deployment

The key Government departments with interest in CCS include those of Energy, Environment, and Minerals Resources, while the major industrial companies comprise Sasol, Eskom and Petro SA.

South Africa joined the CSLF during 2003 while the South African National Energy Development Institute (SANEDI), which is the public entity entrusted with the co-ordination and undertaking of public interest energy research, development and demonstration, is a member of the GCCSI (GCCSI, 2012a).

The Government established the South African Centre for Carbon Capture and Storage (SACCCS) as the focal point to investigate the feasibility of CCS in South Africa. SACCCS, which is a subsidiary of SANEDI, is working together with university departments, national and international government departments, South African and international industry and a range of international organisations. It has established a structured approach to assessing the suitability of CCS for application in South Africa (SACCCS, 2011; Beck, 2011). The status of these five phases is outlined in Figure 14 and described below.

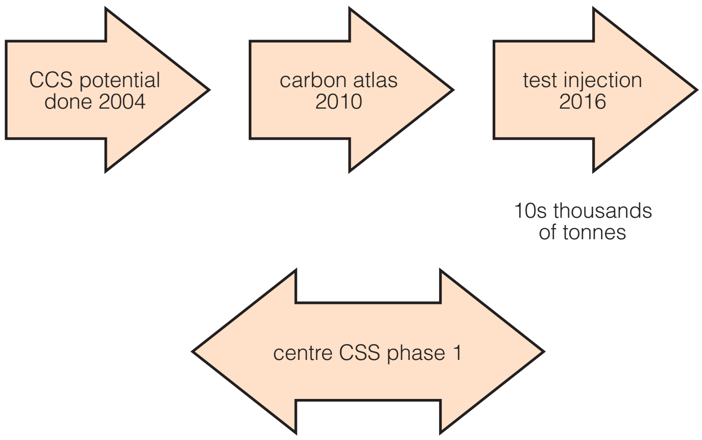

Figure 14 Intended approach to develop and deploy CCS in South Africa (SACCCS, 2011)

Preliminary investigation of CCS potential (completed) – prior to the formation of the Centre, a preliminary investigation was undertaken for the then Department of Minerals and Energy to ascertain whether South Africa had potential storage sites in which to store CO_2 to be captured from its major emission sources. Results of that investigation, released during 2004, showed that South Africa had large-scale CO_2 emissions that could be captured and that there should be adequate CO_2 storage capacity, although this was based on the then standard theoretical determinations. This preliminary investigation provided justification for further, more detailed studies.

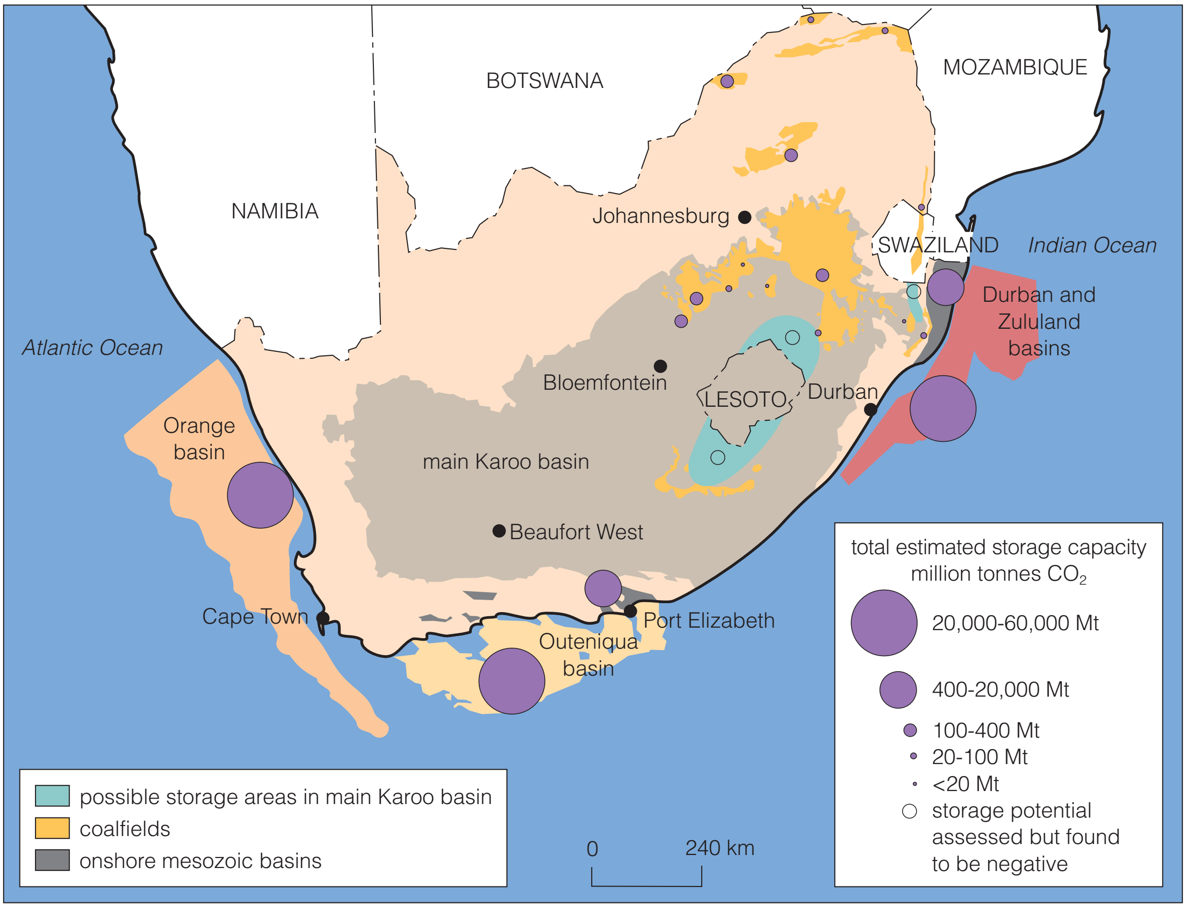

Figure 15 Possible CO_2 storage opportunities in onshore and offshore deep saline formations within South Africa (SACCCS, 2011)

Geological Storage Atlas (completed) – following the preliminary theoretical study, a CO_2 Geological Storage Atlas was developed that provides more authoritative information and has characterised potential storage sites at a theoretical level in South Africa. It was issued in September 2010, with a complementary technical report being released in January 2011. In its preparation, the Council for Geoscience and the Petroleum Agency used existing seismic and historical drill-core data from the onshore and offshore sedimentary basins, to estimate the storage potential in depleted oil and gas reservoirs, deep and unmineable coal seams and deep saline formations. A key finding was that the large potential suggested by the previous study could not be realised due to the low permeability and porosity found in almost all the possible onshore locations. This has meant that the estimated CO_2 geological storage capacity has been revised down to 150 Gt, with 98% of that located offshore in saline formations within the coastal regions of the Outeniqua, Orange and Durban/Zululand basins, Figure 15.

CO_2 Injection Experiment (Proposed) – the intention is to show to decision makers that CCS can be safely undertaken in South Africa. Following procedures used in similar injection activities currently under way internationally, some tens of thousands of tCO_2 will be injected into South African reservoirs and monitored so as to determine the suitability of the local geology as a storage medium, including an assessment of the CO_2 dispersion and transformation reactions and its effects on the surroundings. This will be followed with the determination of the viability of CCS for South Africa via a business plan.

Demonstration Plant (Proposed) – this phase will test and demonstrate the industrial scale integrated capture, transport and safe injection of CO_2 into South African geological formations. The expectation is that the scale of operation will include the storage of hundreds of thousands of tCO_2/y.

While CO_2 from the synfuel plants is recognised as a near-term opportunity, as the gas is available in concentrated form as a waste product, for this phase there will also be a need to consider CO_2 capture for lower concentration sources such as from coal-fired power plants, for which the technology can be acquired from established sources.

Commercial Operation (Proposed) – if the assessment following the demonstration plant test programme proves to be positive, the aim is to establish a full-scale commercial plant, although this will be beyond the remit of SACCCS. The magnitude of the commercial-scale operation will be of the order of millions of tCO_2/y.

This programme is proceeding steadily with the preparatory work under way to determine the most appropriate location for the test injection, which is expected to begin operation in 2016. Throughout these activities, the intention is to build up technical and economic capacity such that informed decisions can be taken regarding the scope for CCS deployment in the country. This includes, for example, working with multi-lateral donors such as the World Bank to examine issues associated with the implementation of CCS in South Africa, and the CSLF/GCCSI to ascertain the non-climate change benefits of CCS, including job creation and protection, poverty alleviation, capital construction benefits, and rural development.

7.6 Development of alternative carbon mitigation actions

Within the framework of the IRP, South Africa intends to improve industrial energy efficiency, increase nuclear power capacity while establishing some 17.8 GWe of renewable power within the generation mix by 2030. Although this covers the full range of renewable technology options, to date only two have made any significant progress towards deployment as outlined below.

7.6.1 Energy efficiency initiatives

A demand-side energy efficiency programme has been initiated by Eskom, the aim of which is to reduce demand in the short term through power quota allocations. For the medium term, Eskom intends to encourage electricity savings through programmes promoting the increased installation of solar water heaters and the use of energy-efficient light bulbs. However, these programmes are making slow progress, due to a lack of skilled personnel and a shortage of funding (Pegels, 2010). For the longer term, Eskom hopes to smooth out peak demand and trough through further demand side management measures based on the introduction of smart metering.

7.6.2 Nuclear power

South Africa intends to increase the role of nuclear energy as part of the process of diversifying South Africa's primary energy sources to ensure energy security. This will mean Eskom will aim to increase nuclear capacity from 1.8 GWe to 11.4 GWe. Eskom has commenced pre-feasibility studies to determine the most cost-effective option (Department of Energy, 2010). However, the programme already appears to be behind schedule, which would have required the go ahead to have been given by the end of 2011. Concerns remain that nuclear power, which will largely be imported, will not enhance localisation in terms of jobs creation and skills development, at least in the near term.

7.6.3 Solar power

In principle, the main focus should be on solar power as the total area of high radiation is some 194,000 km^2, with the better options being in the Northern Cape, North West, Free State, Eastern Cape and Western Cape provinces (Pegels, 2010). Of these areas, the Northern Cape Province has greater solar intensity as well as vast, sparsely populated areas that could be used to site the CSP power plants. However, the initial capital investment in CSP power plants would be very high and there would be a need for extensive infrastructure development including major transmission systems. CSP plants also use large volumes of water for cooling purposes in the steam cycle and to clean the vast mirror areas. Consequently, it seems that significant roll-out of CSP in South Africa will only be feasible if either dry cooling methods and water minimised cleaning techniques can be established or if the focus is on provinces other than the relatively arid Northern Cape. At the same time, there is interest in solar pv options for smaller-scale applications.

In the 2011 bidding process, 18 solar pv projects, which range in size from 5 MWe to 75 MWe, with a total capacity of 632 MWe, and 2 solar CSP projects, totalling 150 MWe were approved, which represents a significant first step to establishing these technologies (Engineering News, 2011).

7.6.4 Wind power

There is also a reasonable potential for wind power, although, to date, there is only one operational commercial wind farm of 7 MWe. Providing the the IPP gain confidence in the new tendering process, its introduction may act as an incentive for additional wind farms (GWEC, 2011b). Some eight onshore wind projects, totalling 634 MWe, were approved as part of the 2011 bidding process.

8 Conclusions

This report concludes with an assessment of the relevance of CCS for each of the designated countries, within the context of their respective carbon mitigation approaches, together with comment on the challenges and opportunities to ensure adequate implementation.

8.1 Recognition of the need for CO_2 mitigation

Brazil, China, India, Indonesia and South Africa are major emerging economies, all of which are vulnerable to adverse effects from climate change, with their governments having to balance economic, environmental and social priorities. All have large carbon footprints; however, in each case, they have made commitments to reduce carbon intensities over the period to 2030 and, in some cases, beyond. The approach to be adopted varies from country to country, depending on both technical and economic drivers.

8.2 Importance of CCS compared to alternative mitigation options

China, India, Indonesia and South Africa have fossil fuel based economies in which in three cases coal is the dominant energy source while for the other (Indonesia) coal is at least a major and growing component of the energy mix. These countries see the use of their large indigenous coal supplies as a means to underpin economic growth with competitive power generation, which directly and indirectly provides jobs for many of the population while also ensuring energy security. At the same time, there are limitations on the renewable energy opportunities that can complement coal use in a cost effective manner.

In all four countries, establishing higher-efficiency coal-fired power plants is seen as an important and near-term step in reducing carbon intensities. In each case, there is a complementary need to curb the excessive transmission losses from the national grids that are neither designed to handle the rapid increase in coal-fired power generation, especially where the load varies significantly between provincial systems, nor readily accommodate the variability arising from growing levels of intermittent renewable power. While these countries all recognise that CCS offers an important means to limit CO_2 emissions from large energy-intensive sources, they are all concerned that the large energy penalty will require a massive upturn in their levels of coal use, and that this in conjunction with the large increase in capital costs will make their power production uneconomic with adverse impacts on their economies within the global context.

At the same time, China, Indonesia and South Africa have shown interest in CCS as a future mitigation option, with government policies identifying it as a key development priority.

China, in particular, has taken forward a major research and development programme leading to some industrial pilot-scale demonstrations of coal based CO_2 capture options, together with either CO_2 storage in saline aquifers or CO_2 use for EOR. This has been undertaken alongside the introduction of very large SC and USC coal-fired power plants with high quality conventional emissions control systems (Minchener, 2012). There are also plans in place to take the CCS demonstrations further, both to consider additional capture options and to scale-up some operations, in all cases with a prime focus on CO_2 based EOR applications. It needs to be stressed that a major driver for China is to establish the basis for technology export, in the same way that it has for clean coal-fired power plants (Minchener, 2010). There are clear indications that the likely costs for CCS can be lowered significantly by China from OECD estimates, thereby enhancing potential global take up. At the same time, China has pushed forward with its plans to provide 15% of its 2020 primary energy needs from non-fossil fuel sources, that is renewables and nuclear. As with coal systems, China has established a major presence for wind and solar, including manufacturing at scale, and it will expand its efforts to operate within international markets.

Indonesia has a less well established approach. CCS is seen as an important option for carbon mitigation as are renewable energy options. The former is focused initially on the need to limit CO_2 emissions from its increased extraction of natural gas with high CO_2 impurity levels and Indonesia seeks to undertake a natural gas based CO_2 EOR pilot-scale demonstration project. However, in each case, although there are policies in place to take forward the technologies, there is a lack of an enabling environment and so progress to date has been very limited.

In South Africa coal currently dominates the energy mix. Large new SC power plants are being established, with air cooling due to the arid conditions. There is a comprehensive coal-based CCS assessment programme in place with a major and critical objective to establish a large-scale CO_2 test injection project. At the same time, it too is seeking to underpin the introduction of renewable energy options. This is all based on imported technology although the government seeks to ensure significant localisation of the manufacturing capability.

India has major ambitions to establish itself as an economic powerhouse and sees rapid large-scale growth as the way to lift its population out of poverty. It is increasing its coal power capacity at a considerable rate, including a very major introduction of SC power plant, while also attempting to underpin the introduction of a significant level of renewable energy through wind and solar power. For wind and to a lesser extent solar power, Indian companies are establishing a global market presence. However, unlike the other three fossil fuel based economies, it has no policy support for CCS, with a consequent lack of any significant R&D activity in place.

In the case of Brazil the very different energy mix compared to the other four countries means that there is little interest in CCS for the power sector. Domestic power generation is based on hydropower, with much smaller amounts of other renewable energy and some fossil fuel capacity. There is a desire to provide alternatives to hydropower as this is becoming vulnerable to water shortages, and wind power appears particularly attractive. However, while there is a lack of policy to support CCS, the government's limitations on CO_2 release from oil and gas extraction from the newly discovered deposits has provided a powerful driver for CCS-related R&D. The primary focus is on stripping CO_2 from natural gas for EOR applications, although the programme is broader in looking at alternative CO_2 storage options as well as various capture approaches. There is national network of institutes undertaking R&D with a strong industrial focus.

8.3 Need for international support to take forward CCS in developing countries

The development and deployment of CCS, when the conditions are right, involves the formulation of appropriate policies, regulations and standards, a sound understanding of capture options for fossil fuel fired power plants and, in due course, other energy-intensive industries, together with careful consideration of the logistics of CO_2 transport if close to large population groupings, and the very careful characterisation of potential CO_2 storage locations, including test injection programmes, all of which lead to detailed feasibility and then engineering design studies. Consequently, for developing countries, there is tremendous scope to learn by doing through co-operation with organisations that have the relevant expertise and experience. All five countries have received varying levels of bilateral and/or multilateral support for CCS related capacity building initiatives (GCCSI, 2011).

There is considerable merit in such support being continued and enhanced, particularly where it can be used to accelerate the development and deployment of CCS technologies (ADB, 2011a). The focus would need to be on those countries that have established policies to counter climate change and have recognised the potential importance of CCS as a carbon mitigation technique, namely China, Indonesia and South Africa.

With regard to the types of projects to be undertaken, there is considerable interest in using the captured CO_2 where it can provide a positive financial impact since, at present, without specific regulatory requirements and/or some form of carbon pricing, the economics of CCS do not favour deployment unless a project receives some form of financial support (APEC, 2012). There are, however, situations where the subsequent use of the captured CO_2 can provide a revenue stream that makes the project economics more attractive. The most short-term practicable example is EOR. While this is an understandable position, it is important to recognise that CO_2 based EOR is but one step towards comprehensive CO_2 storage, which will be required when significant deployment is undertaken.

Thus, while future international co-operation could include various worthwhile generic capacity building activities, the emphasis should be on pushing forward with larger-scale CO_2 capture and EOR demonstrations in China, a demonstration of gas stripping for CO_2-based EOR in Indonesia and the implementation of the CO_2 test injection project within South Africa. Such interventions would represent a significant step forward for demonstrating large-scale CCS in developing countries while confirming the major potential for CO_2 reductions in a particular sector within the country of interest once CCS is deployed.

In addition to these possible three country specific interventions, there is also merit in a broad outreach initiative to cover all three countries and other developing nations. The aim would be to share experiences between the three target countries and to build up capacity and awareness of CCS in other developing countries where such activities have not yet been rigorously pursued.

It is also important to support the nearer term but equally critical initiatives to establish higher efficiency and cleaner coal fired units for power and non-power applications. The majority of the developing countries will continue to use coal and it is very important to ensure that it is used in an efficient way while also achieving an acceptable environmental performance. This is a worthwhile target in its own right but it also helps to counter the current adverse efficiency impacts of CCS that will be particularly problematic in developing economies. This could be incorporated into the outreach initiative.

An important example is the need to encourage co-operation in the drive to develop more advanced steam conditions, through sharing of information and undertaking co-operative R&D. This is particularly applicable to China and India, for whom there would be a valuable benefit in working with counterparts in Europe, Japan and the USA. Looking further, for other developing countries in, say, South East Asia, there is considerable benefit in capacity building initiatives to establish clean coal technologies prior to any major projects for CCS. Many of these countries are starting to increase coal fired capacity and are considering SC systems although there can be local circumstances (eg lower grade coal use) that create some difficulties. There is also a need to consider non-GHG emissions, which would be a pre-requisite for implementing CCS on coal-fired power plants (Minchener, 2012). The sharing of experiences from, say, China and India as well as OECD countries would help to resolve such issues.

9 References

ABB (2011) *Brazil energy efficiency report*. Available from: http://www05.abb.com/global/scot/scot316.nsf/veritydisplay/1b6ed2d18136aa5bc1257864004d09a6/$file/brazil.pdf (February 2011)
ADB (2011a) *Carbon dioxide capture and storage demonstration in developing countries: Analysis of key policy issues and barriers.* Asian Development Bank, Manila, The Philippines, 36 pp. Available at: http://cdn.globalccsinstitute.com/sites/default/files/publication_20110513_ccs-demo-developing-countries-key-policy-issues.pdf (April 2011)
ADB (2011b) RETA 7575: *Determining the potential for carbon capture and storage in Southeast Asia*. Asian Development Bank, Manila, The Philippines (2011)
APEC (2012) *Feasibility of accelerating the deployment of carbon capture, utilization, and storage in developing APEC economies*. Available from: http://www.apec.org/Projects/~/media/Files/Projects/TendersRFPs/2012/20120214_RFP_EWG24_CCUS.ashx Asia Pacific Economic Cooperation (14 February 2012)
Asia Biomass Office (2008) *Construction of biomass power stations in China - outstanding in Jiangsu.* Available from: http://www.asiabiomass.jp/english/topics/0912_04.html (2008)
Balachandar G (2011) *Equipment from China to power coal projects*. Available from: http://www.mydigitalfc.com/news/equipment-china-power-coal-projects-598 (11 September 2011)
Baruya P (2009) *Prospects for coal and clean coal technologies in Indonesia.* CCC/148, London, UK, IEA Clean Coal Centre, pp 70 (Jun 2009)
BBC News (2012) *Brazil country profile*. Available from: http://news.bbc.co.uk/1/hi/world/europe/country_profiles/1227110.stm (25 January 2012)
Beck B (2011) The South African perspective on CCS. Available from: http://unfccc.int/files/methods_and_science/other_methodological_issues/application/pdf/developing_national_demonstration_and_legal_framework.pdf *Presented at a UNFCCC workshop on modalities and procedures for CCS under CDM* (2011)
BGR (2010) Reserves, resources and availability of energy resources 2010. Available from: http://www.bgr.bund.de/EN/Themen/Energie/Produkte/annual_report_2010-summary_en.html Published by Federal Institute for Geosciences and Natural Resources (2010)
Biomass energy (2012) *Shifts in China's biomass energy policy*. Available from: http://www.biomass-energy.org/2011/09/china-constructing-over-700-mw-of-biomass-power-capacity-so-far-in-2011/ (30 January 2012)
Bloomberg (2011) *India's $555 million coal tax may fund electricity lines*. Available from: http://www.bloomberg.com/news/2011-02-21/india-coal-tax-may-be-used-to-fund-transmission-lines-for-renewable-plants.html (21 February 2011)
Bloomberg (2012) *Brazil may auction contracts for 100 megawatts of solar power*. Available from: http://www.bloomberg.com/news/2012-02-01/brazil-may-auction-contracts-for-100-megawatts-of-solar-power.html (1 February 2012)
Boden T, Marland G, and Andres R (2011) *India fossil fuel CO_2 emissions*. Available from: http://cdiac.ornl.gov/trends/emis/tre_ind.html Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn, USA 10.3334/CDIAC/00001_V2011 (2011)
BP (2011) *Statistical review of world energy*. Available from: http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_repo rt_2011.pdf (June 2011)
BP (2012) *World Energy Outlook 2030*. Available from: http://www.bp.com/sectiongenericarticle800.do?categoryId=9037134&contentId=7068677 (January 2012)
British Geological Survey (2007) *A regional assessment of the potential for CO_2 storage in the Indian subcontinent*. Available from: http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Carbon%20capture%20and%20storage/1_20100111132743_e_@@_CO2storageIndia.pdf Sustainable and Renewable Energy Programme Commissioned Report CR/07/198 (2007)

Businessweek (2011) *South African renewable energy fund has 800 million rand*. Available from: http://www.businessweek.com/news/2011-11-17/south-african-renewable-energy-fund-has-800-million-rand.html (17 November 2011)
Carvalho E (2011) *Hydropower in Brazil*. Available from: http://www.w-e- x.com/downloads/WEX_2011_Hydropower_Erton%20Carvalho_CBDB%20%5BCompatibility%20 Mode%5D.pdf (October 2011)
Chikkatur A (2008*) A resource and technology assessment of coal utilization in India*. Available from: http://www.c2es.org/docUploads/india-coal-technology.pdf Harvard University, Cambridge, MA, USA (October 2008)
China View (2007) *Chinese government urges efforts for energy saving, pollutant reduction*. Available from: http://news.xinhuanet.com/english/2007-06/03/content_6190993.htm (3 June 2007).
China Daily (2011a) *Key targets of China's 12th five-year plan*. Available from: http://www.chinadaily.com.cn/china/2011npc/2011-03/05/content_12120283.htm (5 March 2011)
China Daily (2011b) *Road map for social, economic development unfolded*. Available from: http://www.chinadaily.com.cn/china/2011npc/2011-03/06/content_12122579.htm (6 March 2011)
China Daily (2011c) *China to pilot carbon emission trading*. Available from: http://www.chinadaily.com.cn/usa/business/2011-07/18/content_12922115.htm (18 July 2011)
China Knowledge (2010) *China's natural gas consumption to triple in 2010: PetroChina*. Available from: http://www.chinaknowledge.com/newswires/News_Archive.aspx (11 June 2010)
CIA (2011) *South Africa*. Available from: ihttps://www.cia.gov/library/publications/the-world-factbook/geos/sf.html Central Intelligence Agency (2011)
CIAB (2010) *Power generation from coal: measuring and reporting efficiency performance and CO_2 emissions*. Available from: http://www.iea.org/ciab/papers/power_generation_from_coal.pdf International Energy Agency, Coal Industry Advisory Board, Paris, France (2010)
Clean Technica (2011) *80% of Contracts in latest Brazil power auction are for wind power*. Available from: http://s.tt/14Yl9 (22 December 2011)
Climate Policy Initiative (2010) *Review of low-carbon development in China's key sectors*. Available from: www.climatepolicyinitiative.org/generic_datas/view/publication/2 Beijing (November 2010)
Crombie M, de Mello L and Miracca I (2011) *CO_2 capture project phase 3-oxyfuel large scale pilot and demonstration projects.* Available from: http://www.ieaghg.org/docs/General_Docs/OCC2/Abstracts/Abstract/occ2Final00020.pdf Presented at 2nd Oxyfuel Combustion Conference, Queensland, Australia (12-16 September 2011)
CSLF (2011) *A global response to the challenge of climate change*. Available from: http://www.cslforum.org/ Carbon Sequestration Leadership Forum (2011)
DECC (2009) *Understanding carbon capture and storage potential In Indonesia*. Available from: http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/carbon%20capture%20and%20storage/1_20100111133127_e_@@_ccspotentialindonesia.pdf Report prepared by the Indonesia CCS Study Working Group, Department of Energy and Climate Change (August 2009)
Department of Energy (2010) *Integrated resource plan for electricity draft report, 2010, revision 2.* Available at: http://www.energy.gov.za/files/media/pr/INTEGRATED_RESOURCE_PLAN_ELECTRICITY_2010.pdf Department of Energy, Republic of South Africa, 84 pp (October 2010)
Department of Energy (2011) *Integrated resource plan for electricity 2010-2030 final report*. Available from: www.doe-irp.co.za/.../IRP2010_2030_Final_Report_20110325.pdf Department of Energy, Republic of South Africa (25 March 2011)
Department of Environment (2011) *National climate change response white paper*. Available from: www.environment.gov.za/PolLeg/WhitePapers/national_climatechange_response_whitepaper.pdf Department of Environment, Republic of South Africa (2011)
Dhingra S (2010) Renewable energy in India-policies and development. Available from: www.ics.trieste.it/media/719474/15.%20Dhingra.pdf *Presented at Expert Group Meeting On Instruments and Potential for the Use of Renewable Energies for Regional Development*, Trieste, Italy (3-5 May 2011)

East Asia Forum (2011) *Indonesia's energy challenge*. Available from: http://www.eastasiaforum.org/2011/08/26/indonesia-s-energy-challenge/ (26 August 2011)
Ecoseed (2011) *Brazil contracts 1.9 GW of wind power projects in auction*. Available from: http://www.ecoseed.org/wind (26 August 2011)
EIA (2010) *China*. Available from: http://www.eia.gov/cabs/china/pdf.pdf Energy Information Administration, US Department of Energy, USA (November 2010)
EIA (2011a) *Brazil country analysis*. Available from: http://www.eia.gov/cabs/brazil/Full.html Energy Information Administration, US Department of Energy, USA (January 2011)
EIA (2011b) *Indonesia country analysis brief.* Available at: http://205.254.135.7/countries/cab.cfm?fips=ID Energy Information Administration, US Department of Energy, USA (May 2011).
EIA (2011c) *South Africa country analysis brief*. Available at: http://www.eia.gov/cabs/South_Africa/pdf.pdf Energy Information Administration, US Department of Energy, USA (5 October 2011)
EIA (2011d) *India country analysis brief.* Available at: http://205.254.135.7/countries/cab.cfm?fips=IN Energy Information Administration, US Department of Energy, USA (November 2011)
Elaw (2008) *Executive summary: national plan on climate change*. Available from: http://www.elaw.org/system/files/Brazil+Climate+Change_0.pdf Government of Brazil (December 2008)
Energy Research Centre (2010) *South Africa's renewable energy policy roadmaps*. Available from: http://www.erc.uct.ac.za/Research/publications/10Edkinesetal-Renewables_roadmaps.pdf University of Cape Town (June 2010)
Energy Resources Development of Indonesia (2009) *The policy of biofuel in Indonesia*. Available from: http://www.iges.or.jp/en/bf/pdf/activity20090204/FramingPresentations/Priyanto.pdf (22 February 2009)
Engineering News (2011) *SA unveils the names of first 28 preferred renewables bidders*. Available from: http://www.engineeringnews.co.za/article/sa-unveils-the-names-of-first-28-preferred-renewables-bidders-2011-12-07 (7 December 2011)
European Commission (2008) *Development of cofiring power generation market opportunities to enhance the EU biomass sector through international cooperation with China*. Final report of a collaborative EU-China project. Contract 19668/ TREN/05/FP6EN/S07.60657/019668, European Commission, Brussels, Belgium (2008)
European Energy Review (2011) www.europeanenergyreview.eu/index.php?id=3365 European Energy Review (21 November 2011)
Financial Times (2011) *China's nuclear freeze to last until 2012*. Available from: http://www.ft.com/cms/s/0/68694fe0-6525-11e0-b150-00144feab49a.html#ixzz1lvfKyIPb (12 April 2011)
Freund P (2009) Cheltenham, UK, *personal communication* (October 2009)
GCCSI (2009a) *Strategic analysis of the global status of carbon capture and storage report 3: Country Studies Brazil*. Available from: http://cdn.globalccsinstitute.com/sites/default/files/publications/8732/strategic-analysis-global-status-ccs-country-study-brazil.pdf (31 March 2009)
GCCSI (2009b) *Strategic analysis of the global status of carbon capture and storage report 3: Country Studies India*. Available from: http://www.globalccsinstitute.com/sites/default/files/publications/8537/strategic-analysis-global-status-ccs-country-study-india.pdf (31 March 2009)
GCCSI (2011) *CCS capacity development at the end of 2011*. Available from: www.globalccsinstitute.com/community/blogs/authors/alicegibson/2011/12/23/ccs-capacity-development-end-2011 Global CCS Institute, Australia (23 December 2011)
GCCSI (2012a) *Global CCS Institute*. Available from: www.globalccsinstitute (2012)
GCCSI (2012b) *CCS too much for India for now?* Available from: http://www.globalccsinstitute.com/community/blogs/authors/alicegibson/2012/02/16/ccs-too-much-india-now (16 February 2012)
Geothermal Energy Association (2010) *Geothermal energy: international market update*. Available

from: http://www.geo-energy.org/pdf/reports/GEA_International_Market_Report_Final_May_2010.pdf (May 2010)
Government of India (2005) *Integrated energy report*. Available from: http://planningcommission.nic.in/reports/genrep/intengpol.pdf (December 2005)
Government of India (2011) *Power sector at a glance ALL INDIA*. Available from: http://www.powermin.nic.in/indian_electricity_scenario/introduction.htm Ministry of Power (December 2011)
Guardian (2009) *China sets first targets to curb world's largest carbon footprint*. Available from: http://www.guardian.co.uk/environment/2009/nov/26/china-targets-cut-carbon-footprint (26 November 2009)
Guardian (2011) *Brazil approves Belo Monte hydroelectric dam.* Available from: http://www.guardian.co.uk/environment/2011/jun/01/brazil-belo-monte-dam (1 June 2011)
GWEC (2010a) *Wind energy outlook 2010*. Available from: http://www.gwec.net/index.php?id=169 Global Wind Energy Council (2010)
GWEC (2010b) *PR China:total installed capacity*. Available from: http://www.gwec.net/index.php?id=125 Global Wind Energy Council (2010)
GWEC (2011a) *Brazil.* Available from: http://www.gwec.net/index.php?id=118brazilian Wind Energy Association for Global Wind Energy Council (June 2011)
GWEC (2011b) *South Africa enters the renewable energy age*. Available from: http://www.gwec.net/index.php?id=30&no_cache=1&L=0%EF%BF%BD%27&tx_ttnews[pointer]=1&tx_ttnews[tt_news]=318&tx_ttnews[backPid]=97&cHash=10c3cba0f9 Global Wind Energy Council (7 December 2011)
GWEC (2012) *India*. Available from: http://www.gwec.net/index.php?id=124 Global Wind Energy Council (2012)
Hindustan Times (2010) *India's 20th nuclear power station goes critical*. Available at: http://www.hindustantimes.com/india-news/bangalore/India-s-20th-nuclear-power-plant-goes-critical/Article1-631532.aspx (November 2010)
Holloway S, Garg A, Kapshe M, Deshpande A, Pracha A, Khan S, Mahmood M, Singh T, Kirk K and Gale J (2009) *An assessment of the CO_2 storage potential of the Indian subcontinent*. Available from: http://nora.nerc.ac.uk/9895/1/Indian_subcontinent.pdf (2009)
Hu R (2011) Centre for Renewable Energy Development, Beijing, China, *personal communication* (December 2011)
IEA (2008) *Energy technology perspectives 2008: scenarios and strategies.* International Energy Agency, Paris, France (2008)
IEA (2009a) *Technology roadmap: carbon capture and storage*. Available from: www.iea.org/papers/2009/CCS_Roadmap.pdf International Energy Agency, Paris, France (2009)
IEA (2009b) *Energy statistics and balances of non-OECD countries and energy statistics of OECD countries*. Available from: http://www.iea.org/stats/index.asp International Energy Agency, Paris, France (2009)
IEA (2009c) *China CCS roundtable summary*. Available from: www.iea.org/ccs/China_Summary.pdf (9 April 2009)
IEA (2009d) *Brazil CCS roundtable summary*. Available from: www.iea.org/ccs/Brazil_Summary.pdf (8 July 2009)
IEA (2009e) *South African CCS roundtable summary*. Available from: http://www.iea.org/ccs/South_Africa_Summary.pdf (2 October 2009)
IEA (2009f) *Indonesian CCS roundtable summary*. Available from: http://www.iea.org/ccs/Indonesia_Summary.pdf (12 November 2009)
IEA (2010) *Energy technology perspectives 2010: Executive summary*. Available from: http://www.iea.org/techno/etp/etp10/English.pdf International Energy Agency, Paris, France (1 July 2010)
IEA (2011a) *Technology development prospects for the Indian power sector*. Available from: http://www.iea.org/papers/2011/technology_development_india.pdf International Energy Agency, Paris, France (February 2011)
IEA (2011b) *CO_2 emissions from fuel combustion: highlights*. Available from:

http://www.iea.org/co2highlights/CO2highlights.pdf International Energy Agency, Paris, France (2011)
IEA (2011c) *World energy outlook 2011: Energy for All.* Available from: http://www.iea.org/papers/2011/weo2011_energy_for_all.pdf International Energy Agency, Paris, France (October 2011)
India Business Connections (2011) *India moving up fast as economic powerhouse*. Available from: http://indiabusinessconnections.wordpress.com/ (18 January 2011)
Inter-ministerial Committee on Climate Change (2008) *Executive summary: National plan on climate change.* Available at: http://www.elaw.org/system/files/Brazil+Climate+Change_0.pdf (December 2008)
International Trade Administration (2010) *Renewable energy market assessment report: Indonesia*. Available from: http://ita.doc.gov/td/energy/Indonesia%20Renewable%20Energy%20Assessment%20(FINAL).pdf US Department of Commerce (2010)
Jakarta Post (2010) *Bright future for biodiesel in Indonesia*. Available from: http://www.thejakartapost.com/news/2010/02/08/bright-future-biodiesel-indonesia.html (2 August 2010)
Jakarta Post (2011a) *Geothermal firm awaiting government contract assurance*. Available from: http://www.thejakartapost.com/news/2011/08/19/geothermal-firm-awaiting-govt-contract-assurance.html (19 August 2011)
Jakarta Post (2011b) *Government guarantee for IPP projects is 'unclear'*. Available from: http://www.thejakartapost.com/news/2011/09/13/govt-guarantee-ipp-projects-%E2%80%98unclear%E2%80%99.html (13 September 2011)
Junfreng L, Pengfei S, Hu G (2010) *China wind power outlook 2010.* Available at: http://www.greenpeace.org/raw/content/eastasia/press/reports/wind-power-report-english-2010.pdf 108 pp (Oct 2010)
Ketzer J, Villwock J, Caporale G, Henrique da Rocha L, Rockett G, Braum H and Giraffa L (2007) Geological storage in Brazil: The CARBMAP Project. Available from: http://www.netl.doe.gov/publications/proceedings/07/carbon-seq/data/papers/wed_025.pdf *Presented at Sixth Annual Conference on Carbon Capture & Sequestration, Pittsburgh, Pennsylvania, USA* (7-10 May 2007)
KPMG (2011*)* *Carbon disclosure project: South Africa's carbon chasm*. Available from: https://www.cdproject.net/CDPResults/south-africa-carbon-chasm.pdf (2011)
Liu L (2011) Huaneng Clean Energy Research Institute, Beijing, China, *personal communication* (May 2011)
MacNaughton J (2011) *When will CCS be commercially viable?* Available from: http://www.ukccsc.co.uk/Meetings/industry-readiness-June-2011/04_MacNaughton_CCS_costs_as_presented.pdf *Presentation to CCS in Next Decade*, London (20 June 2011)
Mao J (2011) Tsinghua University, Beijing, China, *personal communication* (May 2011)
Marcus S (2011) *India loses 45% of the electricity it produces, expect surge in energy efficiency investmen*t. Available from: http://blog.cleantech.com/sector-insights/energy-efficiency/india-loses-45-of-the-electricity-it-produces-expect-surge-in-energy-efficiency-investment/ (4 May 2011)
Master Resource (2009) *India's tripled CO_2 emissions by 2030: A 'carbon constrained' world?* Available from: http://www.masterresource.org/2009/09/india-co2-emissions-to-triple-by-2030/ (4 September 2009)
McKinsey (2010) *India's urban awakening: building cities, sustaining economic growth.* Available at: http://www.mckinsey.com/mgi/reports/freepass_pdfs/india_urbanization/MGI_india_urbanization_fullreport.pdf (Apr 2010)
Mills S (2007) *Prospects for coal and clean coal technologies in India.* CCC/129, London, UK, IEA Clean Coal Centre, pp 73 (Dec 2007)
Mills S (2010) *Coal use in the new economies of China, India and South Africa.* CCC/161, London, UK, IEA Clean Coal Centre, pp 45 (Jan 2010)
Minchener A (2009) *Future coal supply prospects*. CCC/146, London, UK, IEA Clean Coal Centre, pp 59 (Mar 2009)
Minchener A (2010) *Developments in China's coal-fired power sector*. CCC/163, London, UK, IEA Clean Coal Centre, 55 pp (Jan 2010)

Minchener A (2011a) *Coal-to-oil, gas and chemicals in China*. CCC/181, London, UK, IEA Clean Coal Centre, pp 49 (Feb 2011)
Minchener A (2011b) *CCS challenges and opportunities for China*. CCC/190, London, UK, IEA Clean Coal Centre, pp 95 (Dec 2011)
Minchener A (2012) *Non-greenhouse emissions from coal fired power plants in China*. CCC/196, London, UK, IEA Clean Coal Centre, pp 53 (Apr 2012)
Ministry of the Environment (2010) *Indonesia second national communication.* Available from: www.unfccc.int UN Framework Convention on Climate Change (November 2010)
Ministry of Environment and Forests (2010) *India: greenhouse gas emissions 2007.* Available from: http://moef.nic.in/downloads/public-information/Report_INCCA.pdf Indian Network for Climate Change Assessment, Government of India (May 2010)
MNRE (2009) *Development of conceptual framework for renewable energy certificate mechanism for India*. Available from: http://mnre.gov.in/pdf/MNRE_REC_Report.pdf Ministry of New and Renewable Energy (June 2009)
MNRE (2011) *India's renewable future: challenges and prospects*. Available from: www.renewableenergyworld.com/rea/news/article/2011/02/indias-renewable-future-challenges-and-prospects Ministry of New and Renewable Energy (4 February 2011)
Mott MacDonald (2008) *CO_2 capture-ready UMPPs, India*. Available from: http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Carbon%20capture%20and%20storage/1_20100111133143_e_@@_CO2CaptureReadyIndia.pdf Report 233512/01/A - 24 April 2008/ (April 2008)
Muztagh (2011) *Map of China*. Available from: http://www.muztagh.com/map-of-china/ (2011)
Nalbandian H (2008) *Performance and risks of advanced pulverised coal plant*. CCC/135, London, UK, IEA Clean Coal Centre, pp 70 (May 2008)
NaturalGas (2011) *Electric generation using natural gas*. Available from: http://www.naturalgas.org/overview/uses_eletrical.asp (2011)
NETL (2008) *Reducing CO_2 emissions by improving the efficiency of the existing coal-fired power plant fleet*. Available from: http://www.netl.doe.gov/energy-analyses/pubs/CFPP%20Efficiency-FINAL.pdf DOE/NETL-2008/1329 (23 July 2008)
NRDC (2009) *From Copenhagen accord to climate action*. Available from: http://www.nrdc.org/international/copenhagenaccords/ National Resources Defense Council (2011)
NREL (2000) *Lessons learned from existing biomass power plants*. Available from: http://www.nrel.gov/docs/fy00osti/26946.pdf NREL/SR-570-26946, National Renewable Energy Laboratory, Colorado, USA (February 2000)
Offshore (2010) *Petrobras tests new technologies for CO_2 capture, storage*. Available from: http://www.offshore-mag.com/articles/print/volume-70/issue-2/special-report__carbon/petrobras-tests-new.html (2010)
Oil voice (2011) *China's natural gas consumption set to surge in 2011*. Available from: http://www.oilvoice.com/n/Chinas_Natural_Gas_Consumption_Set_to_Surge_in_2011/4e7910625.aspx (24 January 2011)
ORNL (1995) *Biomass fuel from woody crops for electric power generation*. Available from: https://bioenergy.ornl.gov/reports/fuelwood/toc.html Oak Ridge National Laboratory Report ORNL-6871 (21 September 1995).
Pegels, A (2010) *Renewable energy in South Africa: potentials, barriers and options for support*. Energy Policy, Elsevier, vol. 38(9), pages 4945-4954 (September 2010)
People's Daily Online (2010) *China to cut fossil fuel in total energy mix to 85 pct by 2020: ex-lawmaker*. Available from: http://english.peopledaily.com.cn/90001/90778/90862/7139699.html (14 September 2010)
Pew Centre (2009) *Hydropower: climate techbook*. Available from: http://www.pewclimate.org/docUploads/Hydropower10%2009_FINAL_cleanPDF.pdf (October 2009)
Postnote (2006) *Carbon footprint of electricity generation*. Available from: http://www.parliment.uk/documents/upload/postpn268.pdf Science and Technology Postnote 268, UK Parliamentary Office of Science and Technology (October 2006)
Power (2011) *Restructuring the South African power industry*. Available from:

http://www.powermag.com/issues/features/Restructuring-the-South-African-Power-Industry_4195.html?hq_e=el&hq_m=2352931&hq_l=19&hq_v=9905aea480 (1 December 2011)
Power (2012) *Abundant clean energy fuels Brazil's growth*. Available from: http://www.powermag.com/gas/Abundant-Clean-Energy-Fuels-Brazils-Growth_4333_p2.html (1 February 2012)
Project Monitor (2008) *ONGC, StatoilHydro for joint exploration*. Available from: http://www.projectsmonitor.com/detailnews.asp?newsid=15523 (24 February 2008)
PV power plants (2011) *PV power plants 2011 - Industry Guide.* Available from: http://www.pv-power-plants.com/index.php?id=973 (2011)
PV resources (2012) *Large scale pv power plants*. Available from: http://www.pvresources.com/PVPowerPlants/Top50.aspx (10 January 2012)
RAP (2011) *Air quality management in China*. Available from: www.raponline.org/document/download/id/921 The Regulatory Assistance Project (June 2011)
Reinforced Plastics (2012) *India saw US$10.3bn of clean energy investment in 2011*. Available from: http://www.reinforcedplastics.com/view/23700/india-saw-us103bn-of-clean-energy-investment-in-2011/ (7 February 2012)
Renewables Info (2010) *Hydropower advantages and disadvantages*. Available from: http://www.renewables- info.com/drawbacks_and_benefits/hydropower_advantages_and_disadvantages.html (22 November 2010)
Renewable Energy World (2010) *Renewable energy policy update for China*. Available from: http://www.renewableenergyworld.com/rea/news/article/2010/07/renewable-energy-policy-update-for-china (21 July 2010)
Research and markets (2011) *Research report on Chinese hydropower industry: 2011-2012*. Available from: http://www.researchandmarkets.com/reports/1607709/research_report_on_chinese_hydropower_industry (April 2011)
Reuters (2009) *Indonesia CO_2 pledge to help climate talks-greens*. Available from: http://www.reuters.com/article/2009/09/29/idUSSP495601 (29 September 2009)
Reuters (2011a) *Petrobras to begin offshore CO_2 sequestration*. Available from: http://www.reuters.com/assets/print?aid=USTRE7124PJ20110203 (3 February 2011)
Reuters (2011b) *China's CO_2 emissions rose 10 percent in 2010: BP data*. Available from: http://www.reuters.com/article/2011/06/08/us-energy-bp-emissions-idUSTRE75728120110608 (8 June 2011)
Reuters (2011c) *China may lift nuclear approvals by mid-2012: report*. Available from: www.reuters.com/article/2011/06/25/us-china-nuclear-idUSTRE75O0EU20110625 (24 June 2011)
Reuters (2011d) *China scales up solar power capacity plan by 50 percent*. Available from: http://www.reuters.com/article/2011/12/15/us-china-renewables-idUSTRE7BE0H320111215 (15 December 2011)
Reuters (2012) *China urges hydropower developers to heed environment*. Available from: http://www.reuters.com/article/2012/01/17/china-hydropower-idUSL3E8CH2AC20120117 (17 January 2012)
Ricketts B (2011) *Addicted to coal*. Available from: Presented at 60th Rubens Coal science Lecture, London, UK (3 October 2011)
Rockett G, Machedo C, Ketzer J and Centeno C (2011) *The CARBAMAP project; matching CO_2 sources and geological sinks in Brazil using GIS*. Energy Procedia 4, 2764-2771 (2011)
RTCC (2011) *China flicks the switch on incandescent bulbs*. Available from: http://www.rtcc.org/energy/china-flicks-the-switch-on-incandescent-bulbs/ (4 November 2011)
SACCCS (2011) *South Africa Centre for CCS*. Available from: www.sacccs.org.za/ (2011)
SATREPS (s2011) *Pilot study for carbon sequestration and monitoring in Gundih area - East Java Province, Indonesia*. Available from: http://www.jst.go.jp/global/english/kadai/h2305_indonesia.html Science and Technology Research Partnership for Sustainable Development (2011)
Schilling H (1993) *Improving the efficiency of pulverized coal fired power generating plant.* VGB Kraftwerkstechnik 73(8) pp 564-76 (1993 English Edition)
Solar Paces (2011) *CSP - how it works*. Available from: http://www.solarpaces.org/CSP_Technology/csp_technology.htm (2011)

South Africa (2010) *Pocket guide to South Africa energy and water 2010/11*. Available from: http://www.gcis.gov.za/resource_centre/sa_info/pocketguide/2010/017_energy.pdf (2010)
Stanford (2011) *The future of South African coal; market, investment and policy changes*. Available from: http://iis-db.stanford.edu/pubs/23082/WP_100_Eberhard_Future_of_South_African_Coal.pdf (January 2011)
Sustainable Energy Today (2010) *The carbon footprint of electricity production*. Available from: www.sustainableenergytoday/2010/01/carbon-footprint-of-electricity.html (4 January 2010)
Tharakan P (2012) Asian Development Bank, Manila, The Philippines, *personal communication* (January 2012)
The Times of India (2012) *Discoms may go green once DERC gives nod*. Available from: http://articles.timesofindia.indiatimes.com/2012-02-08/delhi/31037048_1_renewable-energy-renewable-power-solar-power (8 February 2012)
UNDP (2010) *China and a sustainable future: towards a low carbon economy and society*. Available from: hdr.undp.org/en/reports/national/.../china/name,19646,en.html (April 2010)
USAID (2007) *Indonesia country report* (June 2007)
US DOE (2011) *Geothermal technologies programme*. Available from: http://www1.eere.energy.gov/geothermal/powerplants.html US Department of Energy (2011)
World Bank (2010) *Unleashing the potential of renewable energy in India*. Available from: http://siteresources.worldbank.org/EXTENERGY2/Resources/Unleashing_potential_of_renewables_in_India.pdf (2010)
World Coal Institute (2009) *India - the coal resource, a comprehensive overview of coa*l. Available from: http://www.worldcoal.org/pages/content/index.asp?PageID=402 World Coal Institute (March 2009)
World Nuclear Association (2011) *Nuclear power reactors*. Available from: http://www.world-nuclear.org/info/inf32.html (March 2011)
World Nuclear Association (2012a) *Nuclear power in China*. Available from: http://www.world-nuclear.org/info/inf63.html (January 2012)
World Nuclear Association (2012b) *Nuclear power in India*. Available from: http://www.world-nuclear.org/info/inf53.html (January 2012)
World Wind Energy Association (2011) *World wind energy report 2010*. Available from: http://www.wwindea.org/home/images/stories/pdfs/worldwindenergyreport2010_s.pdf (April 2011)
WRI (2011) *Shifting policies stall South Africa's renewable energy growth*. Available from: http://insights.wri.org/open-climate-network/2011/10/shifting-policies-stall-south-africas-renewable-energy-growth World Resources Institute (14 October 2011)
zeroco2 (2011) *Brazil: energy & climate change-policy and progress. CCS initiatives and projects*. Available from: http://www.zeroco2.no/projects/countries/brazil (2011)
Zhang J (2010) Overview of CCUS activities in China. Available from: http://www.cagsinfo.net/pdfs/workshop2/Session-1/Overview-CCUS-Activities-China.pdf *Presented at the CAGS aquifer storage of CO_2 workshop, Wuhan, Hubei Province, China* (26-29 October 2010)
Zhou N, Levine M and Price L (2010) *Overview of current energy efficiency policies in China*. Available from: http://www.sciencedirect.com/science/article/pii/S0301421509005849 Energy Policy, Volume 38: Issue 11 (November 2010)