Electricity Supply Options, Sustainable Development and Climate Change Priorities

Case Studies for South Africa

September 2007

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UNEP Risø Centre
on Energy, Climate and Sustainable Development
Risø National Laboratory
Technical University of Denmark – DTU, Roskilde, Denmark

ISBN: 978-87-550-3629-1

Publisher: Magnum Custom Publishing (A Division of Magnum Books Pvt Ltd)
New Delhi, India; website: www.magnumbooks.org

September 2007

When citing this report the following citation should be used:
Winkler H, Mukheibir P, Mwakasonda S, Garg A and Halsnaes K, 2007. *Electricity Supply Options, Sustainable Development and Climate Change Priorities: Case Studies for South Africa*. UNEP Risoe Centre on Energy, climate and Sustainable Development, Roskilde, Denmark. ISBN: 978-87-550-3629-1. September 2007

The findings, interpretations, and conclusions expressed in this report are entirely those of the the author(s) and should not be attributed in any manner to UNEP (the project sponsors) or RISØ National Laboratory

Preface

This report summarizes the results of the *Projecting future energy demand: Balancing development, energy and climate priorities in large developing economies* project that has been managed by the UNEP Risø Centre on behalf of UNEP DTIE. The project, sponsored by UNEP, is a partnership between the UNEP Risø Centre and centers of excellence in South Africa, China, India and Brazil.

The focus of this report is on the energy sector policies that mainstream climate interests within development choices. The country study results for future energy and environment projections that are included in this report are backed by intensive economy-energy-environment modeling by the Energy Research Centre at the University of Cape Town, South Africa, wherein general scenario analysis of the energy sector explores some policies in more depth.

The report argues that starting from development objectives is critical to mitigation efforts in developing countries. Instead of defining local benefits as ancillary to mitigation, reductions of GHG emissions should be seen as the co-benefits of policies that drive local sustainable development. A development-focused approach seems more likely to be implemented than the imposition of GHG targets by the international community—especially as South Africa has adopted development targets such as the Millennium Development Goals and promoted the Johannesburg Plan of Action.

Much of the contribution that this approach can make lies in considering the specific energy policies that can meet national development objectives, given that almost 80% of South Africa's emissions come from energy supply and use. The case studies presented here take as their starting point development objectives, rather than climate change targets. The form of climate action which it investigates is sustainable development policies and measures.

The case study considers options in the electricity sector, recognizing that making electricity development more sustainable can contribute to climate change mitigation. One of the cases focuses both on domestic options such as renewable energy and nuclear power in South Africa, as well as considering the climate impacts on hydroelectric imports from the Southern African region. Climate change is projected to increase both the temperature as well as the annual rainfall in the Congo and Zambezi river catchments. The combined case could reduce 84 Mt CO_2 for 2030 (13% less than reference) and 579 kt SO_2 (–20% in 2030), the latter providing important benefits for the local environment.

The report begins by outlining the sustainable development framework. Chapter 2 examines development, energy and climate change linkages as they apply in South Africa. The second part (chapters 3–5) contains future projections, starting from the current status, examining current development trends and then modeling future electricity supply options. The third part reports results, first for the country against energy indicators of sustainable development, and finally with some cross-country comparative results.

The country study results are "owned" by the Energy Research Centre team, while URC has mainly provided the research framework, cross-country comparison and editorial support led by Amit Garg and Kirsten Halsnaes. The report has benefited immensely from joint modeling work, discussions and insights on scenarios between ERC, over the years, with international modeling experts including those involved in the International Energy Workshop held in Cape Town in 2006, and several other eminent researchers, to whom the authors are grateful. This report has also benefited from our discussions with other project partners and eminent researchers Dr Fatih Birol and Dr Laura Cozzi of IEA, Prof P.R. Shukla of India, Dr Jiang Kejun and Dr Hu Xiulain of China, and

Prof Emilio Lebre la Rovere of Brazil. We are thankful to them. The report also draws from the work of numerous South Africa co-researchers with whom some of the authors had the privilege to work, of which ERC's modeling group led by Alison Hughes deserves special mention. Last but not the least, the coordination, encouragement and project facilitation extended by Dr Mark Radka (Head of UNEP Energy, UNEP DTIE, Paris), Dr John Christensen (Head of URC) and Daniel Puig are acknowledged.

We are sure that this report would be of interest to various domestic and international audiences including policymakers, researchers and scientists.

Harald Winkler
Pierre Mukheibir
Stanford Mwakasonda

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Part I

Overview and Methodological Issues

CHAPTER – 1

Sustainable Development as a Framework for Assessing Energy and Climate Change Policies

Global responses to climate change have been driven by a relatively narrow focus on the issue that rarely considers potential synergies between sustainable development and climate change policies at national level. "Ancillary benefits" such as improved energy efficiency or reduced health impacts from local air pollution may be significant but they are of secondary importance in most climate change circles, seen only as reducing the total cost of compliance with climate change commitments. With their focus on long term change, climate change specialists are often accused of ignoring more pressing problems in developing countries.

At the same time, in many developing countries policies that are sensible from a climate change perspective can emerge as side-benefits of sound development programmes. In the energy sector, for example, price reforms, sector restructuring, and the introduction of energy efficiency measures and renewable energy technologies—all undertaken without any direct reference to climate change—can mitigate climate and other environmental risks while achieving their main goal of enhancing economic and social development.

A less polarized way of meeting the challenges of sustainable development and climate change is to build environmental and climate policy around development priorities that are more important to developing countries. This approach sees the potential contribution by developing countries to the solution of the climate change problem not as a legally driven burden but as a welcomed side-benefit of sustainable development.

The sustainable development agenda of a country could be very wide and the literature includes hundreds of different definitions. It is beyond the scope of this research to go into an assessment of the theoretical literature about sustainable development, rather the approach taken here is pragmatic and the focus is to consider how current development trends in the energy system can be made more sustainable.

The perspective taken is that climate policy goals are not a major priority area in developing countries since other development goals including poverty alleviation, energy provision etc., are more important immediate concerns. However, many general development policies have large side-impacts on climate change, and in order to capture these, we have outlined a framework for how sustainable development (SD) dimensions, energy and climate can be assessed jointly. The approach is here to use a number of key SD indicators[1] that reflect economic, social, and environmental dimensions of sustainable development, and to use these to examine specific clean energy policies.

1.1 Sustainable Development Indicators

A number of quantitative or qualitative indicators that reflect these human well-being dimensions have been defined and applied to the assessment of development, energy and climate policies. Obviously, it is most easy to apply well-being indicators to the evaluation of sector or household level policy options rather than at the macroeconomic level. This is the case, because the well-being issues addressed here include various elements that directly reflect the freedom and rights of individuals and households. A meaningful representation of these therefore requires rather detailed information that is most easy to cover in micro-oriented or sectoral studies.

Table 1 provides an overview of how economic, environmental and social sustainability dimensions related to energy and climate change can be covered by specific indicators. These indicators are defined in a way, where they can be linked to specific quantitative measurement standards and modeling output.

Table 1: Examples of indicators that can be used to address economic, environmental and social sustainability dimensions seen from an energy sector perspective

SD Dimension	SD Indicator
Economic	
Cost Effectiveness	Net costs, Financial flows
Growth	Income generation
Employment	No of people and man-hours
Investments	Energy investments
Energy Sector	Energy consumption, Access and costs
Environmental	
Climate change	GHG emissions
Air pollution	Local air pollution, particulates, Environmental health benefits
Water	Discharges to water
Soil	Exposure to pollutants
Waste	Waste discharge
Exhaustible resources	Fossil fuels
Biodiversity	Specific species
Social	
Local participation	Direct participation of local companies or people in policy implementation
Equity	Distribution of costs and benefits, income distribution
	Energy consumptions and costs to different income groups
Poverty alleviation	Income or capabilities created for poor people
Education	Literacy rates, primary and secondary education, training
Health	Life expectancy, Infant mortality, Major diseases, Nutrition, Burden of Disease (BoD)

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[1] A SD indicator in this context is used as a sort of measurement point for a quantitative assessment of the impacts of implementing specific policies with regard to areas that are considered to be key national focal points for addressing sustainable development. See also a more elaborate discussion about the use of SD indicators in Halsnæs and Markandya, Chapter 5, 2002

1.2 Balancing Energy, Sustainable Development and Environment

The approach of balancing energy, development and climate priorities in addition to the suggested SD indicators also includes recommendations about how institutional elements of studies can reflect specific aspects of inter- and intra-generational issues of SD. Detailed energy-economic and environmental modeling was conducted to derive these indicators in future, along with projecting many other relevant parameters such as total primary energy supply, power generation, total final energy consumption for fuels and sectors, CO_2 and SO_2 emissions. These projections were made for 2010, 2020 and 2030. Chapter 3 provides methodological details and assumptions behind these modeling projections.

It is worth recognizing that the well-being indicators that are suggested in Table 1 include many of the dimensions that were covered in the Millennium Development Goals (MDGs) that were adopted by the World Summit on Sustainable Development in Johannesburg in August 2003 (UNDP, 2003). Some of the major MDGs are to decrease poverty, to reduce hunger and to improve education and health. Environmental issues are only directly referred to in the MDGs in relation to air pollution impacts on health and to the degradation of natural resources. Energy obviously is indirectly linked to all these environmental issues. However, there are several other strong linkages between the top priorities of the MDGs as for example poverty alleviation and energy issues and the same is the case with the MDGs related to water and food supply. Supply of high quality and clean energy offers income generation opportunities for business as well as for households and may allow time for educational activities. At the same time access to clean energy improves health conditions and energy is needed for health clinics and educational activities.

The UN Millennium Task Force has conducted in-depth studies on the requirements for achieving the different goals, and part of this work is a specific assessment of energy services for the poor (Modi et al., 2004). The energy task force group concluded on the basis of the Modi study that a number of energy targets were a prerequisite for achieving MDGs including introduction of modern fuels to substitute traditional biomass use, access to modern and reliable energy sources for the poor, electricity for education, health and communication, mechanical power, and transportation.

Many studies of development and energy linkages assume that energy is a key component in development without a further examination of—in which way and in which configurations energy most effectively supports development. This is a limitation since investments in energy provision compete with other investments in scarce resources, and energy consumption has several externalities including local and global pollution, which negatively affects human well-being. Furthermore energy investments tend to create lock-in to technology trajectories, which can make it very expensive to change track later if there is a need for managing externalities or other concerns.

Energy has a key role in economic development through its role as a production input, and as a direct component in human well-being. Toman and Jemelkova (2002) in an overview paper provide a number of key arguments for how and in which way energy plays a role in development. They note that "there are several ways in which increased availability or quality of energy could augment the productivity and thus the effective supply of physical and/or human capital services. The transmission mechanisms are likely to differ across the stages of development... for more advanced industrialized countries, increased energy availability and flexibility can facilitate the use of modern machinery and techniques that expand the effective capital-labor ratio as well as increase the productivity of workers. Whereas supply-side energy changes in less advanced countries economize on household labor, here energy availability can augment the productivity of industrial labor in the formal and informal sectors."

The general conclusion that arrives both at macro level and at household level about the relationship between economic development and energy consumption is that increased energy availability disproportionately could affect economic development. Toman and Jemelkova (2002) identify the following factors behind this as:

- ❑ Reallocation of household time (especially by woman) from energy provision to improved education and income generation and greater specialization of economic functions.
- ❑ Economics of scale in more industrial-type energy provision.
- ❑ Greater flexibility in time allocation through the day and evening.
- ❑ Enhanced productivity of education efforts.
- ❑ Greater ability to use a more efficient capital stock and take advantage of new technologies.
- ❑ Lower transportation and communication costs.
- ❑ Health-related benefits: reduced smoke exposure, clean water, and improved health clinics through electricity supply.

In addition to energy's potential for supporting economic growth disproportionately, there can also be a tendency to see decreasing energy/GDP intensity with economic development, as a consequence of increasing energy efficiency with the introduction of new energy technologies.

The conclusions by Toman and Jemelkova regarding industrialized countries are based on detailed empirical analysis from the US on the role of energy in industrialization processes including work by Schurr et al. (1982) that identifies more flexible energy forms (like electricity) and higher energy conversion efficiency as major factors in productivity increases for non-energy production factors. A consequence of this is that energy/GDP intensities tend to increase or to be stable in earlier phases of industrialization, while they later tend to decrease. This suggests that economic development, energy consumption, and in some cases[2] pollution can be decoupled from economic development. This tendency is subsequently illustrated with data for some industrialized and developing countries in this project.

In less advanced countries larger and cleaner energy provision can support human well-being through several channels including increasing opportunities for income generation activities and a number of benefits in relation to education, health, decreased time for household chores, and increased leisure time. The magnitude of these benefits has been assessed in detailed studies for a number of developing countries, and some results will be presented subsequently.

SD and environmental linkages can be understood in many different ways dependent on the underlying paradigm of development (Halsnæs and Verhagen, 2006). Some of the controversies that have been going on in the theoretical debate about sustainable development have been between economists and ecologists. Economists have tended to focus on economic growth patterns and substitutability between man-made and natural capital, while ecologists have emphasized limits to growth and constraints. Recent work by a group of leading economists and ecologists has done an attempt to "merge" the two disciplines in a practical approach that can be used as a background for addressing SD and environmental linkages. A short introduction to this is given in the following:

Arrow et al. (2004) summarize the controversy between economists and ecologists by saying that ecologists have deemed current consumption patterns to be excessive or deficient in relation to sustainable development, while economists rather have focused on the ability of the economy to maintain living standards. It is here concluded that the sustainability criteria implies that inter-temporal welfare should be optimized in order to ensure that current consumption is not excessive[3]. However, the optimal level of current consumption cannot be determined i.e., due to various uncertainties, and theoretical considerations are therefore focusing on factors that could be predicted to make current consumption unsustainable. These factors include the relationship between market rates of return on investments and social discount rates, and the relationship between market prices of consumption goods (including capital goods) and the social costs of these commodities.

A key issue that arises from this approach is what is meant by consumption patterns, and how these should be understood in relation to human well-being and its major components. Energy is—as already said, a key component in consumption both at macroeconomic and household level, and energy to a large extent is based on exhaustible resources and creates pollution.

Furthermore, it is important to recognize that developing countries exhibit some specific institutional factors that are key framework conditions for individual and collective consumption choices, which go beyond market frameworks due to inefficiencies, limited information, and weak institutional capacities in these countries. One of the implications of these institutional weaknesses in developing countries is that the use of various production factors including energy is very inefficient, which both implies supply constraints, high costs, and high pollution intensity.

The Development, Energy and Climate project includes a number of analytical steps and are covered in detail in Halsnaes et al. (2006). These provide a methodology up-scaling the results from individual country case studies and link them in a macroeconomic national modeling framework.

CHAPTER – 2

Development, Energy and Climate Change Linkages in South Africa

Economic growth concerns in the post-industrial evolution period took little consideration for environmental sustainability. Significant energy demands in industrialized countries were observed during the 1950s and 1960s, as a result of the coupling of economic growth and energy consumption. Realization and awareness about the social deprivation of the majority of the world's population through the economic paths taken since the 1950s began taking prominence in the 1970s. As a consequence, calls for development paradigms that would include social considerations along with economic growth were voiced. In the late 1970s and early 1980s, the growing realization of the deterioration in the environment prompted a significant number of people to call for development paradigms that not only consider economic growth and the social dimension, but also incorporate environmental issues. This thinking became the genesis of the idea of sustainable development. The late 1980s saw those concerns growing to a global level, and eventually to include the perception of the climate change threat which in turn increased the justification for sustainable development paradigms (Winkler, 2006).

Sustainable development continues to receive different definitions, depending on the context of definition. One of the most common definition infers development that meets the present needs and goals of the population without compromising the ability of the future generation to meet theirs. Imperatively, understanding sustainable development requires defining economic development, social development and environmental development.

Economic development is essentially economic progress of country's wealth and its inhabitants, leading to the willingness and ability to pay for the goods and services that enhance income and efficient production. Social development essentially refers to the improvement in the well-being of individuals and society leading to an increase in social capital, institutional capital and organizational capital and hence in economic development. Environmental development involves the

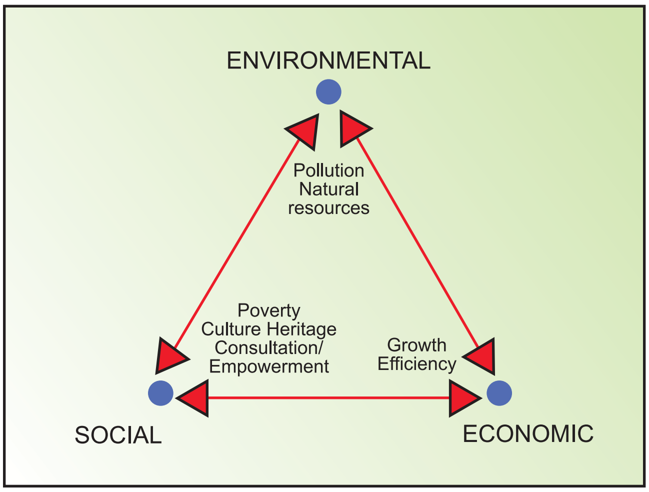


Figure 1: Elements of sustainable development

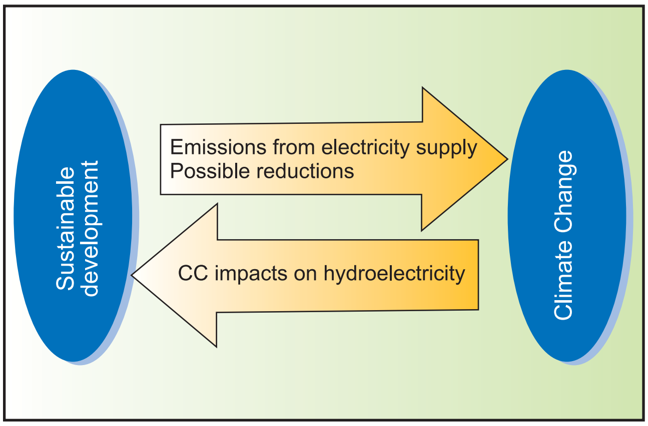


Figure 2: Two-way interaction between sustainable development and climate change

management of ecological services and human beings that depend on them. This framework is depicted in Figure 1 (Winkler, 2006).

From a sustainable development paradigm, one can then find linkages with climate change by identifying synergies between the two. The connection between sustainable development and climate change works in two directions (Munasinghe & Swart, 2005). This case study examines the potential contribution that more sustainable energy development can make to climate change mitigation, as well as possible impacts of climate change on energy development in South and Southern Africa. The interaction in both directions is illustrated in Figure 2.

In South Africa, the two-way connection is particularly marked in the energy sector, the major source of greenhouse gas (GHG) emissions. South Africa's electricity sector is the major source of GHG emissions, and mitigating climate change is primarily an energy problem. The challenge of climate change relates to the dependence of South Africa's economy on fossil fuels. Coal accounts for three-quarters of primary energy supply (DME, 2003a), and for over 90% of electricity generation (NER, 2002a). Industrial processes and agriculture also contribute to greenhouse gas emissions, but energy-related emissions constitute 78% of the South Africa's inventory of greenhouse gases in 1994 (Van der Merwe & Scholes, 1998). Making energy development more sustainable at the national level can contribute to global sustainability by mitigating climate change.

At the same time, hydroelectricity in the medium- to long-term holds major potential for the Southern African Power Pool—and hydroelectricity is the energy source most directly susceptible to climate change impacts through changes in run-off.

The case study makes contributions to two thematic areas in the Development and Climate Project:

- ☐ Electricity supply options provide input to thematic area 1: "GHG stabilization scenarios, relationship to the development agenda, future energy growth patterns and technologies including technological change, innovation and penetration"; and
- ☐ The impacts of climate change on regional hydroelectricity contribute to thematic area 3: "climate change impacts, vulnerability and adaptation in the energy sector".

The report is structured to broadly follow the conceptual approach outlined in practical guidance for the Development and Climate project (Halsnaes et al., 2005), (see Figure 1 in the Appendix). Detailed policy options within the electricity sector are described in section 5. The linkage of national energy development modeling and global SRES scenarios is considered in a later chapter. The description of the reference case and its assumptions (steps 3 and 4 in Figure 1) are outlined in that section and the next (4.3).

The selected cases, focusing on electricity supply options (step 5) are elaborated in section 5. The climate change implications for one particular option, importing hydroelectricity from the Southern African region are discussed in section 5.4. Chapter 6 addresses the sustainable development implications of different options, drawing on indicators of sustainable development. Implications for the climate change negotiations are briefly highlighted in Chapter 8 where in conclusions are also summarized.

South Africa's development path was outlined in the ruling party's (African National Congress) Reconstruction and Development Programme (RDP) in 1994. The main development objective outlined in the program was that of meeting people's basic needs and job creation through public works. Since then there has been a new development—macroeconomic policy. Making energy supply and use more sustainable is a central challenge in South Africa's development path. Energy is a critical factor in economic and social development, while the energy system has impacts on the environment. Managing energy-related environmental impacts is a major goal of the energy policy (DME, 1998), in addition to making energy development more sustainable at a national level.

Perhaps the most important energy policy objective for South Africa is to provide increasing access to affordable energy services (DME, 1998). While overall electrification increased from roughly one-third in 1990 to more than two-thirds by 2006, the majority of the population in rural areas still remains without electric power. Overall, the energy sector has performed well—relative to other sectors—in meeting development objectives.

On a larger scale, South Africa has embarked on a number of actions that will reduce the pace of carbon emissions growth. South Africa, as most developing countries, has policies and measures that have been taken for technological, environmental or economic development, but will result in GHG emission reduction or climate change mitigation.

Major objectives of government policy for the energy sector are spelled out in the 1998 Energy White Paper as:

❑ Improving energy governance;
❑ Increasing access to affordable energy services;
❑ Stimulating economic development;
❑ Managing energy-related environmental impacts; and
❑ Securing supply through diversity (DME, 1998).

While most programs to be implemented under the five thematic areas do not primarily address climate change, it can be recognized that benefits related to GHG and mitigation of climate change will accrue with these policy objectives.

For future sustainable energy supply, South Africa is looking to more Southern African regional resources, as opposed to purely domestic resources, especially within the Southern African Development Community (SADC), which has considerable hydropower and natural gas potential. The Southern African Power Pool, composed of the national utilities of all SADC countries, now has an operational control centre in Harare that will facilitate increased electricity trading in the region. Eskom, the national power utility, has identified more than 9,000 MW potential for regional imports, even without considering the massive potential of the Grand Inga scheme in the Democratic Republic of Congo, which has the potential of over 40,000 MW in the longer term. Regional cooperation on energy development is also a major drive within the New Partnership for Africa's Development.

While the energy sector in South Africa could be used to provide a clear example on synergies between development and sustainable development, policies and measures in other sectors, if taken with sustainable development considerations, can also have significant potential for reducing GHG emissions. Conducting a complete analysis across all sectors in South Africa would require an inter-disciplinary team, significant time and data.

The following table, adopted from a study by ERC, shows some emission reduction estimates due to different policies and measures in a number of sectors.

Table 2: Sector development, sustainable development and GHG emissions
Source: (Winkler et al., 2002b)

Development objectives	Possible shift to more sustainable development	GHG reduction or increase relative to business-as-usual (current stated policy)
Housing Low Cost Housing Program: Approximately 300,000 new units per year.	All new low-cost houses built with energy efficiency measures (ca. R2,000 per household for a package of thermal interventions) Energy-efficient housing standards – mandatory through building regulation, etc.	0.05 and 0.6 $MtCO_2$-equivalent per year, if aggregated across all low-cost housing
Energy		
Increased access to affordable energy services ● Continue electrification under restructured market, at 300,000 connections per year.	Aim for *universal access* to modern energy services ● Off-grid electrification with renewables where appropriate, {but also using LPG, modern biomass, mini-grids and other systems (links to diversity)} ● Implement free basic electricity (poverty tariff) of 20- 50 kWh / household / month for 1.4 million poor households	indoor air pollution, but increased GHG emissions from power generation Increase of 0.146 $MtCO_2$ (upper bound estimate)
Improving energy governance ● Restructuring of Electricity Distribution Industry (EDI) ● Restructuring of Electricity Supply Industry (ESI)	Regulation under restructuring to ensure that national energy efficiency programme is implemented. Opportunity in restructuring for renewable energy IPPs, but also barriers. Require minimum of renewable energy in generation. Adopt Renewable Energy White Paper with quantified targets for renewable energy generation.	Not estimated
Stimulating economic development	Remove energy trade barriers & facilitate investment in energy sector, including power-purchase agreements for renewable IPPs National energy efficiency programme to ensure 5% reduction in electricity consumption by 2010 ● 39 000 additional jobs and R800 million additional income	Reduce CO_2 emissions by 5.5 million tons in 2010 Demand-side management leading to reductions of annual CO_2 emissions of 8 $MtCO_2$ in 2010 and 19 $MtCO_2$ in 2025.

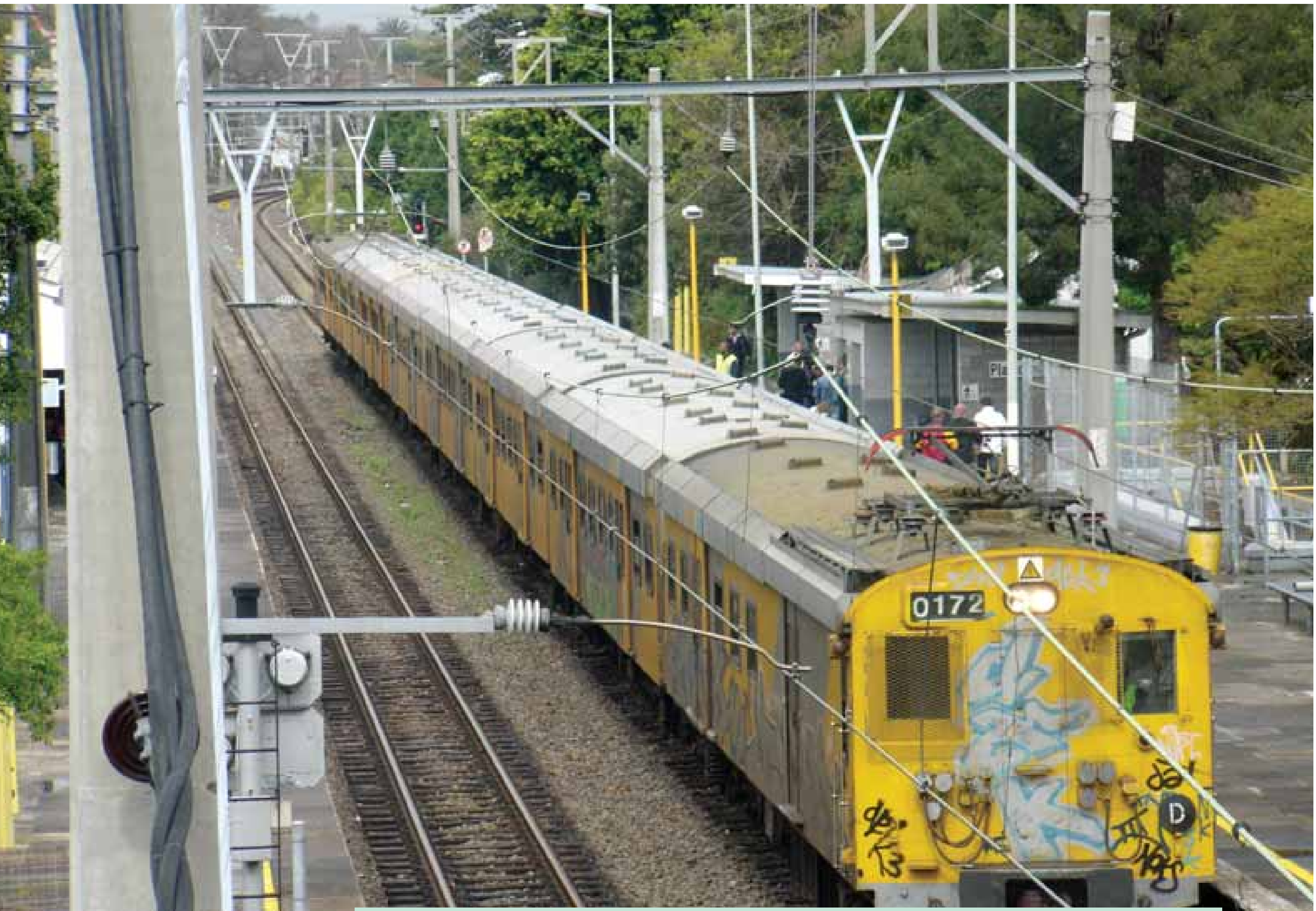
contd…

Development objectives	Possible shift to more sustainable development	GHG reduction or increase relative to business-as-usual (current stated policy)
	More intensive demand-side management by utility Industrial energy efficiency Adjust tariffs to allow return on investment in energy efficiency Include external costs in cost-of-supply approach to electricity pricing	Potential reductions of 60 200 tons CO_2 p.a. from a single plant
Managing energy-related environmental impacts	Improve air quality by reducing energy-related emissions ● indoor: LPG, extend low smoke fuels ● outdoor: Promulgate National Ambient Air Quality Standards (SO_2 draft exists) - urban Integrate strategies between with transport and energy sectors	Study required to quantify links between reduced local air pollution and reduced GHG
Securing supply through diversity ● Stimulate use of new & renewable energy sources ● Develop gas markets ● Develop Southern African Power Pool (SAPP)	Renewable Energy Portfolio Standard (REPS), 5% of electricity generation by 2010, and 20% by 2025. Develop large-scale wind and solar thermal IPPs Use Mozambique gas for residential and commercial applications in Gauteng Explore additional imports of gas, from Namibia and West Coast Import additional hydro power (run-of-river)	Reductions in CO_2 emissions of 10 $MtCO_2$ in 2010; and 70 $MtCO_2$ in 2025 (based on baseline emissions projections for bulk electricity). Need to include comparative costs.
Transport		
Increased public transport (modal shift) Reduce cost of transport Reduce air pollution from transport (local emissions and GHGs)	Taxi recapitalisation Phase 2 with compressed natural gas Replace air travel with high-speed rail Use natural gas in Cape Town for range of transport interventions Using alternative fuels and phasing out leaded fuel	Not estimated
Agriculture, forestry, land and rural development		
Land reform: ● Restitution; redistribution (30% of all land) and tenure reform.		Not estimated
Land use: ● Develop small farmers	Promote sustainable agriculture: Reduce soil erosion, promote minimum tillage systems	Not estimated
Forestry: ● privatise state commercial forests ● promote community forestry	Sustainable and community forestry	Not estimated

contd…

Development objectives	Possible shift to more sustainable development	GHG reduction or increase relative to business-as-usual (current stated policy)
Basic human needs and social services		
Water: access to clean drinking water. Short-term 20-30 ltr per person per day, medium to long-term 50-60 ltr. Current policy is to supply 25 ltr free of charge.		Not estimated
Sanitation: aim to provide adequate sanitation. Make up backlog in rural areas. Current subsidy of R600 per household is available to build Ventilated Improved Pit-latrines (VIPs).		Not estimated
Nutrition: provide adequate food for children under five.		Not estimated
Social services: spend on education, health (primary health care, HIV/AIDS) and social welfare.	Basic income grant – R100 / household / month	Not estimated
Growth and employment		
Job creation: 400 000 jobs per year	Investment in labour-intensive sectors, rather than capital-intensive sectors	Not estimated
Growth of GDP: 6%		Not estimated
Industrial development and trade		
Investment and industrial strategy	Energy-intensive spatial development initiatives replaced by less energy-intensive sectors, e.g. tourism	Relative decrease in GHG emissions

1 USD = 6 Rand (R); 1 • = 8 Rand (R) for this study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Part II

Future Projections

CHAPTER – 3

Status and Plans for the Electricity Sector with Special Reference to Regional Hydroelectricity

Making energy supply and use more sustainable is a central challenge in South Africa's development path. Energy is a critical factor in economic and social development, while the energy system has impacts on the environment. Managing energy-related environmental impacts is a major goal of energy policy (DME, 1998), in addition to making energy development more sustainable at a national level.

The generating technology in South Africa is based largely on coal-fired power generators. To avoid transport costs, all the large coal power stations are concentrated around the coalfields in Mpumalanga, Gauteng and the Northern Province (see Figure 3). Most of the power generation in South Africa is derived from the national power utility, Eskom. The utility generated 95.9% of electricity sent out in 2002, with municipalities and private auto-generators[2] contributing 0.6% and 3.5% respectively. The total quantity of electricity generated in 2002 was 203.6 TWh (NER, 2002a).

By 2003 there were 51 power stations in the country, of which 23 were coal-fired, accounting for 87.8% of the total licensed capacity of 43,048 MW (excluding capacity in reserve and under construction). Three older

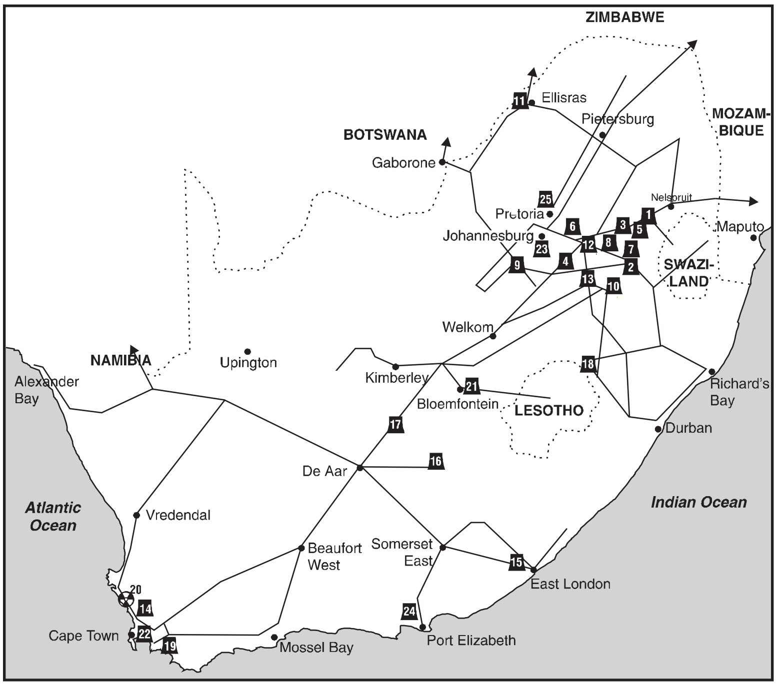
ESKOM-OWNED
Coal-fired
1 Arnot
2 Camden*
3 Duvha
4 Grootvlei*
5 Hendrina
6 Kendal
7 Komati*
8 Kriel
9 Lethabo
10 Majuba
11 Matimba
12 Matla
13 Tutuka

Gas turbine
14 Acacia[0]
15 Port Rex[0]

Hydroelectric
16 Gariep[0]
17 Vanderkloof[0]

Pumped storage
18 Drakensberg[0]
19 Palmiet[0]

Nuclear
20 Koeberg



MUNICIPAL-OWNED
21 Bloemfontein
22 Cape Town
23 Johannesburg
24 Port Elizabeth
25 Pretoria

* In reserve storage
[0] Used for peaking and emergency

Figure 3: Map of SA power stations by fuel and ownership
Source: (Spalding-Fecher et al., 2000)

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[2] Autogenerators are industries that generate electricity for their own use, including SASOL, sugar companies and the pulp and paper industry.

coal stations were in reserve because of excess capacity constituted 3,541 MW. Net maximum power produced was lower than licensed capacity at 38,004 MW. The only non-coal stations of significance are the Koeberg nuclear station (4.6% of operational capacity) and three pumped storage facilities (collectively 4.0%) (NER, 2003). These stations are the only ones that are not located in the north-east of the country and assist with grid stability in the Western Cape.

Table 3 shows the share of electricity sent out by fuel type (note that percentages of capacity and electricity generation can differ, depending on load factors).

Figure 4 shows the flow of electricity from production, through distribution and to end use customers. In addition to domestic resources, imports (primarily hydroelectricity) are shown.

3.1 Access to Affordable and Cleaner Energy

Perhaps the most important energy policy objective for South Africa is to provide increasing access to affordable energy services (DME, 1998). The goal of 100% access to electricity is often re-stated (Mlambo-Ngcuka 2003, 2005, 2004). Increasingly there is recognition that connections alone are not enough, and that the affordability of using electricity is critical. It was therefore decided by the government to provide a subsidy of 50 kWh per household per month of free electricity.

The challenge of increasing access is accompanied by the challenge of providing cleaner energy supply, imperative from both sustainable development paradigm and international obligations like the United Nations

Table 3: Net electricity sent out (MWh) by fuel in 2003

	Eskom	Municipal	Private	Total	Share of total energy sent out
Coal	194 046 490	1 038 433	7 379 448	202 464 371	94.1%
Nuclear	12 662 591	-	-	12 662 591	5.9%
Pumped storage	-938 433	-75 170	-	-1 013 603	-0.5%
Hydro	777 041	10 632	14 663	802 336	0.4%
Bagasse	-	-	259 317	259 317	0.1%
Gas	341	3 654	-	3 995	0.002%
Total	206 548 030	977 549	7 653 428	215 179 007	

* Negative values: Pumped storage uses more electricity in pumping water up than it generates, and hence is a net consumer.
Source: (NER 2001, 2003)

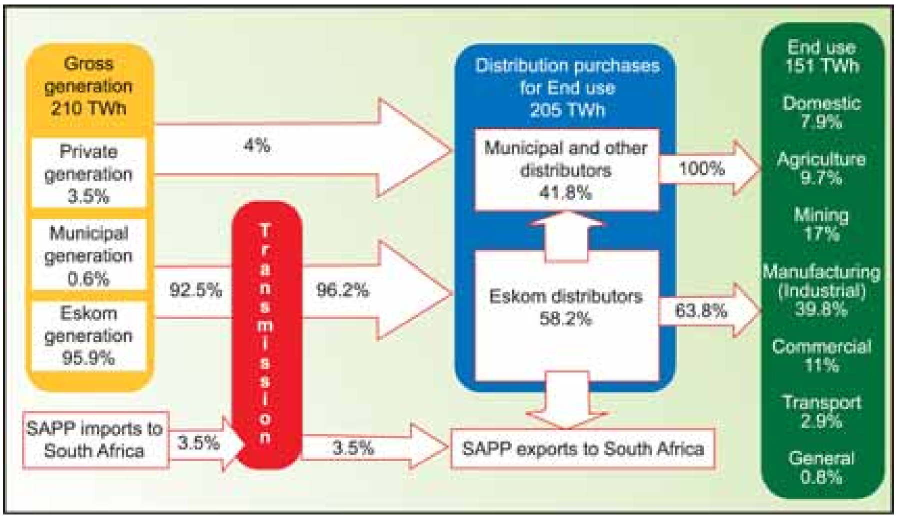

Figure 4: Energy flow through the electricity supply industry in South Africa[3]
Source: (NER 2003)

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[3] The original diagram gives no percentages for imports and exports. For 2000, however, 5,294 GWh were imported from SAPP utilities and 3,967 GWh exported. As a percentage of gross energy sent out of 198,206 GWh, imports constituted 2.6% and exports 2.0%. It is not exactly clear how this would change the percentages above, but the impact of 1,327 GWh difference between imports and exports is unlikely to result in changes in front of the decimal point.

Climate Change Convention (UNFCCC). A major contribution of 'cleaner energy supply' would need to come from a different fuel mix for electricity generation, which is not only dominated by coal at present, but continues to provide most capacity in most future scenarios. South Africa has adopted targets for renewable energy and energy efficiency. Renewables are aimed to deliver the equivalent of 10,000 GWh by 2013, from electricity, biofuels, and solar water heaters. Some studies suggest that significant effort is needed to turn this aspirational target into reality (Alfstad, 2004). The energy efficiency strategy seeks to reduce consumption from projected levels by 12% by 2014, using a range of measures.

To meet increasing demand, new capacity will soon be needed. An important goal of government policy for electricity supply is that of the 1998 White Paper on Energy Policy, namely to "ensure security of supply through diversity" (DME, 1998). The strong commitment to ensuring security of supply and to do so by pursuing all energy sources has been restated by the then Energy Minister in her budget vote speech (Mlambo-Ngcuka, 2004).[4] Government will examine all available energy technologies, and plan for future capacity needs based on planning to select the least-cost option. In his 2004 State of the Nation speech, the President acknowledged the need for new capacity by announcing that a tender would be awarded in the first half of 2005, to deliver "new generating capacity to provide for the growing energy needs from 2008", (Mbeki, 2004).

At some levels, plans for South Africa's energy future have been discussed with stakeholders and put into the public domain. The Department of Minerals and Energy published the first integrated energy plan (IEP) in 2003 (DME, 2003b), based on modeling done at the then Energy Research Institute. The aim for the second IEP (due at the end of 2006) is to have it produced by DME officials. Details of Eskom's Integrated Strategic Electricity Plans are not published. Only more aggregate level plans are published for the use by the National Electricity Regulator of Eskom's modeling and plans for the national integrated resource plan (NIRP) (NER, 2004a).

South Africa has in the past had excess electricity capacity, but this is rapidly running out. A process of tendering for new power stations kicked off in 2005. In addition, three re-commissioning "mothballed" coal-fired power stations were brought back into service. By 2020, it is expected that some 17 GW of new capacity will be needed (against a nominal total of 40 GW). The choice of fuel and technology—PBMR nuclear, gas, imported hydro, FBC, renewables—will be critical for South Africa's energy future.

Major options for both the IEP and the NIRP for the electricity sector include de-mothballing of coal-fired power stations, new pulverized fuel plants, fluidized bed combustion, open cycle gas turbines (for peak generation), and combined cycle gas turbines. Other options considered in some plans include nuclear power from the Pebble-Bed Modular Reaction (PBMR) and various renewable energy technologies, notably wind, solar thermal electricity, biomass and landfill gas. More details on options is included under the policy options described in section 5. Imported hydroelectricity, an option particularly relevant to the present case studies, is often mooted—but the largest source depends on political stability in the Democratic Republic of the Congo (DRC).

3.2 Southern African Power Pool

At the regional level, a major new opportunity lies in hydroelectricity in the DRC. The potential at Inga Falls is equivalent to the current size of the South African grid at approximately 40 GW (see section 5.4). The proposed Mepanda Uncua site in Mozambique also has the potential to add a further 1300 MW to the SAPP (NER, 2004a).

Proposals for NEPAD include interconnectors within the region (Eskom, 2002), building on the

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[4] She said that 'the state has to put security of supply above all and above competition especially' (Mlambo-Ngcuka, 2004).

Southern African Power Pool (SAPP). The summary of NEPAD action plans on energy stated that "guaranteeing a sustainable supply of affordable energy is one of the best ways to address poverty, inequality, and environmental degradation everywhere on the planet" (NEPAD, 2002).

The Southern African power grid is becoming more interconnected. Major plans under NEPAD include interconnectors, as can be seen in Eskom plans shown in Figure 5. A central feature of this map from a South African perspective includes importing hydroelectricity from Inga Falls in the DR Congo (40 GW potential).

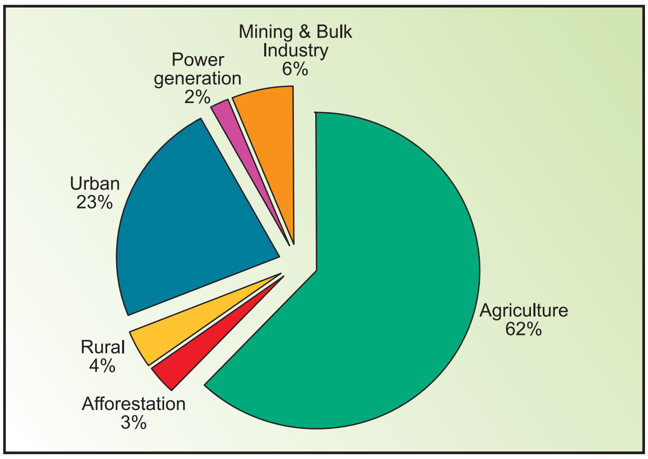


Figure 6: Water demand for 2000 per sector
Source: DWAF (2004b)

Linkages are not limited to the electricity sector. Gas networks are also expanding, with the pipeline from Mozambique's Pande and Temane fields already delivering gas from 2004. Initially, this is focused on providing SASOL's synfuel and chemical plants with a cleaner fuel (switch from coal to gas). Possibilities for bringing in Liquefied Natural Gas (LNG) and building gas-fired power stations are being talked about.

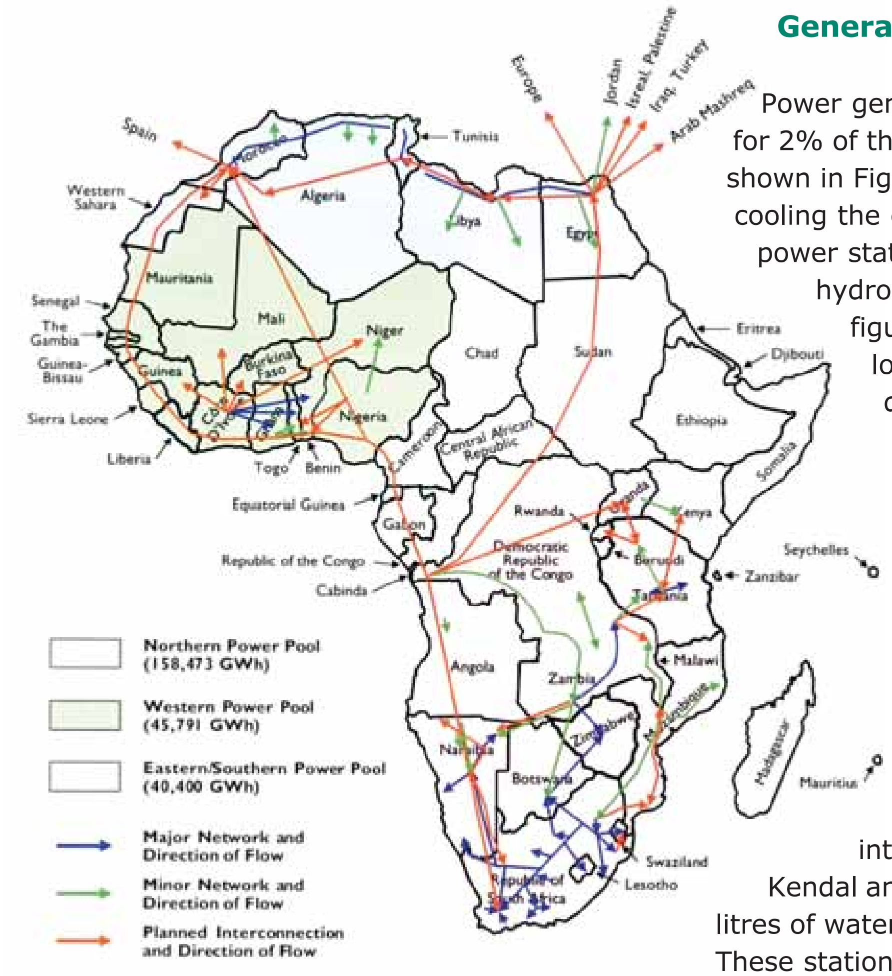


Figure 5: Africa grid map
Source: NER 2003, citing Eskom

3.3 Water Usage for Electricity Generation

Power generation in South Africa accounts for 2% of the annual demand for water, as shown in Figure 6. Fresh water is used for cooling the generators at most coal-fired power stations. Water used for hydroelectricity is not included in this figure, even though some water is lost due to evaporation in large dam installations.

However, fresh water is one of South Africa's most critical resources. Most of the coal stations dump their heat from the condensers in conventional cooling towers, which use between 1.8 and 2.0 litres of water for every kWh of electricity generated (ERC, 2004). Some stations have introduced dry-cooling, such as Kendal and Matimba, and use only 0.1 litres of water for every kWh (ERC, 2004). These stations are among the largest dry-cooled stations in the world. As can been seen from Table 4, the costs in lost efficiency

Table 4: Eskom's coal-fired power stations and wet/dry cooling

	Nominal capacity	First unit (Mwe)	Thermal commissioned	MJ / kg efficiency	Cooling for coal	Operating status
Arnot	2 100	1971	33.3	22.35	Wet	Partly operating
Camden	1 600	1966			Wet	Mothballed
Duhva	3 600	1980	34.5	21.25	Wet	Operating
Grootvlei	1 200	1969			Wet	Mothballed
Hendrina	2 000	1970	32.34	21.57	Wet	Operating
Kendal	4 116	1988	34.31	19.96	Dry	Operating
Komati	1 000	1961			Wet	Mothballed
Kriel	3 000	1976	35.02	20.04	Wet	Operating
Lethabo	3 708	1985	34.89	15.27	Wet	Operating
Matimba	3 990	1987	33.52	20.77	Dry	Operating
Majuba	4 100	1996			Wet/dry	Operating
Matla	3 600	1979	35.47	20.58	Wet	Operating
Tutuka	3 654	1985	35.32	21.09	Wet	Operating

Source: (National Electricity Regulator)

for dry cooling are small. Eskom reports the environmental implications of using one kWh as 1.29 litres for 2003, significantly lower than the average water usage in 1992 at 1.45 litres/kWh consumed (Eskom, 2003). Average thermal efficiency of Eskom power stations improved slightly from 1992 (34.2%) to 2000 (34.4%), with variations of 0.1% on an annual basis. However, in 2001, it declined to 34.1%, recovering to 34.2% by 2003 (Eskom, 2000, 2003). In 2001, the final units of the dry-cooled Majuba power station came on-line, slightly reducing thermal efficiency, but saving water.

3.4 Energy Institutions

Currently, matters pertaining to energy regulations are under the auspices of the National Energy Regulator (NER), formed in 2005 from separate electricity, gas and nuclear regulators that merged into a single energy regulation entity. In 2005 the Renewable Finance and Subsidy (REFSO) was established, creating another important milestone in energy governance in South Africa (see section 5.3). However, there is no clear agency for energy efficiency currently in place. A National Energy Research Institute is to be established, conducting and commissioning energy research for government. Eskom and municipal distributors are being combined into six Regional Electricity Distributors (REDs), starting with one around Cape Town.


TOYOTA

CHAPTER – 4

Current Development Trends for Electricity in South Africa

The previous section has briefly outlined the status and some plans in the South African electricity sector, and its links with regional hydroelectricity. In considering how the sector might develop in the future, an understanding of the drivers of change is a useful starting point. We consider drivers for electricity sector change in the South African context, relating these to the SRES scenarios. Based on this understanding, current development trends are described, and some indication given on how these are translated into quantitative modeling for the national integrated resource plan and the base case for this study.

4.1 Drivers of Future Energy Trends and SRES Scenarios

The IPCC's Special Report on Emission Scenarios (IPCC, 2000) took a long-term view on a multiplicity of possible futures. Surveys of the literature indicated a wide range of future conditions, ranging from variants of sustainable development to collapse of social, environmental and economic systems (IPCC, 2001a). It was found to be important to consider a range of possible futures for the values of the underlying socio-economic drivers.

For this study, however, the drivers are primarily at the national level. The purpose of this study is not so much to examine a range of different possible global futures, but to explore alternatives in a national (energy) system to the global problem of climate change. The specific assumptions made in the modeling for this study on key drivers are outlined in the following paragraphs.

4.1.1 Economic growth

Most government projections of economic growth assume a smooth growth rate into the future. Annual GDP growth was assumed to be 2.8% per year in the first Integrated Energy Plan (DME, 2003a), while the Integrated Resource Plan also considers forecasts of 1.5% and 4% (NER, 2001/2). A central GDP growth figure of 2.8% seems a reasonable approach.

These plans typically consider time-frames of 25 or 30 years. GDP is a key driver for projections of energy demand in many sectors, with population playing an important role in the residential sector.

4.1.2 Population and household growth

We assume that the past pattern of household/population growth will continue, but based on other studies, assume lower growth rates due to the impact of AIDS. While the topic is strongly debated, some highly respected studies show a substantial levelling off in population during the study period. Academically, studies by Prof Dorrington of the University of Cape Town, Commerce Faculty for the Actuarial Society of South Africa are well respected. (ASSA, 2002).

Other major institutions also project trends in population, some distinguishing between scenarios with more or less impact of AIDS. However, due to the HIV/AIDS in the country, population projection might be higher than actual. The Development Bank of Southern Africa (DBSA) uses population projection, differentiating on low and high impacts of HIV/AIDS (Calitz 2000a, 2000b).The first Integrated Energy Plan also included projections of population growth (ERI, 2001). Not all studies covered all years. Compared to the SRES families, population projections for this studies are lower, but closest to B2.

Population drives demand not only in the residential sector, but also influences other sectors. Demand for passenger transport services, for example, is also a function of population, while freight transport is related to GDP.

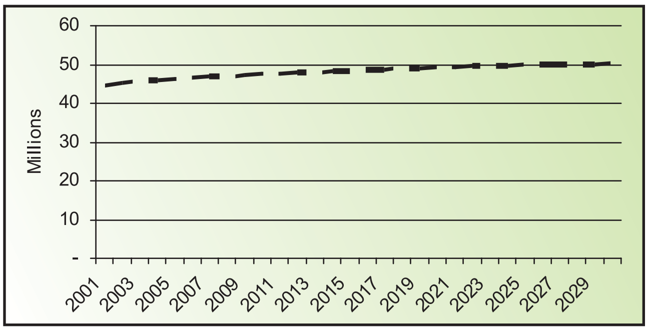


Figure 7: Population projections by ASSA model
Data source: (ASSA, 2002).

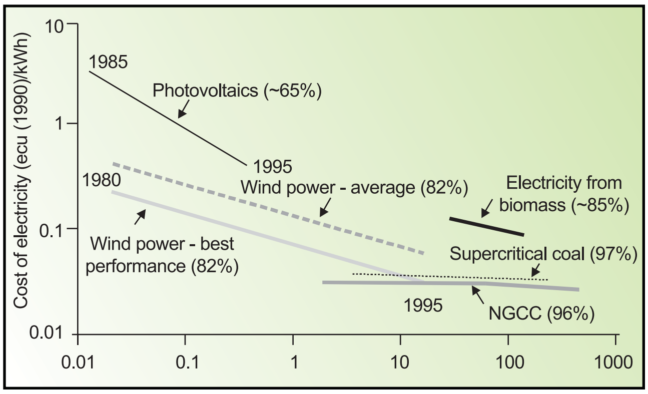


Figure 8: Learning curves for new and mature energy technologies
Source: (IEA & OECD, 2000).

4.1.3 Technology learning

We assume that technology costs for new energy technologies change over the period. This is particularly true for new technologies, which benefit from learning-by-doing and economies of scale. The first prototype is typically much more expensive than later models, which are produced in smarter, more cost-effective ways and often in larger production runs. Learning by experience reduces costs (Arrow, 1962), and this general finding has been found true for energy technologies as well (IEA & OECD, 2000).These can be assessed by learning ratios, measuring the reduction of cost per installed capacity for each doubling of cumulative capacity.

The IEA has published estimates of learning or ‘experience curves’, which show the decline in costs (c/kWh) as cumulative electricity production doubles. We assume that technology learning occurs for renewable energy technologies and the PBMR nuclear. For mature technologies, such as pulverized fuel coal, we assume that most of the learning has already taken place.

For renewables, we assume that learning is a function of global cumulative capacity. Data is taken from IEA (2003) and is similar to Figure 8.

For the PBMR nuclear, learning is not a function of global capacity, but occurs domestically. A policy case is modeled which assumes that 25 stations of 165 MW capacity are built in South Africa, and examines the implications for economic, social and environmental parameters. The investment costs for the PBMR are assumed to show learning, but based on total production for domestic use and export. Over the period, over 32 modules are produced. It is assumed that cost reduction through learning will have been realized at this point. Specifically, costs are modeled to decline from R 18,707 per installed kW in 2010 to R 11,709 by 2021 (NER, 2004a). These cost assumptions are illustrated in Figure 9.

As with the renewables case learning is a function of global cumulative capacity, for the PBMR cost reductions are therefore essentially a function of local production.

4.1.4 Environment—air quality act

The new Air Quality Act (No. 39 of 2004) provides a regulatory framework that can address both local air pollutants and global pollutants such as GHGs (RSA, 2004). The Act includes mechanisms in domestic legislation that can be used to implement international obligations as well, by listing priority pollutants and activities, as well as requiring pollution prevention plans to be submitted and controlling the use of certain fuels.

Under section 29 (1), the minister or MEC has the discretionary power to declare any substance contributing to air pollution as a priority air pollutant. GHGs could be declared priority air pollutants. The pollutants could be further specified, e.g., CO_2 from fossil fuel combustion. This is likely to be applied to emitters above a certain volume, i.e., to include coal-fired power stations, synfuel plants and other large point sources, but most likely not individual households burning gas or coal. The Minister can then require persons to submit and implement a pollution prevention plan—and the plan may have to include requirements specified by the minister. We assume that environmental quality improves over the period.

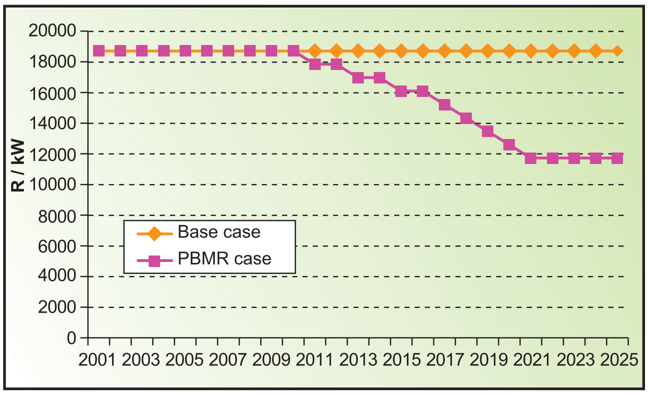
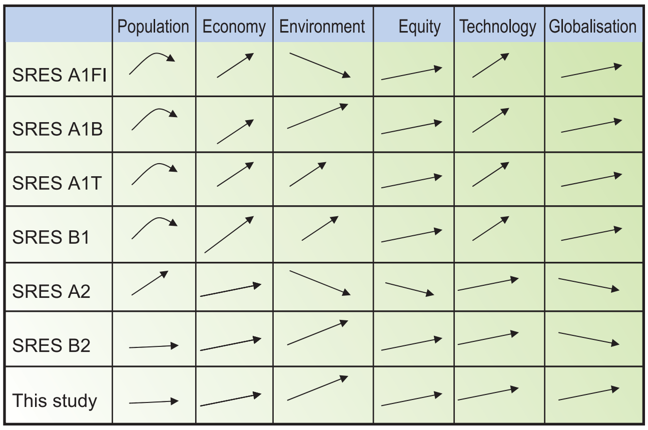


Figure 9: Schematic description of assumed PBMR costs in reference and policy scenarios



	Population	Economy	Environment	Equity	Technology	Globalisation
SRES A1FI	↷	↗	↘	↗	↗	↗
SRES A1B	↷	↗	↗	↗	↗	↗
SRES A1T	↷	↗	↗	↗	↗	↗
SRES B1	↷	↗	↗	↗	↗	↗
SRES A2	↗	↗	↘	↘	↗	↘
SRES B2	→	↗	↗	↗	↗	↘
This study	→	↗	↗	↗	↗	↗

Figure 10: Qualitative directions of key drivers for this study and the SRES B2 family

Source: for SRES scenarios: (IPCC, 2000); see text for drivers in this study

4.1.5 Other important factors

Equity and poverty are hard to predict into the future. We choose a middle path between assuming that poverty is reduced dramatically, and a future world in which the share of poor households is unchanged. Since the analysis in this study focuses on the supply-side, detailed assumptions for the share of poor households in the residential sector are not so relevant. The indication in Figure 10 is that equity improves moderately.

Fuel prices for the study are taken from a variety of domestic and international sources, as shown in the Appendix in Table 1. Generally preference is given to national statistics and sources for most fuels, except projections for internationally traded commodities such as oil. The general discount rate used in the study is 10%.

4.1.6 Conclusion on drivers

In conclusion, the drivers for the base case in this study are similar to the SRES B2 family. The notable exception is the driver for globalization, which shows a moderate downward trend in SRES B2, but is assumed to be moderately positive for this study.

4.2 Current Development Trends

Historically, the energy sector has been driven mainly by energy security concerns, especially during the period of isolation. However, as the discussion of the report shows, the country has now moved to an era of fuel diversity but the extent of such diversity will depend on the resource endowment of the country and its immediate environs as imported fuels may have major vulnerabilities that countries tend to avoid.

The energy sector will change in response to several factors. A number of trends indicate that even without new implicit energy policy, the future energy sector will differ from the present situation. In particular:

- The import of gas and exploration for gas off South Africa's coast make the introduction of gas very likely. The minister of energy has plans to make it contribute 10% of total energy and to introduce modern gas network infrastructure by 2010. This is already happening for synfuels and chemicals, and given the good prospects of further development of combined-cycle gas turbine systems, it will become part of the power production system. Eskom has already mentioned their wish to do so. Costs and alternative uses of the gas are likely to limit the use of gas for electricity (see below).
- Increasing emphasis on the regulation for both demand-side and supply-side of the energy sector.
- Technology innovation will continue for several technologies including the nuclear pebble bed reactor, natural gas infrastructure, domestic energy appliances, etc.
- The overall economic growth will continue to be strong and largely driven by energy intensive activities, being a developing country aspiring to improve its economic situation.

There are some specific features that need elaboration which are discussed below.

4.3 The IRP Base Case

The NER's "base plan" represents the plan chosen to minimize costs, assuming moderate growth in electricity demand and moderate penetration of DSM (NER, 2002a). The base plan for 2001–2025 includes the following:

- The return to service of four mothballed coal-fired power stations or units within stations, mainly for peaking and mid-merit operation (total 3,556 MW). This would start from 2007, when demand forecasts are expected to exceed supply.
- Building two new pulverized coal plants starting from 2013 for base-load (14,080 MW).[5]
- Gas-fired plants, simple from 2011 and one combined cycle from 2014 (1,950 MW). However, there are alternative uses for gas—chemicals and liquid fuels at Sasol; heat; reducing agent for iron. CCGT has been explored for converting Cape Town's Athlone power station, but is relatively expensive (Kenny & Howells 2001).
- Pumped storage facilities from 2011 (3,674 MW).
- Demand side interventions (residential and industrial/commercial; load management and end-use energy efficiency; interruptible load) distributed over the period (equivalent to 4,807 MW).

Modifications of this option might introduce new coal technologies, including supercritical plants, fluidized bed combustion and integrated gasification combined cycle. However, these are more expensive than conventional PF plants (Kenny & Howells, 2001). Flue gas desulphurization is one option for directly

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[5] The second NIRP only shown two coal-fired stations, built between 2007 and 2019, totalling 7,700 MW (NER, 2004a).

reducing pollution from coal-fired power plants, involving flue gases being scrubbed with lime. However, such systems are expensive and may affect tariffs in the future. Potential new technologies may result in the use of coal-bed methane in the Limpopo area which is yet to be tapped (Lloyd, 2003). Also, introduction of carbon capture and storage technologies may offer new opportunities which may link in particular with gasification technologies.

4.4 Model Description

In order to consistently account for the attributes of the energy system and the role that energy interventions play in that system, we use the MARKAL (short for market allocation) energy model.[6] MARKAL (an acronym for MARKet ALlocation) is a mathematical model of the energy system that provides a technology-rich basis for estimating energy dynamics over a multi-period horizon. The objective function of MARKAL is to minimize the cost of the system modeled.

The data entered into this modeling framework includes detailed sector-by-sector demand projections and supply-side options. Base case estimates of end-use energy service demands (e.g., car, commercial truck, and heavy truck road travel; residential lighting; steam heat requirements in the paper industry) are developed by the user on the basis of economic and demographic projections. In addition, the user provides estimates of the existing stock of energy related equipment, and the characteristics of available future technologies, as well as new sources of primary energy supply and their potentials (Loulou et al. 2004).

MARKAL computes energy balances at all levels of an energy system: primary resources, secondary fuels, final energy, and energy services. The model aims to supply energy services at minimum global cost by simultaneously making equipment investment and operating decisions and primary energy supply decisions. For example, in MARKAL, if there is an increase in residential lighting energy service (perhaps due to a decline in the cost of residential lighting), either existing generation equipment must be used more intensively or new equipment must be installed. The choice of generation equipment (type and fuel) incorporates analysis of both the characteristics of alternative generation technologies and the economics of primary energy supply. Supply-side technologies, e.g., power plants, require lead times. MARKAL is thus a vertically integrated model of the entire energy system.

MARKAL computes an intertemporal partial equilibrium on energy markets, which means that the quantities and prices of the various fuels and other commodities are in equilibrium, i.e. their prices and quantities in each time period are such that at those prices the suppliers produce exactly the quantities demanded by the consumers. Further, this equilibrium has the property that the total surplus is maximized over the whole horizon. Investments made at any given period are optimal over the horizon as a whole.

In Standard MARKAL several options are available to model specific characteristics of an energy system such as the internalization of certain external costs, endogenous technological learning, the fact that certain investments are by nature “lumpy”, and the representation of uncertainty in some model parameters. MARKAL is capable of including multiple regions, but in this study, South Africa is represented as a single region.

4.5 Electricity Supply in the Base Case for this Study

The expansion of electricity generation capacity is shown in Figure 11 grouped by plant type. The base case is broadly consistent with the integrated resource plan (see section 4.3), since the base case for the NIRP was conducted in collaboration with Eskom, the NER with the ERC’s modeling group (NER, 2004b).

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[6] See www.etsap.org for documentation, and (Loulou et al., 2004).

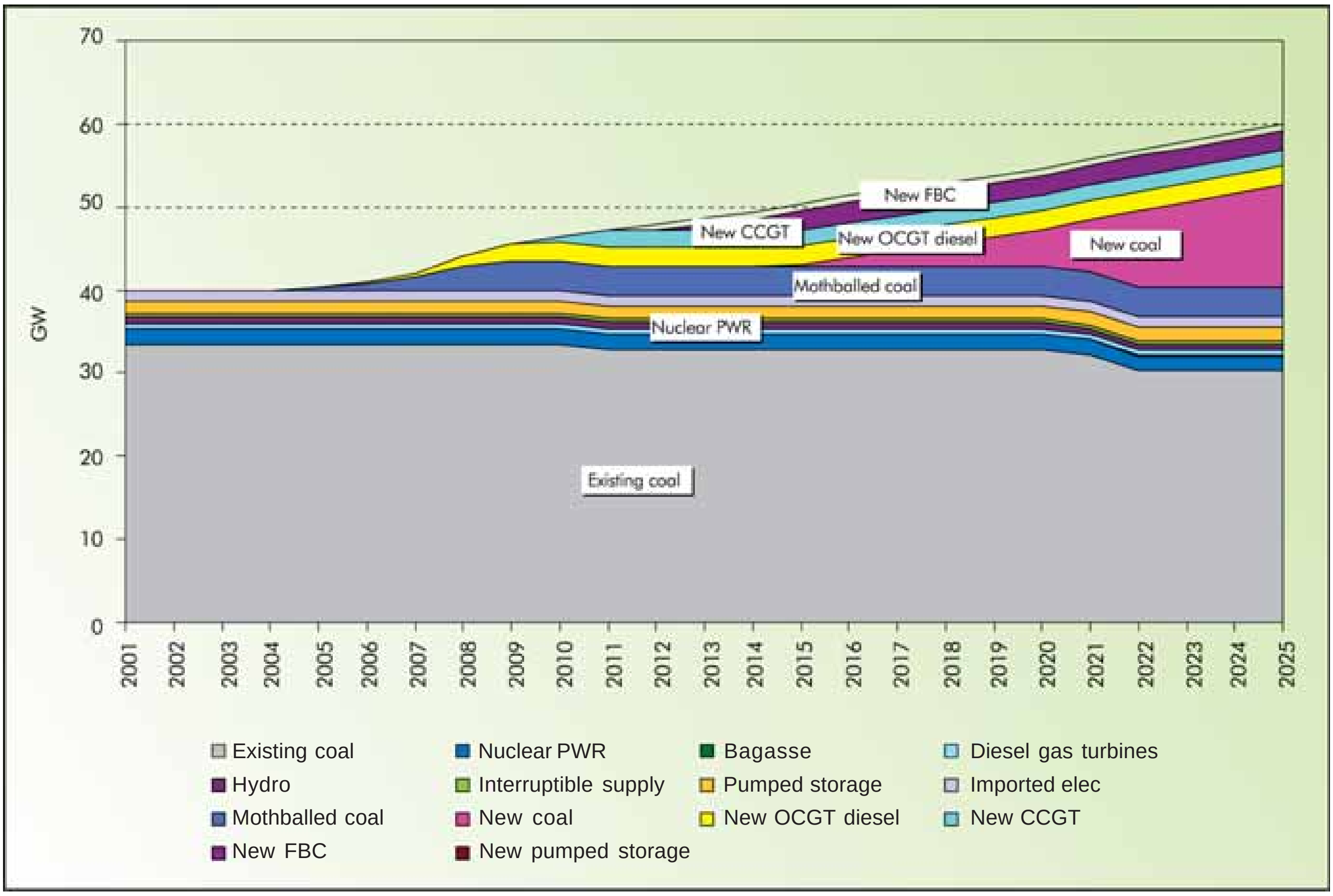

Figure 11: Electricity generation capacity by plant type in the basecase

Small differences between the base case presented here and the NIRP relate to the treatment of the reserve margin and the exact timing of new investment. The underlying projections are reported in Table 2 of the annexures.

The base case is dominated by coal, as can be seen in Figure 11. Coal continues to supply most of the capacity in the base case, even though some of the plants may come to the end of their life around 2025, unless new investments are made to refurbish them. Mothballed coal stations are brought back into service, and new pulverized fuel stations are built. New fluidized bed combustion, using discard coal, are also included in the base case. Hence existing and "cleaner coal" technologies are described in this section, rather than as separate policy options (section 5).

Major other sources of new capacity in the base case are gas (open cycle and combined cycle). Smaller contributions come from existing hydro and bagasse, electricity imports, existing and new pumped storage and interruptible supply (see Figure 11)

4.5.1 Conventional and "cleaner" coal technologies

Over 93% of the electricity now generated in South Africa in 2001 was generated by conventional coal power stations. All of these are pulverized fuel stations without flue gas desulphurization, although future coal power stations in South Africa are likely to have this. From 1980 on Eskom has only built power stations of capacity greater than 3000 MWe comprising of six units each. Because of their huge coal requirements, typically of about ten million tons a year, it is too costly to transport the coal over long distances and so the power stations have been built on the coal fields and the coal transported from the mines by conveyor belts. This means that all the large coal power stations are concentrated around the coalfields in Mpumalanga, Gauteng and the Northern Province.

South African coal has high ash (29.6%), low sulphur content (0.87%) and low calorific value (19.36 MJ/kg coal) as per the average values reported by Eskom (2005). South Africa has become a world leader at burning poor quality coal, some with heating value lower than 16 MJ/kg. The combination of cheap coal and big, standardized coal stations without desulphurization has allowed South Africa to produce comparatively cheap electricity. This is due to abundant coal reserves, government support to Eskom through forward financing and the absence of policies to internalize the external costs of coal use.

Coal is likely to remain a dominant energy source and least expensive option in the planning horizon. Pursuing clean coal technologies has thus become important. The restructuring of electricity generation is likely to result in some of Eskom's power stations being sold, as well as in allowing independent power producers to enter the generation market. The current price of electricity, however, is too low and is a deterrent in attracting new competitors to the market. Proper regulation is therefore important.

Regardless of coal's dominance, it is important to diversify energy resources to other energy forms such as natural gas and renewable energies. This will be in line with the policy objectives of improving both supply security and meeting climate concerns.

4.5.1.1 Conventional pulverized fuel coal-fired plant

Pulverized fuel (PF) coal is a mature technology and costs are unlikely to decrease very significantly over time or as more plants are constructed. Existing plants are located on or very near coal mines to minimize transport cost, mostly in the Mpumalanga province. PF plants require water for cooling or lose some efficiency with dry cooling (an efficiency loss of about 1 percentage point) (Winkler et al., 2005). New PF stations will include flue gas desulphurization (FGD) to comply with World Bank emissions standards.

The capital cost of the plant based on international average costs, is R 9,799/kW sent out (2003 prices). Investment costs range from 7,500–10,800 R/MW sent out with a relative deviation of 12.5%. The international average O&M cost of R 1,089 million/year for a 3,600 MW station has been adjusted to R 620 million/year for South African conditions—significantly lower than the international range of O&M costs from 900 to 2,090 million Rand per annum (NER, 2004b).

The average thermal efficiency quoted on the Higher Heating Value (HHV) was 35.5%. Efficiency ranges from 32.4–37.8%. The average thermal efficiency of Eskom power plants has been in a narrower range between 34.1–34.5% over the ten years from 1994 to 2003 (Eskom, 2003). New plants would be more efficient initially, but this efficiency is degraded by a factor of 4% over the assumed 30-year lifetime of the station, based on the paper for CCGT technologies done by the Commission for Electricity Generation Regulation in Ireland.

4.5.1.2 Fluidized bed coal-fired plant

The major option investigated here is the future use of fluidized bed combustion (FBC), a process in which coal is mixed with limestone and air is blown through it in a moving bed of particles. The IRP base case envisages 466 MW of FBC by 2013 (NER, 2001/2, 2004b).

FBC boilers are capable of burning coal which is otherwise discarded, making it cheap. The technology is maturing abroad and cost reductions are possible in future.

Flue gas desulphurization will take place during combustion by direct injection of the sorbent into the combustion chamber. Dolomite or limestone could be used. Dolomite is cheaper but a mine would have to be developed because not much is currently mined in South Africa.

A fuel cost of R 21/ton to discarding coal (including transport) is used, compared to approximately R 70/ton for coal for electricity generation. All of the fuel cost is considered to be fixed if the plant is run at maximum available load factor. The life of the plant is expected to be 30 years.

In the medium- to long-term, advanced coal technologies such as super-critical coal and integrated gasification combined cycle (IGCC) are possible The baseline scenario of the integrated resource plan does not include such stations (NER, 2001/2, 2004b), although some analysts indicate that IGCC plants are possible by 2025 (Howells, 2000).

CHAPTER – 5

Policy Cases: Electricity Supply Options

South Africa has had excess capacity, since the 1970s and 1980s up to the 1990s, but this situation will soon come to an end. Over the next two to three decades, some 17,000 MW will need to be built at approximately 1,000 MW per year. After 2025, many large stations will near the end of their life, and although options for refurbishment will then be considered, significant portions of existing capacity will need to be replaced. The broad options for electricity supply include all available energy resources and conversion technologies—coal, nuclear, imported gas and hydro, and renewable energy (see previous plans and studies e.g. (NER, 2004b; DME, 2003a; Winkler et al., 2005; ERC, 2004; SANEA, 2003)).

The major options include:

- ☐ Base-load coal stations, with flue-gas desulphurization (FGD);
- ☐ "Cleaner coal" technologies, in particular the Fluidized Bed Combustion (FBC) technology;
- ☐ Nuclear technology in form of the Pebble-Bed Modular Reactor;
- ☐ imported hydroelectricity from Mozambique, Zambia or the DRC; and
- ☐ imported gas, and
- ☐ renewable energy technologies (wind, solar thermal, biomass, domestic small hydro).

As can be seen in the NIRP, coal and "cleaner coal" are part of the base case, and are described in section 4.5.1. Policy options that go beyond current development trends are the focus of this section.

Key characteristics of the electricity supply options are summarized in Table 5. The data served as input to the modeling and is broadly consistent with the second NIRP. Presenting the data in a consolidated table allows comparison across the various options.

5.1 Gas-fired Power Stations

Combined Cycle Gas Turbine (CCGT) technology has been used commercially around the world. It has been investigated for deployment in South Africa, and several pre-feasibility studies have already been

Table 5: Characteristics of new power plants

	Units of capacity	Investment cost, undiscounted	Fixed O&M cost	Variable O&M cost	Lifetime	Lead Time	Efficiency	Availability factor
Type	**MW**	**R/kW**	**R/kW**	**c/kWh**	**Years**	**Yrs**	**%**	**%**
Coal								
New pulverized fuel plant	642	9,980	101	1.1	30	4	35%	252%
Fluidised bed combustion (with FGD)	233	9,321	186	2.9	30	4	37%	88%
Imported gas								
Combined cycle gas turbine	387	4,583	142	11.5	25	3	50%	85%
Open cycle gas turbine (diesel)	120	3,206	142	16.2	25	2	32%	85%
Imported hydro								
Imported hydro	9200 GWh/yr			2.1	40	6.5		
Renewable energy								
Parabolic trough	100	18,421	121	0	30	2	100%#	24%
Power Tower	100	19,838	356	0	30	2	100%	60%
Wind turbine	1	6,325	289	0	20	2	100%	25, 30, 35%
Small hydro	2	10,938	202	0	25	1	100%	30%
Land fill gas (medium)	3	4,287	156	24.2	25	2	n/a	89%
Biomass co-gen (bagasse)	8	6,064	154	9.5	20	2	34%	57%
Nuclear								
PBMR initial modules	165	18,707	317	2.5	40	4	41%	82%
PBMR multi-modules	171	11,709	317	2.5	40	4	41%	82%
Storage								
Pumped storage	333	6,064	154	9.5	40	7	storage	95%

(#) Note: Assume 100% efficiency for renewable energy technologies, with the availability factor reflecting issues relating to intermittency.
Source: NIRP(NER, 2004b)

undertaken. CCGT technology is commercially mature and therefore costs are unlikely to decrease very significantly over time or as more plants are constructed. Key characteristics are reported in Table 5.

Natural gas currently only accounts for 1.5% of the country's total primary energy supply (DME, 2002c). Total proven gas reserves of South Africa are about 2 tcf,[7] which could rise with further exploration (ERC, 2004). New fields are being explored off the South African West Coast (Ibhubesi), Namibia (Kudu) and Mozambique (Pande and Temane). All of these are relatively small, with larger fields further away in Angola (ERC, 2004). During 2004, gas from Mozambique started being delivered to Gauteng—but for use at SASOL and in industry, rather than in electricity generation. Import of liquefied natural gas (LNG) by tanker is an option being considered (NER, 2004b).

There are various options for plant location and gas supply. Plants could be located inland for pipeline gas imported from Mozambique. In 2004, a pipeline from the Mozambique fields has joined into the existing Sasol gas pipeline system which connects Gauteng, Durban and Secunda. Plants could also be located along the

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[7] Trillion cubic feet – tcf; million cubic feet –mcf.

coast, either using imported LNG or gas from underwater pipelines from South African off-shore fields. We consider the LNG option, since pipeline gas is initially being used for SASOL chemicals, and later synfuels.

Policy interventions to promote gas-fired power plants are mostly not in the electricity sector itself. Apart from the regulation of gas pipelines, gas prices are a critical factor determining viability. The next power station to be built will be an open cycle gas turbine (NER, 2004a). 'Gas turbines' in operation in South Africa use aeronautical diesel fuel to drive jet turbines, connected to power generators (NER, 2002a). The Integrated Resource Plan includes simple cycle of 2,400 MW–240 MW in 2008 and 2013, 480 MW each year from 2009 to 2012 (NER, 2004b).

A policy case for natural gas is investigated, building three CCGTs of 1,950 MW each, or a total of 5,850 MW by 2020. Gas is being imported by pipeline from Mozambique since 2004, but its preferred use has been for feedstock at SASOL's chemical and synfuel plants (Sasol, 2004). The alternative is shipping of Liquefied Natural Gas, potentially landed at Saldanha in the Western Cape, Coega in the Eastern Cape or Richards Bay in KwaZulu Natal. Gas turbines have relatively short start-up time and play an important role in meeting peak power. Construction of an LNG terminal would add two years to the lead time of a project, due to environmental impact assessments and harbour modifications. This makes the total lead time (even under a fast-track option where LNG terminal construction is done in parallel with building the plant) five years; otherwise it would be eight years (NER, 2004a: Appendix 3). 15 units of 390 MW each could be constructed with lead times of five years spreading them over the period. The policy case is implemented with a higher upper bound than the base case, which following the NIRP included a maximum of 1,950 MW of CCGT.

Coastal power stations may have the advantage of being able to use once-through cooling from sea water. A transmission benefit of 12 % is given to stations situated at the industrial load centres along the coast to account for the reduction in transmission losses compared with stations in the Highveld supplying these loads. An investment credit is also given to such stations that avoid the capital costs of strengthening the transmission infrastructure from the Highveld.

The construction of an LNG terminal, unless it is done in parallel with the construction of the plant, is assumed to add two years to the lead time due to environmental impact assessments and harbour modifications.

5.2 The Nuclear Option—PBMR

National government has repeatedly stated its intention to develop all energy sources, including nuclear (Mlambo-Ngcuka, 2002, 2003, 2004).The country currently has one nuclear light-water reactor at Koeberg (1840 MW_e), but Eskom is developing the Pebble-Bed Modular Reactor (PBMR), further developing an earlier German design (Loxton, 2004). The designers claim it is "inherently safe", using helium as the coolant and graphite as the moderator (PBMR Ltd, 2002). Helium flows can be controlled and the power station can be run to follow load. The station is to be produced in small units of 165 MW, overcoming redundancy constraints associated with large conventional nuclear stations. Due to its modular design, construction lead times are expected to be shorter. The fuel consists of pellets of uranium surrounded by multiple barriers and embedded in graphite balls ("pebbles"). Cabinet has endorsed a 5–10 year plan to develop the skills base for a revived nuclear industry (Mlambo-Ngcuka, 2004).The intention is to produce this technology not only for domestic use, but also for export—China is developing a similar, but more complex reactor (AEJ, 2005).

The PBMR was initially intended primarily for export, but there are now plans to use it domestically to satisfy future demands after using the gas and hydropower options. The assumed production of modules for domestic use and export, is shown in Figure 12.

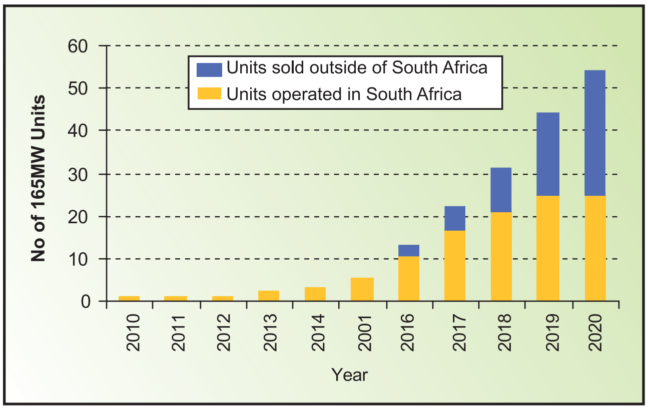

Figure 12: PBMR production for local use and export

In modeling the PBMR new nuclear technology, we assume that the waste management policy is completed and enforced. A major focus has been to develop the PBMR for the export market and prove the technology domestically. The nuclear power is an option that does not produce GHG emissions in its operation but raises major safety issues. The PBMR does not appear in the NIRP and therefore will not be included in the base case. The study does not consider other nuclear plants—new Pressurized Water Reactors or Advanced Light Water Reactors. The characteristics of the PBMR are reported in Table 5 , and particular attention is drawn to the fact that the study assumes learning for the PBMR (and for renewables, see section 4.1.3).

The environmental impact assessment (EIA) process for a demonstration PBMR at the site of the existing Koeberg nuclear power plant is on-going. An earlier authorization by the Department of Environmental Affairs and Tourism, subject to the DME finalizing policy for radioactive waste, was challenged in court by EarthlifeAfrica. In October 2005, the EIA process was recommenced from the start.

5.3 Renewable Energy

Renewable electricity sources are derived from natural flows of energy that are renewable—solar, wind, hydro, biomass, geothermal and ocean energy. A recent estimate of the long-term global technical potential of primary renewable energy by the IPCC was given as at least 2800 EJ/yr (IPCC 2001c: chapter 3). While this number exceeds the upper bound of estimates for total energy demand, the realizable potential is much lower, limited by the ability to capture dispersed energy, markets and costs. While wind and solar photovoltaic technologies have grown at rates of around 30% over five years, they start from a low base (10 GW and 0.5 GW respectively (UNDP et al., 2000); for comparison , South Africa's total capacity is roughly 40 GW).

The Minister of Minerals and Energy has recently re-stated that "renewable energy plays an important role in the energy mix and increases supply security through diversification" (Mlambo-Ngcuka, 2002b). In practice, renewable electricity technologies (RETs)[8] have remained in the research, develop and demonstration phase. In 2003, government adopted a target of 10,000 GWh renewable energy consumption (DME 2003b). Although this is not limited to electricity but also includes solar water heating and biofuels, the policy document explicitly calculates that this would be 4% of expected electricity demand in 2013.

South Africa's theoretical potential for renewable energy lies overwhelmingly with solar energy, equivalent to about 280,000 GW (Eberhard & Williams, 1988: 9). Technological and economic potentials would be lower than the theoretical potentials (Table 6). Other renewable energy sources—wind, bagasse, wood, hydro, and agricultural and wood waste—are much smaller than solar. The key challenge is to realize the potential—to implement the new policy at scale, beyond pilot projects. Below are some existing initiatives and future possibilities for renewable energy systems in the country.

Renewable resources like wind and solar are intermittent in nature. Intermittency means that these technologies cannot be dispatched on demand (IEA, 2003). Technical solutions and business and regulatory practices can reduce intermittency, e.g., by through variable-speed turbines or complementing wind with an energy

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[8] Renewable electricity technologies is used as short-hand for technologies using renewable energy sources. However, it is not the electricity that is renewable, but the energy source.

technology capable of storage, e.g., fossil fuels, pumped storage or compressed air storage. Storage, however, imposes a cost penalty. Since utilities must supply power in close balance to demand and the amount of capacity of highly intermittent resources that can be incorporated into the energy mix is therefore limited. The level of intermittent renewables that can be absorbed requires further study. In Denmark, Spain and Germany, penetration levels of over 15% (and up to 50% for a few minutes) have in some instances caused grid control and power quality problems, but not in other cases (IEA, 2003). With South Africa's penetration of renewables for electricity generation being very low [about 1%, from hydro and bagasse (NER, 2003)], the grid will absorb most fluctuations. South Africa's renewable energy target of 10,000 GWh per year is 4% of the estimated generation in 2013, but would require 3,805 MW assuming a 30% availability factor.

Other renewable energy technologies, like biomass and small hydro, is dependent on seasons. Annual load factors are highly dependent on site but are usually significantly lower than for fossil fuel technologies. They are generally higher for solar thermal and biomass installations than for wind at South African sites, e.g. the solar power tower technology with molten salt storage has an availability factor of 60% (NER, 2004a).

The key characteristics of the renewable energy technologies for electricity generation are summarized in Table 6 . The data served as input to the modeling and is broadly consistent with the second NIRP.

A number of technologies could contribute to the goal, including solar thermal electricity (both the parabolic trough and "power tower" options), wind turbines (at three availability factors, 25, 30 and 35%), small hydro facilities (Eskom and other), biomass co-generation (existing and new) and landfill gas (four sizes). The share of renewable electricity is set at 3.5% (10 TWh out of 283 TWh projected for 2013), to align the model outputs for the renewable policy case with government projections up to 2013.

Table 6: Theoretical potential of renewable energy sources in South Africa, various studies

	DANCED/ DME	**Howells**	**RE White Paper**
Resource	**PJ/year**		
Wind	6	50	21
Bagasse	47	49	18
Wood	44	220	
Hydro	40	20	36
Solar		8500000	
Agricultural waste		20	
Wood waste			9

Sources: (DME, 2000; Howells, 1999; DME, 2002a)

The Energy Minister's 2003 budget speech indicated that renewable energy policy would be subsidized (Mlambo-Ngcuka, 2003). The Renewable Energy Finance and Subsidy Office (REFSO.)[9] established in late 2005 was given the mandate for management of renewable energy subsidies and provision of advice to developers and other stakeholders on renewable energy finance and subsidies, (including size of awards, eligibility, procedural requirements, etc.). A once-off capital grant has been made available for project developers in 2005/06–2007/08 financial years. The subsidies for 2005/6 are R 250/kW capacity for electricity; R 273/kl capacity/year for biodiesel and R 167/kl capacity/year for bio-ethanol or equivalents for other RE technologies. The subsidy can not exceed 20% of the total capital cost, and minimum project size is 1 MW (for electricity), implying a subsidy amount of R 250,000.

To implement the policy case with various RE technologies in MARKAL, a user constraint sets the sum of activities of all RETs equal to 36 PJ in 2013, interpolated linearly from existing 8.5 PJ in the base year (hydro and bagasse) and extrapolated beyond the target year. Estimates of capacity developed for South Africa are shown in Table 7. In MARKAL, upper

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[9] http://www.dme.gov.za/dme/energy/refso.htm

Table 7: Technically feasible potential for renewable energy by technology up to 2013

RE Technology	Potential GWh Contribution	Percentage
Biomass pulp and paper	110	0.1%
Sugar bagasse	5,848	6.9
Landfill Gas	598	0.7%
Hydro	9,245	10.3%
Solar Water Heating: commercial	2,026	2.0%
Solar water heating: residential	4,914	6%
Wind	64,102	74%
TOTAL	86,843	100%

Source: DME (2004)

bounds are placed on LFG and wind). Solar thermal electric technologies are not limited so much by the available resource, but more by cost.

Note that Table 7 includes the solar resource (the largest theoretical potential, only for water heating, not for electricity generation). In the present study, we include solar thermal technologies for electricity generation to draw on the largest energy flow.

The characteristics of the renewable options are summarized earlier for comparison in Table 6. The data served as input to the modeling and is broadly consistent with the second NIRP. For many renewables, O&M costs are only fixed ones, with no fuel costs. Efficiencies are typically assumed to be 100%, but availability factors are important in reflecting the intermittency of some resources. Note that the molten salt storage for the solar power tower increases its availability relative to the parabolic trough (without any storage).

The initial capital costs of RE technologies are relatively high, but the costs of new electricity technologies can be expected to decline as cumulative production increases (IEA & OECD, 2000). Progress ratios are the changes in costs after doubling of cumulative capacity, as per cent of initial cost. In addition to the IEA's overall work, specific progress ratios for wind around 87% (Junginger et al., 2004; Laitner, 2002), and solar thermal electric (89% for power towers and 83% for parabolic troughs), have been published (Laitner, 2002; World Bank, 1999; NREL, 1999). Information on global operation capacity and growth rates is available in the World Energy Assessment (UNDP et al., 2000).

Table 8: Declining investment costs for wind and solar thermal electricity technologies

R/kW	Wind	Parabolic trough	Power tower
2003	7,811	22,750	24,500
2010	6,639	19,250	18,375
2020	5,702	12,250	9,625

Source: (NER, 2004a)

The approach taken here is to use the estimates from the NIRP for the decline of wind and solar thermal costs.

These costs are used to reduce investment costs, and extrapolated to the end of the period.

5.3.1 Local hydropower

The environmental impacts of large dams, including the flooding of sensitive areas, displacement of people, possible seismic effects—have been outlined by the World Commission on Dams (WCD, 2000). South Africa has an average rainfall of 500 mm, which is low by world standards. This, combined with the seasonal flow of the country's rivers and frequent droughts or floods, limits opportunities for hydropower.

The largest of South Africa's hydroelectric facilities are Gariep (360 MW), Vanderkloof (240 MW)—both on the Orange River—and Collywobbles (42 MW) on the Mbashe River. None of these are very large by international comparison, and others are 11 MW or smaller. Few sites exist for the development of large hydro facilities domestically; the potential lies in the Southern African region. Nonetheless, the country has a unique biodiversity endowment and ecological sensitivity that necessitates stringent environmental measures even in the case of small hydro projects (ERC, 2004). The ecological reserve prescribed by the new Water Act (RSA, 1998) requires the sufficient water be left to maintain river ecosystems.

Table 9 reflects an overall assessment of all types of hydropower in South Africa, taking into consideration both conventional and unconventional approaches. Unconventional hydropower development can take place in both rural and urban areas of South Africa by means of tapping hydropower from irrigation canals, bulk water supply pipelines, deep mining undertakings, etc., till date, there is practically no account of significant unconventional hydropower development in South Africa with the exception of the mining industry, which is using hydropower for conversion into mechanical energy (Cabeere, 2002).

In 2003, South Africa had installed hydropower capacity of 667 MW, almost entirely Eskom-owned, apart from 4 MW of municipal and 3 MW of private capacity (NER, 2003). The hydro stations generated 802.7 GWh in the same year (NER, 2003), or about 0.4% of total gross electricity generation in South Africa. Note that this number is somewhat lower than in previous years, depending on the performance of the rest of the grid. In 2001, the contribution of hydroelectricity was about 1.2% of net electricity energy sent out (see Table 3 of the annexures).

Contrary to general belief that the potential for development for hydropower in South Africa is very low, there exists a significant potential for development of all categories of hydropower in the short- and medium-term in specific areas of the country. As can be seen from Table 9, the estimate of firm potential for hydropower development in South Africa, stands at 12,160 MW.

Table 9: Total capacity and potential for all hydropower types

Hydropower Category and Size	**Hydropower Type**	**Installed Capacity**	**Potential for Development**	
			Firmly Established	**Additional Long-Term**
(MW, Kw)		**(MW)**	**(MW)**	**(MW)**
Pico	Conventional	0,02	0,1	0,2
(up to 20 kW)	Unconventional	-	-	60,0
Micro	Conventional	0,1	0,4	0,5
(20 kW to 100 kW)	Unconventional	-	-	3,3
Mini	Conventional	8,1	5,5	3
(100 kW to 1 MW)	Unconventional	-	-	2
Small	Conventional	25,7	27	20
(1 MW to 10 MW)	Transfers	-	25	5
	Refurbishment	-	11	-
Subtotal for small/mini/micro and pico hydropower in South Africa		33,92	69	94
Conventional macro hydropower (> 10 MW)	Diversion fed	-	3 700	1 500
	Storage regulated head	653	1 271	250
	Run-of-river	-	120	150
Subtotal for renewable hydropower in SA		687	5 160	1 994
Macro (large) (> 10 MW)	Pumped storage	1 580	7 000	3 200
Total for macro and small hydropower in SA		2 267	12160	5 194
Macro (large) (> 10 MW)	Imported hydro	800	1 400	35 000 (+)
Grand total for all hydropower		**3 067**	**13 560**	**-**

Source: Bart (2002)

However, the major component of this new estimate is a potential for development of seven pumped storage sites investigated as firmly feasible by ESKOM. Pumped storage stations, however, are net users of electricity (mostly coal-based), pumping water into storage during low-demand and low-tariff periods, and generating electricity during peak demand and high-tariff times. Subtracting the potential for pumped storage, the Cabeere study still shows a "firmly established" potential of 6,560 MW for hydroelectricity (Bart, 2002)

The firm macro and micro hydropower potential of South Africa is an order of magnitude many times bigger than the presently installed hydropower capacity.

A renewable energy option with comparatively low costs (see Table 5 of the annexures) is importing hydroelectricity. Earlier, we have considered renewable energy sources within South Africa. Imported hydroelectricity is considered separately in the section below, not only because of cost differences, but because the resource is potentially vulnerable to the impacts of climate change.

5.4 Imported Hydroelectricity

One of the major options for diversifying the fuel mix for electricity is to meet growing demand by importing hydroelectricity from Southern Africa. South Africa already imports electricity from the Cahora Bassa dam in Mozambique. The scale of this is dwarfed by the potential at Inga Falls in the Democratic Republic of Congo (DRC), estimated to range between 40,000 MW for run-off-river to 100,000 MW for the entire Congo basin (Games, 2002; Mokgatle & Pabot, 2002). If the large potential in the DRC is to be tapped, the interconnections between the national grids within SAPP would need to be strengthened. A Western Corridor project plans to connect South Africa, Namibia, Botswana, Angola, and the DRC with transmission lines. Several of the initiatives under NEPAD are interconnectors (NEPAD, 2002).

5.4.1 Inga falls—DRC

The DRC currently has 1.7 GW of electricity generating capacity at the Inga hydroelectric facility. A 3.5 GW expansion (Inga 3) is planned and will be coupled with the rehabilitation of Inga 1 and 2 (Hayes, 2005; Poggiolini, 2005). The proposed Grand Inga would have a capacity of 39 GW (EIA, 2002). Even the run-of-river capacity would equal SA's current total generation capacity.[10] Political stability in the DRC is an important—but highly uncertain—prerequisite for using this option.

Technical problems would be sufficient transmission capacity and line losses over long distances, but these could be overcome (Kenny & Howells, 2001). If the large potential in the DRC is to be tapped, the interconnections between the national grids within the Southern African Power Pool (SAPP) would need to be strengthened (Mlambo-Ngcuka, 2003).

In terms of the institutional capacity required, the Southern African Power Pool (SAPP) has been established and facilitates the trading of electricity, including a short-term energy market. The prospect of increased interconnection and trade of electricity across borders requires regulation. A Regional Electricity Regulators' Association (RERA) was formally approved by SADC Energy Ministers in July 2002 (NER, 2002b), which will *inter alia* have the tasks for establishing fair tariffs and contracts.

Inga Falls is not the only potential site in Southern Africa. Plans for increasing hydroelectric imports from Mozambique to South Africa are another option.

5.4.2 Mepanda Uncua and Cahora Bassa—Mozambique

The Mepanda Uncua site in Mozambique has a potential for 1,300 MW and an annual mean generation of 11 TWh. It is located on the

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[10] While licensed capacity was 43,165 MW, the total operational was 39568 MW (NER, 2001b), the difference mainly being accounted for by three moth-balled coal stations.

Zambezi River downstream of Cahora Bassa and could be connected to the SAPP grid through a total of four 400 kV AC lines to Cahora Bassa and Maputo. Installed capacity of 1,300 MWe at a plant factor of 64% provides 7,288 GWh/year of firm energy (NER, 2004a). The plant is assumed to come on line in 2011, with a lead time of 6.5 years. Upper bounds are placed on the increase of imported hydro up to the generation from Mepanda Uncua and to limit existing hydro imports.

A scenario in which imported hydro is increased above the quantity in the base case is included in the analysis. One of the major options for diversifying the fuel mix for electricity is to meet growing demand by importing hydroelectricity from Southern Africa. SA already imports electricity from the Cahora Bassa dam in Mozambique (5,294 GWh in 2000) (NER, 2000). We assume that imports from Cahora Bassa continue and grow due to Mepanda Uncua.

The average cost of existing electricity imports was 2.15c/kWh, well below the cost of South African generation in 2001 (NER, 2001). It is not certain that such low prices will continue into the future. The existing import costs are part of a long-term agreement with Mozambique for Cahora Bassa. The future fixed operation costs are assumed to be R 234 million per year, with no variable cost (NER, 2004a). Future prices could thus vary between R 6/GJ for existing up to R 99/GJ for Mepanda Uncua. At the cost of avoided generation from a coal-fired plant, at 22.11 c/kWh (NER, 2004a) or R 61.5/GJ, no hydroelectricity would be used by the model. The approach taken is to assume that the weighted average of electricity imports from existing sources and Mepanda Uncua add up to 59 PJ at R 47/GJ.

5.4.3 Potential impacts of climate change on regional temperature and run-off

The Climate Systems Analysis Group (CSAG), based at the University of Cape Town, has developed climate projection scenarios for the Southern African region. The climate change outputs from the models currently being used produce different simulations. Whilst there are still many uncertainties with regard to the magnitude, the direction of change appears to be consistent (Hewitson et al., 2005).

The greater part of the interior and western part of South Africa is arid or semi-arid. 65% of the country receives less than 500 mm per year and 21% of the country receives less than 200 mm per year (DWAF, 1994).

Since rainfall displays strong seasonality, the natural availability of water across the country is variable, with stream flow in South African rivers at a relatively low level for most of the year. This limits the proportion of stream flow that can be relied upon for use. Moreover, as a result of the excessive extraction of water by extensive forests and sugarcane plantations in the relatively wetter areas of the country, only 9% of the rainfall reaches the rivers, compared to a world average of 31% (DWAF, 1996).

Climate change manifests itself in two distinct ways viz. change in temperature and change in rainfall.

❑ Change in temperature

As can be seen from Figure 13:, observational records demonstrate that the continent of Africa has been warming through the 20th century at the rate of about 0.05°C per decade with slightly larger warming in the June-November seasons than in December-May

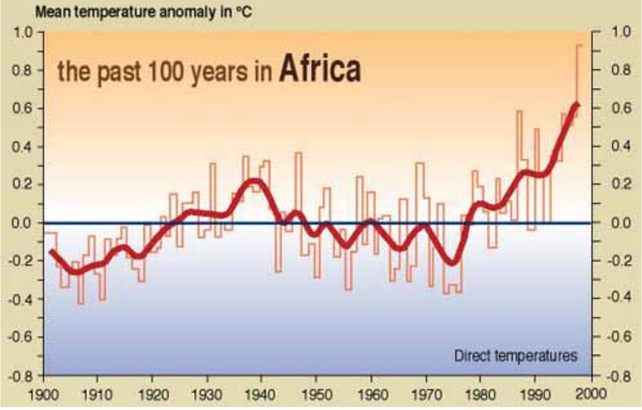

Figure 13: Variations of the earth's surface temperature for the past 100 years in Africa
Source: UNEP (2002)

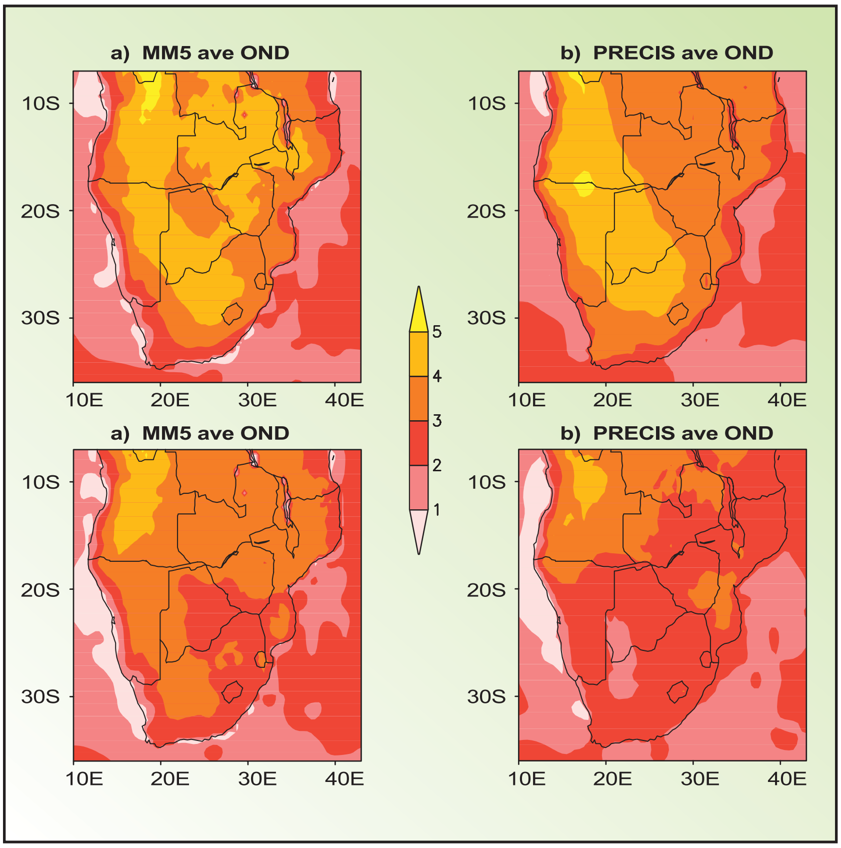

Figure 14: Simulated change in average surface temperature (°C) in 2070 during OND and JFM
Source: Tadross, Jack and Hewitson (2005)

[Hulme et al. (UNEP, 2002)]. By the year 2000, the 5 warmest years in Africa had all occurred since 1988, with 1988 and 1995 being the two warmest years.

The projections for temperature in southern Africa, as can seen by Figure 14, indicate an increase everywhere, with the greatest increase inland and the least in the coastal regions. Temperature is expected to increase by approximately 1°C along the coast and 3°–5°C inland of the coastal mountains by 2070. Along with temperature increases, changes in evaporation are anticipated.

❑ Change in rainfall

Figure 15 shows the current aridity zones in Southern Africa, ranging from arid to moist sub-humid for most of the region. Currently, the equatorial area of the subcontinent receives the most rainfall, whilst the south western area receives the least.

5.4.4 Regional electricity cooperation, hydropower and climate change

One of the major options for diversifying the fuel mix for electricity in South Africa is by importing hydroelectricity from Southern Africa. South Africa already imports electricity from the Cahora Bassa dam in Mozambique[11]. The scale of this is dwarfed by the potential at Inga Falls in the Democratic Republic of Congo (DRC), estimated to range between 40 GW for run-off-river to 100 GW for the entire Congo basin (Games, 2002; Mokgatle & Pabot, 2002).

The hydro potential from Inga Falls could however be, affected by climate change in future. The change in temperature and rainfall has the potential to affect hydroelectric installations in four major ways: evaporation, reduced run-off, flooding, and siltration. This impact potential was studied under this project.

❑ Evaporation

The greatest consumption of water resources from hydroelectric facilities comes from the evaporative loss of water from the surface of

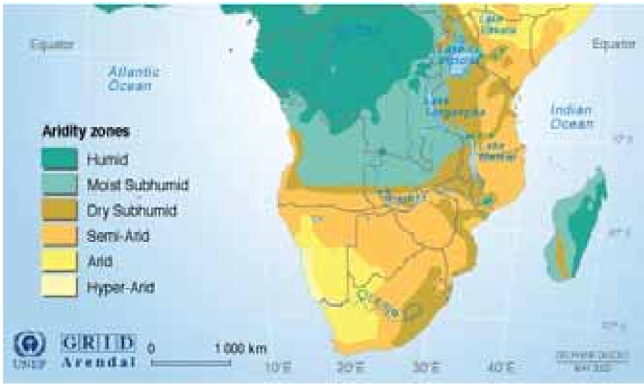

Figure 15: Aridity zones in Southern Africa
Source: UNEP (2002)

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[11] The average cost of existing electricity imports was USD cents 2.15 /kWh, well below the cost of South African generation in 2001 (NER 2001). It is not certain that such low prices will continue into the future.

reservoirs. This loss of water would otherwise have been available for downstream uses as well as for the generation of electricity. Evaporation losses per annum have been calculated to be on average 1.1 meters of depth per square kilometre of surface area. This could be much high depending on the climate of the region. For example this figure for the Aswan High Dam on the Nile river is 2.7 m, 11% of the reservoir capacity (Gleick, 1994).

A study conducted in California shows that hydroelectric facilities have average environmental losses of 5.4 Kl of water per 10 MWh electricity produced (Gleick, 1994). Deep dam with smaller surface areas would be less affected that those with large surface areas.

Increasing temperature generally results in an increase in the potential evaporation and given that temperature is expected to increase globally it can be expected that evaporation on large open waters would increase. For both the Congo and Zambezi catchments, the temperature is expected to increase.

Changes in other meteorological controls may exaggerate or offset the rise in temperature, such as wind speed and humidity. In humid regions atmospheric moisture content is a major limitation to evaporation, so changes in humidity have a very large effect on the rate of evaporation (IPCC, 2001b).

The catchment area for the Congo River is in a high humidity area and therefore the potential for increased evaporation would be low, whilst that of the Zambezi River is less humid and would have a higher potential for evaporation.

❑ Reduced run-off—drought

The direct impact of droughts is that the run-off is reduced and consequently the storage in dams is negatively affected. Because the duration of the droughts cannot be predicted with any certainty, it may be necessary to impose restrictions on the use of water. Where restrictions are necessary, water to meet basic needs will always receive priority in allocations, followed by strategic uses such as power generation and key industries. In general water for irrigation is restricted first (DWAF, 2004a).

Climate change models indicate minimum changes in the hydrology of the Congo basin, whereas other basins have significant vulnerability to climate change (IPCC, 2001b).

In recent years there have been some interruptions in some hydropower plants as a result of severe drought, e.g., Akasompo Dam in Ghana [Graham, 1995 in (IPCC, 2001b)]. Multiple droughts forced Ghana to reduce the generation of hyroelectricity in the early 1980s, which resulted in the rationing of electricity until 1986. This incident was repeated again in the early 1990s.

In Zimbabwe, Kariba contributes 50% of the electricity needs, but generation dropped by 8% due to drought in 1992 (Chenje & Johnson, 1996).

For both these catchments, the average annual rainfall is expected to increase.

❑ Flooding

Flooding does not usually cause too much damage for large dams, but the large loads of sediments carried by the rivers usually settle in the dams and lakes. For in-stream hydro plants, large logs and vegetation can cause damage or block up the system. In some cases the increased volume of water could allow for increased generation potential.

Given that there is predicted increase in annual rainfall and that this may be due to increased rainfall intensity and reduced rain days (Tadross et al., 2005), the occurrence of occasional flooding can be expected.

❑ Siltration

Siltration refers to the deposition of particles of the river load. Siltration is the consequence of erosion which is prevalent in some parts of southern Africa where rains and consequently rivers can be aggressive. Non-existent or sparse vegetation and the desiccation of soils during dry seasons can make the soils susceptible to the water’s action.

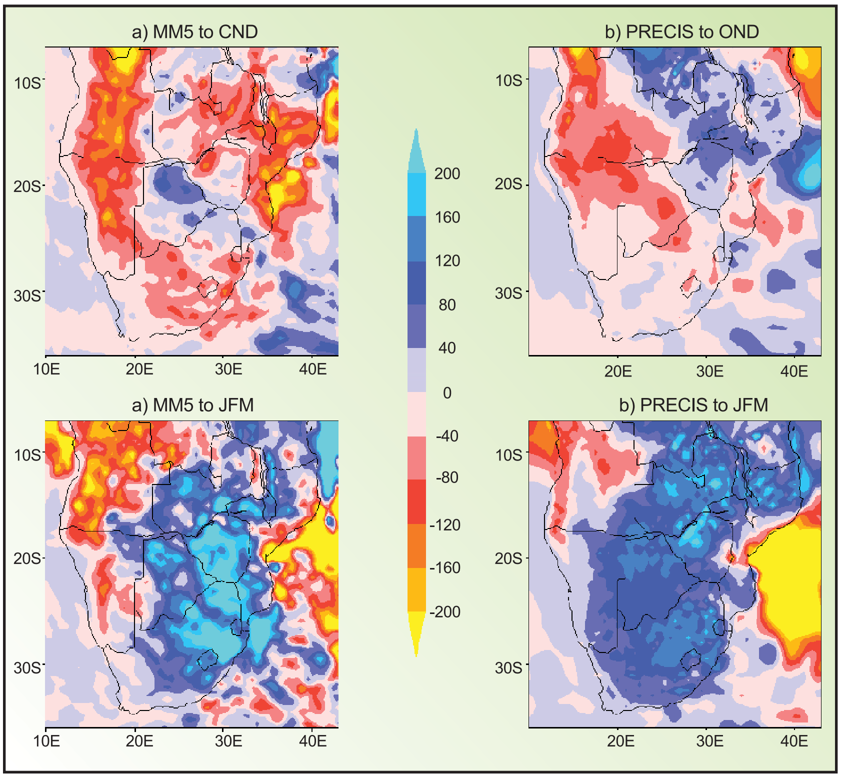

Figure 16: Simulated change for 2070 in seasonal rainfall (mm) during Oct-Dec (OND) and Jan-March (JFM)
Source: Tadross, Jack and Hewitson (2005)

Siltration is a major threat as it lessens the life span of dams and irrigation structures and can reduce the potential of dams to generate hydroelectricity. The construction of berms and swales upstream would help reduce siltration in areas where the erosion potential is high. This would most likely be relevant to the Zambezi River.

Increasing temperature generally results in an increase in the potential evaporation and, given that temperature is expected to increase in both the Congo and Zambezi catchments, it can be expected that evaporation on these large open waters would increase.

The run-off is reduced as a direct impact of droughts and consequently the storage in dams is negatively affected. Because the duration of the droughts cannot be predicted with any certainty, it may be necessary to impose restrictions on the use of water. Where restrictions are necessary, water to meet basic needs will always receive priority in allocations, followed by strategic uses such as power generation and key industries. Climate change models indicate minimum changes in the hydrology of the Congo basin, whereas other basins may have significant vulnerability to climate change (IPCC, 2001b). Using the results obtained from Tadross et al. (2005), it can be observed that both models predict drying over the tropical western side of the subcontinent, with MM5 showing that the drying extends further south for the months of OND. However, they do not correspond in the north-eastern part. For JFM, the models indicate drying to the west in the tropics, and increase in precipitation to the east and south-east. For both these catchments, the average annual rainfall is expected to increase in the long term (Figure 16), resulting in occurrence of occasional flooding.

The overall assessment of potential climate change impacts of large hydroelectric projects in Southern Africa is shown in Figure 17. Essentially, climate change is not likely to affect the run-off to these major facilities; however, increase in evaporation and siltration may be impacts to consider. In summary, climate change is projected to increase both the temperature as well as the annual rainfall in the Congo and Zambezi River catchments. Overall there may not be any appreciable

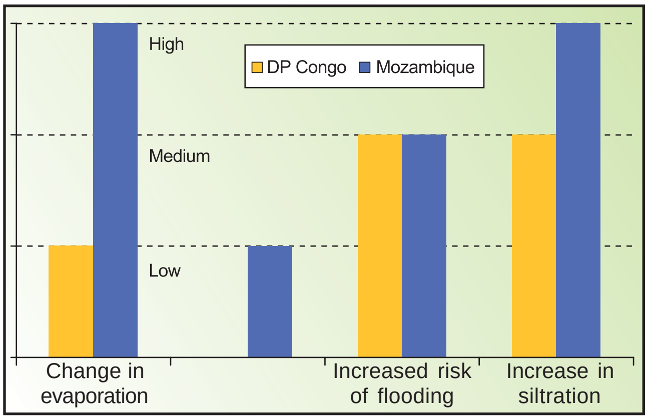

Figure 17: Potential impact of climate change on hydroelectric facilities in Southern Africa

Table 10: Energy, environmental and cost implications of enhanced regional hydroelectricity cooperation for the year 2030

Parameter	**Reference scenario**	**Enhanced regional hydro-electricity cooperation**
Capacity of coal-based generation in national power consumption	45.4 GW	44.4 GW
Decrease in national CO_2 emissions over reference scenario	-	19 Mt-CO_2/ year in 2030
Decrease in national SO_2 emissions over reference scenario	-	92 kt-SO_2/ year in 2030
Average cost of electricity (USD cents/ kWh)	2.64	2.57

Note: Only Mependa Uncua has been modeled here and not the entire Grand Inga. The benefits are therefore relatively lower.

adverse effect on hydro potential from Inga Falls due to climate change.

This analysis was used in the MARKAL model to enhance share of imported hydroelectricity for South Africa in future. This mainly replaces domestic coal based power, therefore reducing related CO_2 and other pollutant emissions. The average cost of electricity also gets reduced due to this regional hydroelectricity cooperation (Table 10).

Imports of hydroelectricity are only one of several options for South Africa. From the country study, it is apparent that regional hydro cooperation could bring substantial socio-economic benefits to South Africa and also to the Southern African region as a whole. These benefits, however, may not be realized due to concerns relating to energy security in a very basic sense—political stability in the DRC would be required, but is highly uncertain. That is—apart from the large regional investments required. Moreover the interconnections between the national grids within Southern African Power Pool (SAPP) would need to be strengthened. A Western Corridor project plans to connect South Africa, Namibia, Botswana, Angola, and the DRC with transmission lines. Several of the initiatives under NEPAD are interconnectors (NEPAD, 2002).

Part III

Comparative Results

CHAPTER – 6

Energy Indicators of Sustainable Development

The modeling results are assessed against a set of sustainable energy indicators. Indicators have been selected that can be quantified with the energy-economy-environment models. The indicators are grouped in the major dimensions of sustainable development.

6.1 Environment

The fuel mix of the energy system is a key indicator affecting environmental impacts of energy supply and use.

Table 11 shows how the mix of solid fuels, petroleum products, nuclear fuel and electricity change for three selected years in the policy case.

The dominant impression is that across all cases and years, the share of solid fuel (mostly coal) remains high. The share of renewables increases to 3.1% in the renewables case, compared to 1.5% in the base case. The PBMR case similarly shows some growth in nuclear fuel use in the middle of the period. A sustained move to greater diversity, however, will require more than a single policy.

GHG emissions in South Africa's energy sector focus mainly on carbon dioxide. Here alternative policy scenarios to enhance individual energy supply options are analyzed

Table 11: Fuel mix for policies and selected years

		Base case	Gas policy case	Hydro policy case	PBMR nuclear case	Renewables policy case
2005	Solids	78%	78%	78%	78%	76%
	Petroleum	17%	17%	17%	17%	17%
	Renewables	1.90%	1.90%	1.90%	1.90%	3.30%
	Nuclear	3.10%	3.10%	3.10%	3.10%	3.00%
2015	Solids	78%	77%	77%	77%	76%
	Petroleum	18%	19%	18%	18%	17%
	Renewables	1.70%	1.70%	1.70%	1.70%	3.50%
	Nuclear	2.50%	2.50%	2.50%	3.70%	2.40%
2025	Solids	78%	76%	78%	74%	77%
	Petroleum	18%	20%	18%	18%	18%
	Renewables	1.50%	1.50%	1.50%	1.50%	3.10%
	Nuclear	2.00%	2.10%	2.10%	6.20%	2.00%

over a reference scenario. The nuclear Pebble Bed Modular Reactor (PBMR) and renewables actually have the same reductions by 2015, but by 2020 and 2030, the PBMR has increased to a capacity where its reductions are higher. To compare across electricity cases, the installed capacity, load factor and associated costs need to be borne in mind. The PBMR has reached 4.48 GW by the end of the period, while renewable energy technologies amount to 4.11 GW and gas 5.81 GW. The investment required over the period in the PBMR is about USD 3.4 billion, compared to USD 3.1 billion in the renewable mix examined in the study. Notably, however, imported hydro reduces the total system costs, while the other three options increase it. The emission reductions are shown graphically in Figure 18.

To assess the effect of combining electricity options, a further scenario was set up to avoid double counting. The emission reductions of individual policy cases, when added up, may overlap. Therefore, the total effect of implementing all policies at the same time may be less than the sum of emission reductions in the policy cases added up. Combined, the emission reductions achieved by the electricity supply options analyzed here add up to 36 Mt by 2020 and 84 Mt CO_2 for 2030, 7% and 13% of the projected base case emissions for each respective year. Figure 18 shows that combining all the policies analyzed here would reduce emissions below their projected growth. All policy cases were included in a combined scenario, to avoid double-counting within the energy system.

However, these are reductions from business-as-usual. Even with all these reductions (and the associated investments), CO_2 emissions would continue to rise from 350 Mt in 2001 to 450 Mt CO_2 in 2025. Stabilizing emission levels would require some additional effort from 2020 onwards.

Table 12: CO_2 emission reductions for policy cases and reference scenario emissions (Mt CO_2)

Scenario	2000	2010	2020	2030
Base	350	438	543	645
Gas	0	0	-12	-12
Hydro-electricity	0	1	-13	-19
PBMR nuclear	0	0	-23	-32
Renewables	0	-6	-11	-18

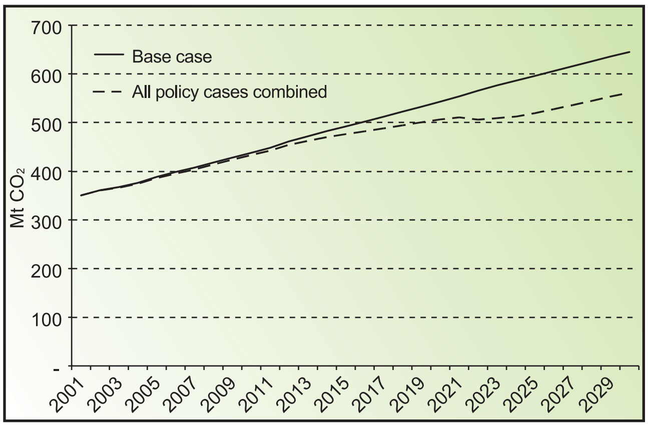

Figure 18: CO_2 emissions for base and with emissions reductions from all policy cases combined

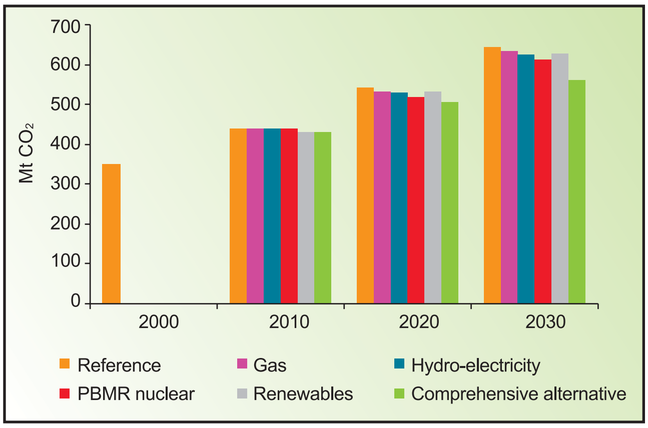

Figure 19: CO_2 emissions under individual policy scenarios

The policy scenarios reported here can avoid CO_2 emissions compared to the reference scenario (Table 12). Benefits in reducing local air pollutants, such as SO_2, are also reported for all cases. Substantial reductions in NO_x emissions can be seen in 2025 for all of the electricity supply options.

Emission factors for several local air pollutants were included in the database, and some interesting and significant results are reported here. Reductions in sulphur dioxide emissions contribute to less acidification of water bodies and impacts on plantations. Since both coal-fired power stations and forestry plantations are located in the north-east of the country, these are significant.

Table 13: SO_2 emissions in the base case, reductions in the policy cases in absolute and percentage terms

Units: kt SO_2	**2001**	**2005**	**2015**	**2025**	**Percentage reductions**			
Base	1491	1684	2226	2772	2001	2005	2015	2025
Gas	4	5	-45	-122	0%	0%	-2%	-4%
Hydro-electricity	-3	-3	-90	-92	0%	0%	-4%	-3%
PBMR nuclear	0	0	-48	-205	0%	0%	-2%	-7%
Renewables	13	-3	-32	-84	1%	0%	-1%	-3%

Table 13 shows SO_2 emissions almost doubling in the base case over 25 years. Given the low sulphur content of South African coal, and the fact that the average efficiency of coal-fired power stations have not been changing much for the past decade (except when dry-cooling was introduced), the impact of changes in the electricity sector in sulphur emissions is likely to be limited. Again, the combined effect of all electricity policy options differs from simple addition of individual options. The combined SO_2 emissions avoided over the 30 years are shown in Figure 20.

SO_2 emissions would still grow, but only to 3,038 kt SO_2. In absolute terms, this avoids 579 kt SO_2 in 2030, i.e. about 20% less than the growth under BAU.

For NO_x, base case emissions rise from roughly 1 million tons to over 2 million tons over 30 years. Substantial emission reductions can be seen in 2025 for all of the electricity supply options, due to switching away from coal to other energy technologies.

Under a comprehensive alternative policy scenario that combines all the above individual scenarios, the CO_2 emission reductions are 36 Mt in 2020 and 84 Mt in 2030, 7% and 13% of the projected reference scenario emissions for each respective year (Figure 20). The SO_2 emissions also reduce by 579 kt (-20% in 2030) (Figure 21). The percentage mitigation of SO_2 emissions is deeper than that of CO_2 emissions for each scenario when compared to the reference scenario, except for PMBR nuclear and renewable scenarios that have lower SO_2 mitigation[12]. This implies that energy sector policies for GHG mitigation will also have

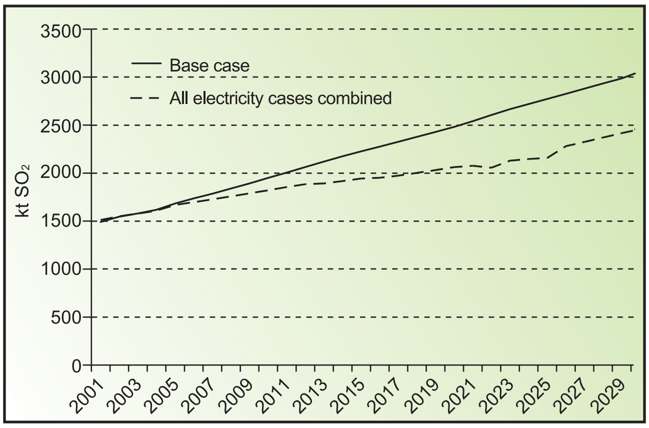

Figure 20: Avoided sulphur dioxide emission by policy case

Table 14: Base case emissions and reductions of oxides of nitrogen for policy cases

kt No_x	**2001**	**2005**	**2015**	**2025**
Base	1,109	1,257	1,645	2,035
Gas	2	2	-15	-39
Hydro-electricity	-1	-1	-43	-52
PBMR nuclear	0	0	-23	-98
Renewables	5	-3	-17	-42

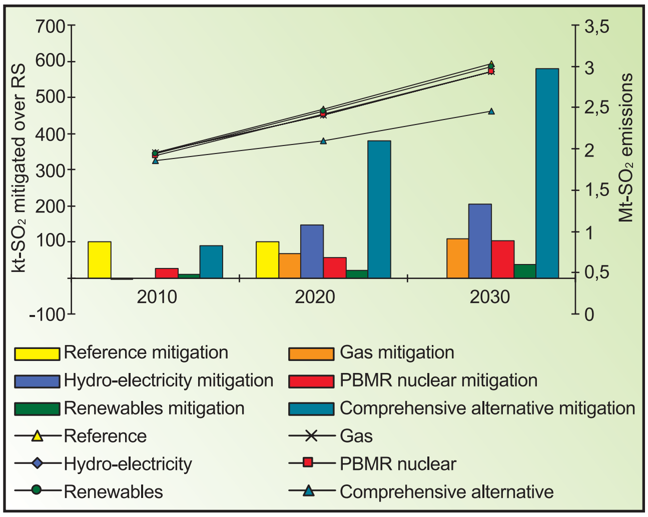

Figure 21: SO_2 emissions (Mt-SO_2) under individual policy scenarios, and corresponding mitigation (kt-SO_2) over the reference scenario (RS) emissions

Source: South Africa, 2006

large local pollution mitigation benefits in South Africa.

The increases in costs for the total energy system are small, although the costing boundary in that case is particularly large. Even with all these reductions (and the associated investments), CO_2 emissions would continue to rise from 350 Mt in 2001 to 450 Mt CO_2 in 2025. South African emissions consistent with a global 550 ppmv stabilization regime would require substantial additional and climate specific efforts from 2015 onwards.

In terms of damage to health most important are emission reductions and other social effects in the residential sector.

6.2 Social

The implications of electricity supply for social sustainability is a key indirect impact of power sector development through the electricity price. Decisions about energy supply and prices are made implicitly by governments, utilities and investors, with less discussion of their social consequences than the indirect effects might merit.

Electricity access and affordability are good social indicators, in spite of the major achievements, about 30 per cent of the population is yet to be electrified (20% urban and 50% rural), mostly the poor.

Energy security in terms of share of imported energy in TPES can also have major social implications since large import of fuels can imply price increases as a reflection of high international oil prices. The shares of energy import change over time with each of the policy scenarios. The overall variation in import shares is relatively small, with crude oil domination (Table 15).

Table 15: Imported energy as share of total primary energy supply

Scenario	2010	2020	2030
Reference	23.5%	24.6%	23.8%
Percentage point change			
Gas	0.0%	0.9%	2.2%
Hydro	0.0%	1.3%	0.8%
PBMR nuclear	0.0%	1.2%	4.3%
Renewables	-0.2%	-0.2%	0.2%

Unsurprisingly, the imports of gas or hydroelectricity imply an increase in import dependency. Perhaps less obvious is that the import of nuclear fuel raises the share of imported energy by 4.3% of TPES in 2025 for the PBMR case, assuming that nuclear fuel is imported. Domestic supply options, including renewable energy technologies, perform better in this regard.

6.3 Economic

Key economic parameters are the total energy system costs. System costs are useful in understanding the impact on the entire energy system, representing its interactions in a consistent framework. It draws a wide costing boundary, i.e., all costs are included from a power station through transmission and distribution system right down to end-use appliances and equipment. Some of these costs are not what may typically be thought of as "energy investment". Total energy system costs are discounted to present value (assuming the discount rate for the study of 10%), and take into account the changes in the energy system. These costs are not the same as the total investment required, which do not take into account savings or avoided investment in alternative policies or technologies.

Energy system costs over two-and-a-half decades add up to large numbers. Total energy system costs include the costs of everything from fuel extraction through transformation (power stations or refineries) to end-use appliances. Since the energy system is large, and the costing boundary is wide, individual policies which affect only one part of the energy system do not produce large changes in the bulk of the system or its structure. In this

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[12] Renewables emit SO_2 while are considered carbon-neutral, while nuclear scenario replaces more coal-based power plants with FDG technology.

Table 16: Total energy system costs for base and policy cases

	Discounted total system costs over the period	Difference to base case	
	R billion	R million	Percentage
Base case	5,902		
Gas	5,902	95	0.00%
Hydro	5,890	-11,525	-0.20%
PBMR nuclear	5,905	3,706	0.06%
Renewables	5,905	3,488	0.06%

Table 17: Investments in electricity supply options and installed capacity by 2025

	Total investment cost 2001-2025, discounted, R bn	Installed capacity by 2025, GW
Base case	134	57.7
Gas case	114	57.8
Hydro case	84	51.5
PBMR case	153	57.7
Renewable case	142	58.5

context, the cost changes are small in relative terms, but nonetheless are in the order of millions to billions of Rands. On the supply side, investing in domestic options—be they renewable energy or nuclear PBMR—increases the costs of the energy system. While these increases are only 0.06% of energy system costs, they are nonetheless over R 3 billion in both cases over the period.

A comparison with a different costing boundary is presented in Table 17. The table shows the total investment costs over the whole period, as well as the installed capacity that results in each policy case. Clearly, domestic investments in hydro capacity are lower, and to a lesser extent this is also true for gas. The largest investments requirement is needed for the PBMR case. Installed capacity in that case is the same as for the base case. The additional investment needed for the renewables case lies between the base and PBMR cases. A larger electricity supply system is needed, given the lower availability factor.

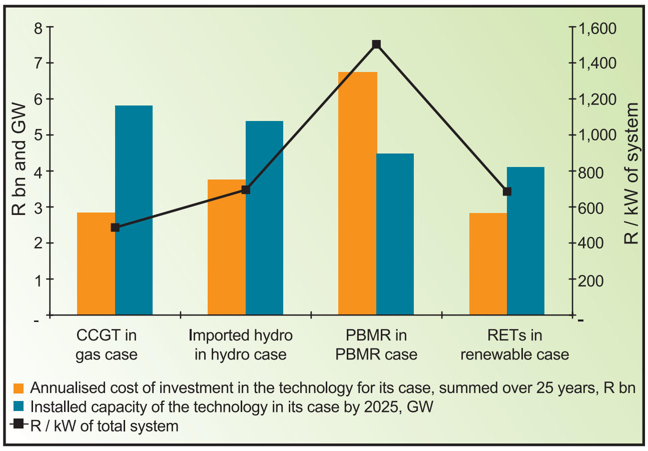

Figure 22: Investment requirements for electricity supply technologies in their policy case, capacity provided in 2025 and cost per unit

A comparison with a different costing boundary focuses on the investment required for technology in its policy case, e.g., in the PBMR policy case, or various renewable energy technology in the renewables case. Figure 22 shows three items—the discounted investment costs in the technology over 25 years (derived by summing annualized investment costs), the capacity of that technology at the end of the period, and the cost per unit (kW) of capacity added to the total system.

The PBMR shows the largest investment requirement. It also adds more capacity than renewables, but less than from gas or imported hydro. In unit cost, imported gas is cheapest, with hydro and renewables next at roughly similar levels. Note that these numbers are not the same as the upfront investment costs (also expressed in R/kW in Table 5 of the annexures).

6.4 Comparison Across Dimensions of Sustainable Development

The economic, social and environmental dimensions of sustainable development should be considered together to conclude on the sustainability of various technologies, policies and measures. To get a clear picture, it can be helpful to pick one parameter for each dimension. Figure 23 draws together the evaluation of a few ´developmental indicators that could directly or indirectly capture some social, economic and environmental aspects of sustainable development. For example, reducing imports could enhance energy security, reducing electricity costs could improve electricity affordability for the poor households, and reducing emissions could provide environmental and social benefits. Only rank orders are shown in the figure, with 1 representing a less sustainable outcome, and 4 a more sustainable outcome. In other words, policy cases closer to the outer sides of the largest triangle are ranked higher in that dimension and therefore represent a more sustainable outcome. There is no attempt to define sustainability, merely an indication that one policy case makes residential energy development more sustainable than the others. If a triangle completely contains another, it would be higher-ranked in all three dimensions. If the triangles overlap, there are trade-offs.[13]

The limitation of the representation is that it selects certain parameters. A more complete overview of key energy indicators of sustainable development is provided in Table 18. Note that this table also reports some social parameters, even though it was noted above that electricity supply options have mainly indirect impacts on social sustainability.

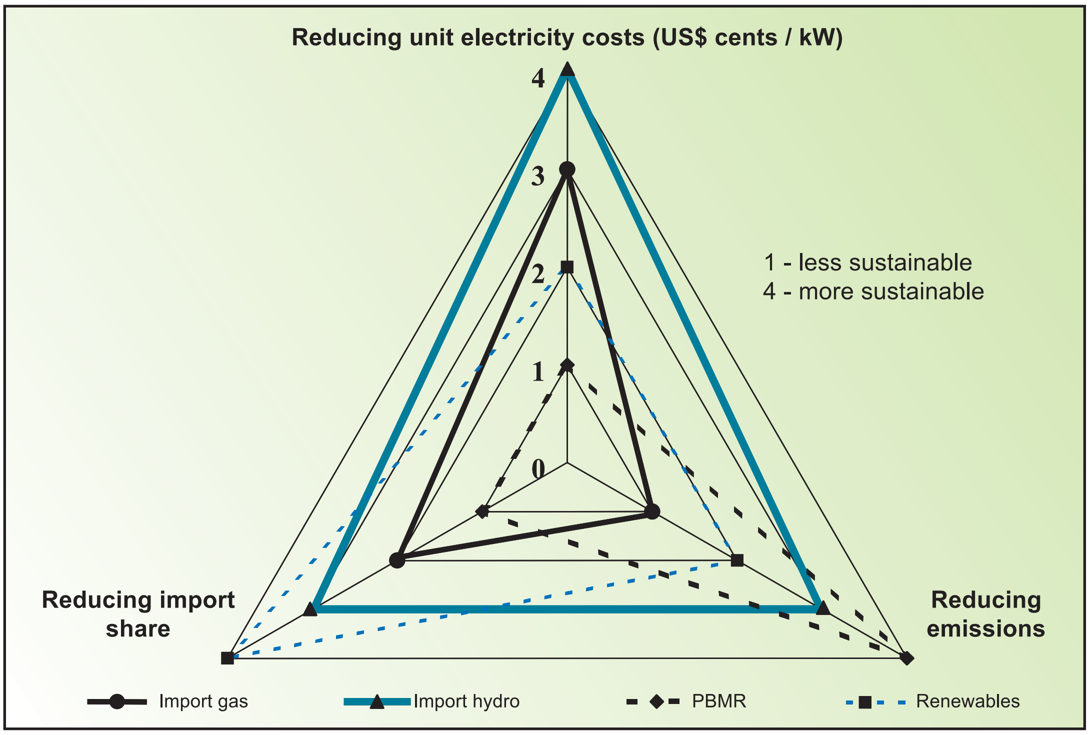

Figure 23: Electricity supply options ranked on selected development indicators
Source: Winkler 2006b

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[13] See Munasinghe (2002: 174). for a discussion on 'win-win' cases and trade-offs in multi-criteria analysis of energy policies against indicators of sustainable development.

Table 18: Summary of indicators of sustainable development across electricity policy cases

Environment												
	2001	**2005**	**2015**	**2025**	**2001**	**2005**	**2015**	**2025**	**2001**	**2005**	**2015**	**2025**
CO_2 emissions and reductions		**Mt CO_2**			**Sulphur dioxide**		**kt SO_2**		**Oxides of nitrogen**		**kt Nox**	
Base	350	389	492	596	1,491	1,684	2,226	2,772	1109	1257	1645	2035
Gas	0	0	-5	-12	-3	-3	-90	-92	2	2	-15	-39
Hydro-electricity	0	0	-13	-17	0	0	-48	-205	-1	-1	-43	-52
PBMR nuclear	0	0	-7	-32	13	-3	-32	-84	0	0	-23	-98
Renewables	0	-3	-7	-15	-1	-1	-9	-30	5	-3	-17	-42
Social												
	2005			**2015**			**2025**					
	GJ/Capita	**ZAR/GJ**	**GJ/ household**	**GJ/Capita**	**ZAR/GJ**	**GJ/ household**	**GJ/Capita**	**ZAR/GJ**	**GJ/ household**			
Base case	97.62	225.90	16.36	116.80	237.83	15.57	136.57	260.68	14.76			
Gas	97.71	225.69	16.32	116.11	239.24	15.53	135.51	262.70	14.71			
Hydro	97.71	225.68	16.32	115.00	241.56	15.53	134.53	264.62	14.71			
PBMR nuclear	97.71	225.69	16.32	116.63	238.18	15.53	135.89	261.98	14.71			
Renewables	97.52	226.22	16.32	117.38	236.65	15.53	135.92	261.91	14.71			
Economic												
Total system costs				**Share of imports**								
	R billion	**R million**	**Percentage**									
Base case	5,902	change	change	2005	2015	2025						
Gas	5,902	95	0.00%	22%	25%	24%						
Hydro	5,890	-11,525	-0.20%	23%	26%	26%						
PBMR nuclear	5,905	3,706	0.06%	23%	26%	25%						
Renewables	5,905	3,488	0.06%	23%	26%	28%						

CHAPTER – 7

Cross-country Comparative Results

This chapter provides a cross-country overview of key assumptions and results in relation to economic growth, energy consumptions, and local and global emissions. More detailed data is given on energy access and affordability in order to reflect the social aspects of the energy transition process that is underway in Brazil, China, India, South Africa, Bangladesh, and Senegal.

The chapter starts with an introduction of the general economic growth and population assumptions that have been used in the studies and with more in-depth discussions on development, energy, and the environment. These latter issues are dealt with in two separate clusters, where the results and conclusions are given separately for Brazil, China, India, and South Africa, and for Bangladesh and Senegal. The reasons for this division are that the development and energy issues that face the two country groups exhibit major differences. Countries like Brazil, China, India, and South Africa are large and relatively stable economies with high current energy investments, while Bangladesh and Senegal are in earlier stages of economic development and their energy systems are also in earlier phases of establishment.

7.1 Development Goals, Policies, and Model Assumptions

The approach of the country studies has been to use different national models and apply a consistent set of assumptions. Some countries have used long-term scenarios and models covering a period until 2100, while others have focused on the time-frame until 2030. The country summaries that are given in this report specifically focus on the time-frame until 2030. Another distinction in the studies is between macroeconomic modeling versus sector level models and project assessment.

Brazil has used the macroeconomic model, EMACLIM (Brazil, 2007), and has supplemented the model runs with more detailed assessments for specific policy cases, while South Africa has used the energy sector

MARKAL model (South Africa, 2007). China has used the IPAC-emission model and IPAC-AIM/technology model which are components of the Integrated Policy Assessment Model for China for long term scenario development (Jiang and Hu, 2007; China, 2007). India has used a soft-linked model framework that employs bottom-up models like MARKAL and AIM, and top-down models like ERB, AIM/Material and SGM (India, 2007).

Tables 19, 20 and 21 show the major economic growth and population assumptions that have been used in the national reference scenarios.

The economic growth and population assumptions that have been used in the country studies are reflecting official national development goals of the countries as well as expert judgments. Official projections typically are available for shorter time horizons such as up to 10 years, while 20–30 years and further ahead are only covered in specific energy sector planning activities. All the teams that are involved in this project are also partners in national energy planning efforts so the assumptions applied are close with those that have been used in official national planning.

The national reference scenarios by definition take policies and measures that are already under implementation into account, while policy scenarios include potential climate change policies. The annexures of this report include tables with information about key national development goals and targets, and policies and measures under implementation in each country.

7.2 Cross-Cutting Assessment of the Studies for Brazil, China, India, and South Africa

7.2.1 General scenario indicators: Intensities and elasticities

The trend in energy intensity of the gross domestic product (GDP) and related CO_2 emissions from the energy sector are in the following illustrated for the period 1970 to 2030 for Brazil, China, India, and South Africa.

Table 19: Economic growth assumptions ***as applied in the development, energy and climate country studies*** (average annual GDP growth rates, %)

Country	1971-1990	1990-2004	2004-2015	2015-2030	2004-2030
Brazil	4.7	2.6	4.2	4.1	4.1
China	7.8	10.1	8	6.6	7.2
India	4.6	5.7	6.2	6	6.1
South Africa	2.1	2.2	2.4	2.8	2.6

Sources: for data up to 2004 (IEA, 2005a); for future projections (Brazil, 2007; China, 2007; India, 2007)

Table 20: Population growth assumptions ***as applied in the development, energy and climate country studies*** (average annual population growth rates, %)

Country	1971-1990	1990-2004	2004-2015	2015-2030	2004-2030
Brazil	2.2	1.5	1.2	1.0	1.1
China	1.6	1.0	0.7	0.5	0.6
India	2.2	1.7	1.4	0.9	1.1
South Africa		1.8	0.5	0.3	0.4

Sources: Brazil, 2007; China, 2007; India, 2007

Table 21: Resultant population projections (Millions)

Country	2000	2010	2020	2030
Brazil	171	198	221	241
China	1267	1380	1460	1530
India	997	1159	1290	1393
South Africa	44	48	47	49

Sources: Brazil, 2007; China, 2007; India, 2007

The data is based on IEA statistics for the period until 1999 and on national scenario projections from 2000 to 2030 which have been developed as part of the project. The scenarios are baselines where no specific climate policies are assumed to be implemented.

Figure 24 shows the trend in total primary energy supply (TPES) intensity of the GDP indexed from 1970 to 2030. As it can be seen the energy/GDP intensity is decreasing in the

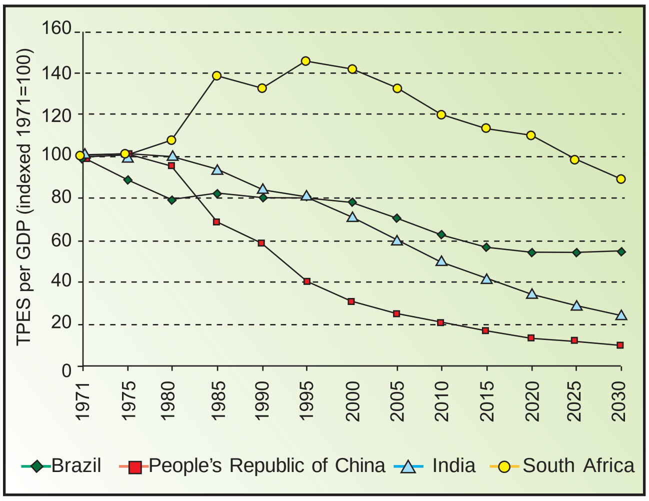

Figure 24: Total primary energy supply intensity of GDP indexed

Source: IEA, 2000a; IEA, 2000b; Brazil, 2007; China, 2007; India, 2007

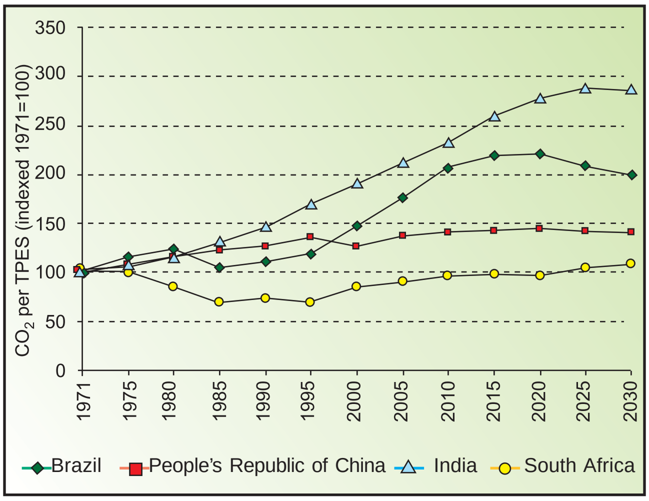

Figure 25: CO_2 Intensity of TPES in Brazil, China, Denmark, India and South Africa 1970 to 2030

Source: IEA, 2000a; IEA, 2000b; Brazil, 2007; China, 2007; India, 2007

whole period for China, India, and Brazil. The picture is a little bit different in South Africa, where the energy/GDP intensity increases with about 40% from 1970 to 1995, where after it decreases. Some of the countries such as China and India are expected to have a very large decrease in energy/GDP intensity from 1970 to 2030 of as more than 80% in the case of China, and about 70% in the case of India.

The trend in CO_2 intensity of energy is very different from the energy/GDP intensity as it can be seen from Figure 25. An increase of almost 150% is expected for India and about 100% for Brazil from 1970 to 2030, and in China the expected increase is about 50%. The increases are predominantly a consequence of the increasing role of commercial fossil energy in the total primary energy supply of these countries. The trend for CO_2 intensity of commercial fossil energy is however declining for most countries after the late 1990s. The CO_2 intensity of energy supply is fairly constant over the period for South Africa, with a slight tendency to increase after 1995.

Finally, Figure 26 shows the resulting CO_2 intensity of GDP for the countries. For one country namely China, the energy/GDP intensity decrease in the whole period from 1970 to 2030 is large enough to offset the increase in CO_2/energy intensity, so the CO_2/GDP intensity is therefore decreasing.

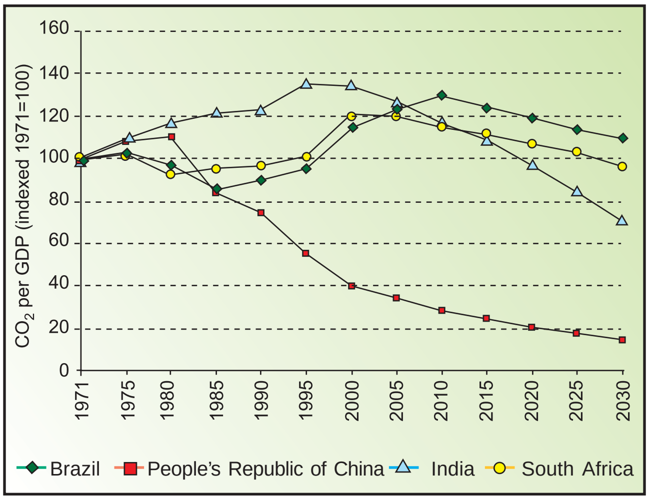

Figure 26: CO_2 intensity of GDP

Source: IEA, 2000a; IEA, 2000b; Brazil, 2007; China, 2007; India, 2007

Differently Brazil, India, and South Africa first experience an increasing CO_2/GDP intensity, but expect a decrease over time in the scenario period from 2000 to 2030.

All together it can be concluded from Figures 24 to 26 that in the period from 1970 to 2030, where a very large GDP growth is expected in most of the countries, a large decrease in energy/GDP intensity is expected. However, the CO_2/GDP intensity will tend to be kept constant or will only decrease after some period. In relation to a GHG emissions reduction perspective a specific focus on climate change policy issues is therefore needed if GHG emissions are to be managed, since this goal is not automatically fulfilled by baseline energy policies as they are projected in the national scenarios that are shown in Figures 24 to 26. The relationship between the trend in GDP, energy, and CO_2 can also be illustrated by the corresponding elasticities, which are shown in Tables 22, 23 and 24.

The contribution of energy to economic growth can be examined in more detail by analyzing the role of energy as a production factor relative to other factors. A recent study (WEO, 2004), based on a standard Cobb-Douglas production function assessed the contribution of production factors to GDP growth for selected countries as shown in Table 25.

The conclusion that can be drawn from Table 25 is that productivity increases based on energy, labor and capital inputs are larger than for other factors, except in the case of China, where some uncertainty about GDP estimates according to IEA, 2004 can explain the difference to other countries in this regard. Another lesson from Table 25 is that countries that are either highly industrialized, like the USA, or at earlier stages of development, tend to have energy as a less contributing factor to productivity increases than other middle income countries like Korea, Brazil and Mexico, where energy intensive industry plays a larger role in GDP.

Similar conclusions are drawn in the Special IPCC report on Emission Scenarios (IPCC, 2000). Based on data covering 1970 to 1990 from different regions of the world, it is concluded that energy consumption and energy intensive industries share of GDP decrease with increasing GDP per capita (SRES, 2000, Figures 3–12, and 3–13).

Decreasing energy intensity with economic growth is a consequence of several factors including a tendency to a relative increase in service sectors and in energy extensive

Table 22: Energy (TPES) elasticity of GDP

Country	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2020**	**2021-2030**
People's Republic of China	0.89	0.34	0.25	0.33	0.36	0.36
India	1.01	0.63	0.61	0.34	0.32	0.31
South Africa	1.33	2.90	1.67	0.35	0.66	0.21

Source: IEA, 2000a; IEA, 2000b; Brazil, 2007; China, 2007; India, 2007

Table 23: CO_2 elasticity of energy (TPES)

Country	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2020**	**2021-2030**
People's Republic of China	1.44	1.31	1.00	1.43	1.12	0.85
India	1.68	1.80	2.04	2.02	1.95	1.17
South Africa	0.53	0.47	2.16	2.29	1.06	2.86

Source: IEA, 2000a; IEA, 2000b; China, 2007; India, 2007

Table 24: CO_2 elasticity of GDP

Country	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2020**	**2021-2030**
People's Republic of China	1.28	0.44	0.25	0.47	0.40	0.31
India	1.69	1.13	1.24	0.69	0.62	0.37
South Africa	0.70	1.37	3.59	0.81	0.71	0.60

Source: IEA, 2000a; IEA, 2000b; China, 2007; India, 2007

Table 25: Contribution of factors of production and productivity to GDP growth in selected countries, 1980-2001

Country	Average annual GDP growth %	Contribution of factors of production and productivity to GDP growth (% of GDP growth)			
		Energy	Labor	Capital	Total factor productivity
Brazil	2.4	77	20	11	-8
China	9.6	13	7	26	54
India	5.6	15	22	19	43
Indonesia	5.1	19	34	12	35
Korea	7.2	50	11	16	23
Mexico	2.2	30	60	6	4
Turkey	3.7	71	17	15	-3
USA	3.2	11	24	18	47

Source: IEA, 2005b Table 10.1

industries, technological change, and energy efficiency improvements This comes in addition to energy's role as a factor that can enhance the productivity of other inputs.

7.2.2 CO_2 and SO_2 emission projections

Figure 27 gives the CO_2 emissions for various countries under the reference scenario and their share of the global CO_2 emissions measured in relation to IEA's WEO 2005 (IEA, 2005). During 2005–2030, India's emissions are projected to grow 3.6% per year, 2.8% per year in China, 2.7% per year in Brazil, and 2% per year in South Africa The countries cumulative CO_2 emissions are projected to increase from being 22% of global emissions in 2000 to 33% in 2030. Coal consumption in China, India and South Africa is the predominant driver of this emission growth, although the CO_2 intensity of coal use improves considerably in these countries due to efficiency improvements from 2005–2030.

Figure 28 shows the corresponding SO_2 emission projections for the countries.

7. 2.3 Issues related to CO_2 and SO_2 decoupling

A key issue related to integrated development, energy and climate policies is whether it is possible to combine local and global environmental policies in a way, where

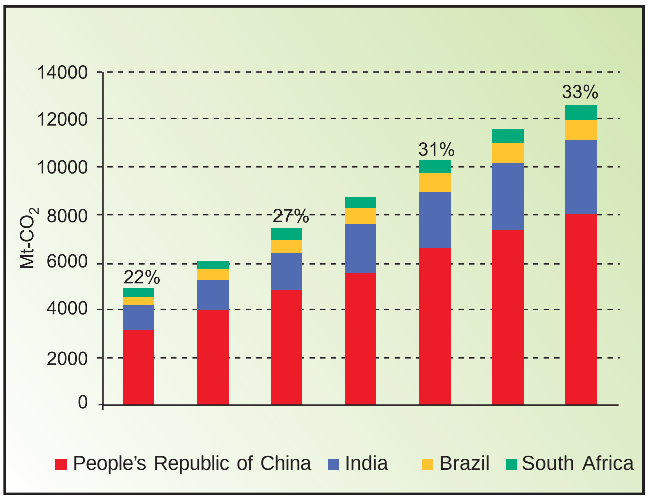

Figure 27: CO_2 emission projections under the reference scenario for Brazil, China, India and South Africa. The percentages above the bars are their cumulative share of the global CO_2 emissions (refer reference scenario in IEA, 2005b).
Source: Brazil, 2007; China, 2007; India, 2007; South Africa, 2007; IEA, 2005b.

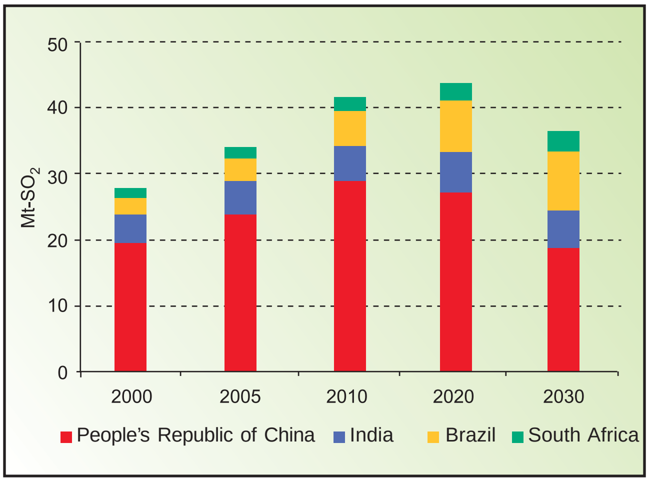

Figure 28: SO_2 emission projections under the reference scenario for Brazil, China, India and South Africa.
Source: Brazil, 2007; China, 2007; India, 2007; South Africa, 2007.

countries while pursuing high priority local environmental concerns, for example in relation to local air quality, also can support CO_2 emission reduction policy objectives.

It should here be recognized that CO_2 and SO_2 emission control policies have various interesting links and disjoints. Starting from SO_2 emission control as the major policy priority, it can in many cases be cheaper to install various cleaning techniques that control SO_2 emissions rather than to implement general efficiency improvements or fuel switching that both reduce SO_2 and CO_2 emissions. On the contrary, starting with CO_2 emission reduction as the major policy priority will often suggest a number of cost effective options that jointly reduce the two types of emissions. However, such policies seen from the SO_2 reduction perspective alone deliver more expensive local air pollution control than cleaning systems. The conclusion is that integrated local and global emission reduction policies in many cases will require special attention to the global aspects.

The relationship between CO_2 and SO_2 emission development is shown in Figure 29 below for Brazil, China, India and South Africa for 2000–2030 under the reference scenario.

Coal consumption for electricity generation is the major source of CO_2 and SO_2 emissions in China, India, and South Africa and coal also is expected to play a major role in the future (China, 2007; India, 2007; South Africa, 2007). However, domestic pressures in the countries have implied increasing efforts over time to introduce various local air pollution control measures such as flue gas desulphurization (FGD), fluidized bed combustion (FBC) and integrated gasification combined cycle (IGCC) that can curb SO_2 and suspended particulate matter (SPM). CO_2 emissions, however, continue to rise but the growth tends to slow down over time. Road transport emissions are a major source of local air pollution and cleaner road transport technologies, although based on fossil-fuels, contribute to reduce SO_2, SPM, NO_x and CO emissions. CO_2 emissions again continue to rise since fossil-fuel based road transport continues to have a major share in all these countries. This also promotes local-GHG emission decoupling.

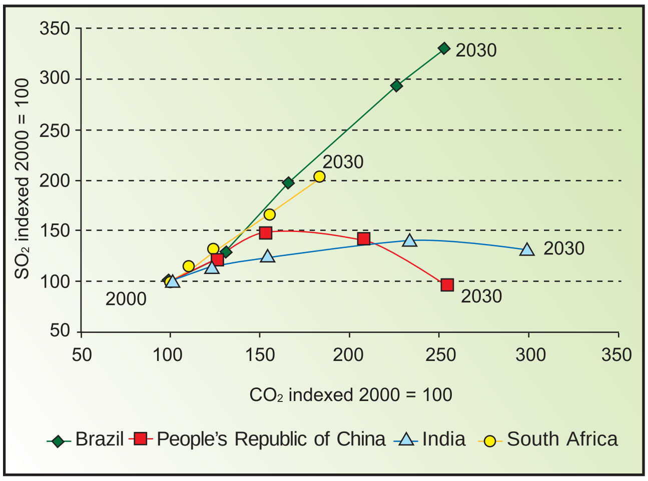

Figure 29: Links and disjoints in CO_2 and SO_2 emissions in Brazil, China, India and South Africa 2000 to 2030 (The emissions are indexed separately for each country to maintain comparability; and dots show the time namely, 2000, 2005, 2010, 2020 and 2030)

Source: Brazil, 2007; China, 2007; India, 2007

The air pollution control policies in China and India initiate a decoupling of global and local emissions from around 2010–2020. The tendency emerges in South Africa around 2025, but is at this time a small effort that is not visible in the aggregate national SO_2 emission data that is shown in Figure 29. This tendency is also confirmed by a steady decline in the growth rate of SO_2 emission from 2000–2030 while CO_2 emissions rise more steeply. All new coal plants in South Africa have FGD, and a vehicle emissions strategy (DME and DEAT policy) mandates the phase-in of lower-sulphur fuels in transport.

The Brazilian case is slightly different mainly due to a different energy mix. Hydropower, which is CO_2 and SO_2 emission free, dominates Brazil's electricity production, so local and global emissions come from other sources as for example transportation. The high growth in SO_2 emissions from Brazil that are projected for the future is derived from a large increase in biofuel production, that has SO_2 emissions but is CO_2 neutral, and from coal consumption. Overall SO_2 emissions are projected to rise by 3.3 times over 2000–2030 while CO_2 emissions will rise by 2.5 times.

7.2.4 Social aspects of energy development

Energy access is a key dimension of sustainable development, and is also indirectly linked to many of the MDGs as outlined previously. This section will provide a short overview of present and expected energy access. As a reflection of this, increasing energy access actually is a key policy priority that is an integral part of baseline scenarios for these countries. Figures 30 and 31 provide scenarios for household electricity access for the period 2000–2030 in various countries.

As it can be seen from Figure 30 almost 97% of Chinese households and 95% of Brazilian households had electricity access in 2000, while the levels were down to 55% in India and 63% for South Africa in this year. By the end of the period in 2030, it is expected that more than 95% of the households have electricity access in the countries.

When national electricity consumption data is studied in more detail it shows up that there are striking differences in per capita electricity consumption in rural and urban areas (Figure 31). Electricity access in 2000 was respectively 45% and 82% for rural and urban households in India, and 45% and 75% for rural and urban households in South Africa.

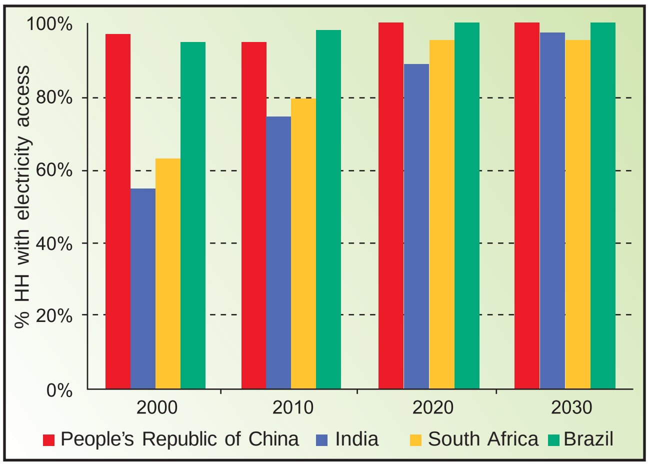

Figure 30: Households with electricity access for reference scenario for 2000 to 2030

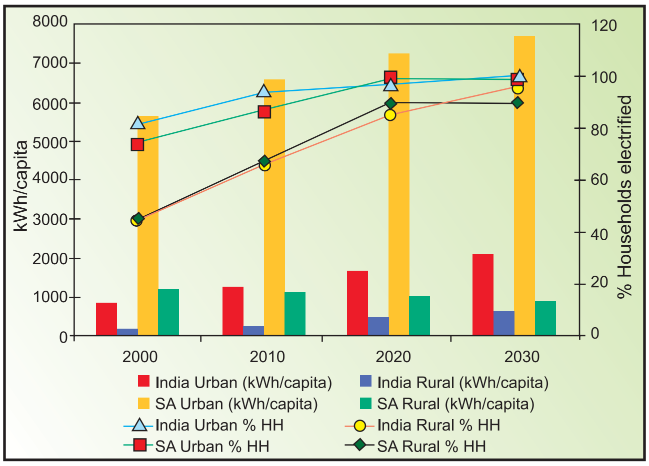

Figure 31: Electricity access and consumption in rural and urban households for 2000-2030 for India and South Africa

The average per capita consumption also varies considerably for rural and urban areas. Urban areas consumed about 4.7 times more electricity per capita in 2000 for India than rural areas, and 3.8 times in South Africa. This ratio is projected to decline to 3.6 times in 2030 for India, indicating a more equitable electricity distribution and regional development patterns in future. The long-term Indian policies have a decentralization thrust, including constitutional provisions of a federal structure and power to the people through Panchayati Raj (local governance) institutions, and equitable availability of social infrastructure (Shukla et al., 2006). However for South Africa the urban/rural electricity per capita ratio is projected to worsen in future and the per capita electricity consumption declines in rural areas during 2000–2030. The main reason is gradual and continuous re-classification of many rural areas as urban areas over 2000–2030, leaving areas with very low electrification rates under rural areas. This lowers the actual electrification rates under the revised rural areas. Although their electrification rates also improve over 2000–2030, they effectively become lower than those the previous years.

Electricity consumption is strongly correlated with economic output. Figure 32 shows GDP per capita and electricity consumption per capita for China, India, and South Africa in the period 1990 to 2030. It can here be seen that the countries expect to move upwards almost along a common line, where increases in income per capita is followed by a very similar increase in electricity consumption across the countries.

Energy access also differs significantly across income groups. Table 26 below shows the household expenditures on energy consumption for different income groups.

The share of the household budget that is spent on energy shows a number of similarities in India and China according to Table 26. Energy expenditures decrease with increasing income and the share of the household budget spend in India and China for urban households similarly vary between more than 10% for the poorest incomes down to around 5% for highest income households.

It should be noted that even the poorest households spend as much as 10% of their income on energy. Despite the fact that they must also be using non-commercial fuels in addition. This points to the key role of energy as a basic need.

Similarly Table 27 summarizes the different residential fuel shares in Bangladesh, Brazil and South Africa. It shows that the expenditure on electricity consumption in South African households is much higher than in Brazil. Despite Brazil's much higher level of electrification, the largest cost burden still derives from wood, and another large share from electricity and LGP. In Bangladesh, wood or biomass accounts for a similar share of expenditures as in Brazil, but the electricity expenditures are lower due to low access rates and incomes. The estimates for biomass use in South Africa suffer from data uncertainty and the costs of biomass are also not well known (Winkler et al., 2005).

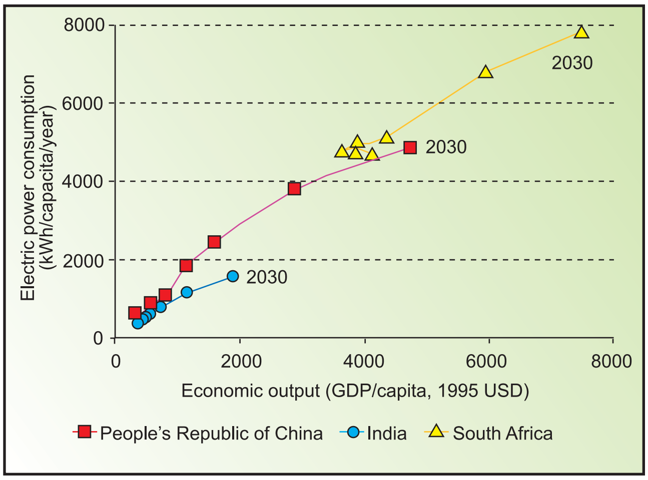

Figure 32: Relationship between GDP per capita and electricity consumption per capita for 1990-2030 for China, India and South Africa (dots show the time namely, 1990, 1995, 2000, 2005, 2010, 2020 and 2030)

Table 26: Household expenditure on energy for Indian households in 2000 and Chinese households in 2004

HH income category	India rural, 2000		India urban, 2000		China urban, 2004	
	Absolute expenditure (USD, 2000 prices)	% share of total HH expenditure	Absolute expenditure (USD, 2000 prices)	% share of total HH expenditure	Absolute expenditure (USD, 2000 prices)	% share of total HH expenditure
Poorest 0-5%	0.46	10.2%	0.65	10.9%	3.00	10.3%
0-10%	0.51	10.1%	0.80	10.7%	3.33	9.8%
10-20%	0.62	9.0%	1.04	10.5%	4.10	8.7%
20-40%	0.73	8.7%	1.46	10.1%	4.79	7.9%
40-60%	0.97	8.9%	1.73	9.6%	5.57	7.2%
60-80%	1.15	8.6%	2.13	8.9%	6.55	6.6%
80-90%	1.44	8.1%	2.67	7.8%	7.67	6.0%
Top 90-100%	1.79	7.2%	4.01	5.7%	10.10	5.0%

Note: Fuel and light expenditure for India**,** Water, oil and electricity expenditure for China
Sources: NSSO, 2001 (India); China Statistics Yearbook 2005 (visit www.stats.gov.cn)

Table 27: Residential fuel shares in households in Bangladesh, Brazil and South Africa

Fuel shares (%) **Country**	**Electricity**	**Coal**	**Gas**	**Paraffin**	**LPG**	**Wood**	**Candles**	**Other**
Bangladesh (expenditure share)	18%	0.3%	5%	12%		33%		32%
Brazil	30%	2%	1%	0.3%	30%	37%	-	
South Africa	62%	9%		12%	2%	12%	2%	

Sources: BBS, 2000; MME, 2003; MME, 2004; DME, 2003; ERI, 2001

7.3 Sustainable Development (SD) Indicators

Chapter 2 of this report introduces an analytical approach that can be used to assess sustainable development dimensions of energy and GHG emission reduction policies. In a pragmatic way, it is proposed to use indicators of economic, social, and environmental SD dimensions such as costs, employment generation, energy access, local and global emissions, income distribution, and local participation in the evaluation of specific policies. See a more detailed discussion about SD indicators in Halsnæs and Verhagen, (2006) and Halsnæs et al., (2006).

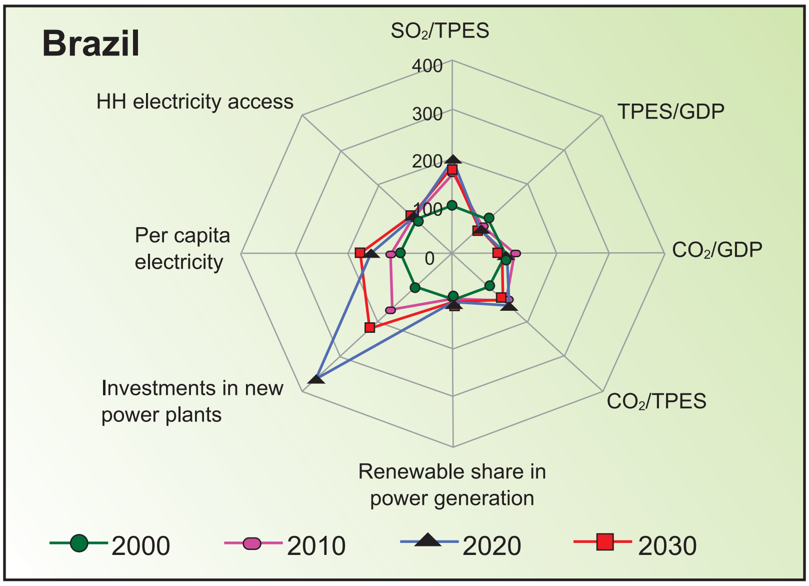

Figure 33: Sustainable development indicator projections for Brazil (Indexed for year 2000 = 100, for all indicators)

Based on this approach, SD indicators have been applied to the country study results for Brazil, China, India and South Africa in order to reflect energy efficiency, supply structure, per capita electricity consumptions, and local and global pollution. The results of this assessment are shown in Figures 33–36 for 2000-2030 for Brazil, China, India and South Africa.

Figures 33–36 are structured as "web-diagrams", where the development trends for the chosen SD indicators are shown for the period 2000–2030 (defined as index values with 2000=100). The SD indicators include variables where low index values are considered to be supporting SD, and other variables, where high index values support SD[14].

Variables that are considered to have a positive impact on SD if the index value is **low** are:

- SO_2 intensity of energy consumptions (SO_2/TPES).
- Energy intensity of GDP (TPES/GDP).
- CO_2 intensity of GDP (CO_2/GDP).
- CO_2 intensity of energy (CO_2/TPES).

While variables that are considered to have a positive impact on SD if the index value is **high** are:

- HH electricity access
- Per capita electricity consumption.
- Efficiency of electricity generation (fossil).

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[14] A low index value for the period 2000 to 2030 implies that the variable is decreasing or only slowly increasing, which for example is positive for CO_2 emission. On the contrary a high index value shows a large increase over time, which for example can be positive in terms of per capita electricity consumption.

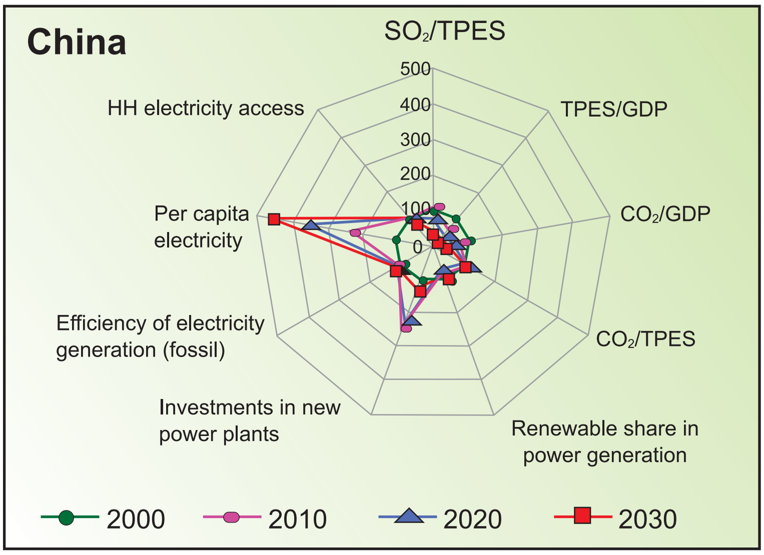

Figure 34: Sustainable development indicator projections for China (Indexed for year 2000 = 100, for all indicators)

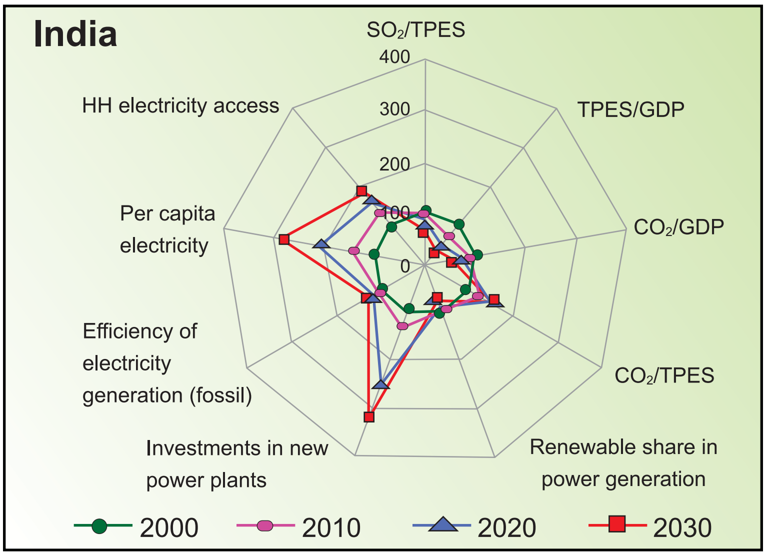

Figure 35: Sustainable development indicator projections for India (Indexed for year 2000 = 100, for all indicators)

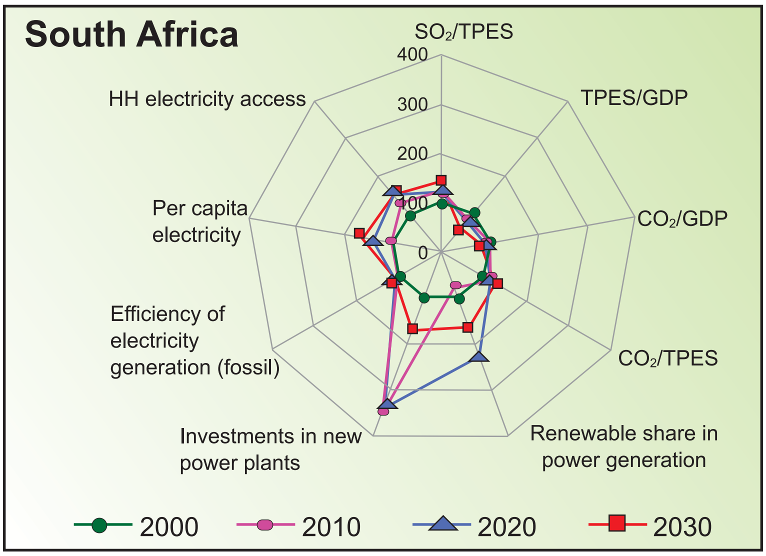

Figure 36: Sustainable development indicator projections for South Africa (Indexed for year 2000 = 100, for all indicators)

- ☐ Investments in new power plants.
- ☐ Renewable share in power production.

The Brazilian baseline development trends from 2000 to 2030 that are shown in Figure 33 are characterized by a large increase in power sector investments and increasing CO_2 and SO_2 intensity of energy consumption. The share of renewable energy increases slightly and there is a relatively small increase in per capita electricity consumption.

The baseline scenario for China for 2000 to 2030 implies an increasing share of renewable energy and a very large increase in per capita electricity, while the CO_2 and SO_2 emission intensities of energy are kept very close to the 2000 levels (Figure 34). There is also a high growth in power plant investments, and the efficiency of power production increases by about 20%.

In India, there is a growth in the CO_2 emission intensity of energy consumption, while the SO_2 intensity is decreasing from the 2000 level (Figure 35). The energy intensity of GDP is also decreasing in the period. The per capita electricity consumption is increasing about three times, and this is also the case for power sector investments.

Finally, South Africa in particular has a high growth in power sector investments from 2000 to 2030 and also some growth in the share of renewable energy in power generation (Figure 36). The CO_2 intensity of GDP is almost constant in the period, while the energy GDP intensity is decreasing slightly. Per capita electricity consumption is expected to have a relatively modest increase like the case of Brazil.

The common conclusions that can be drawn from Figures 33–36 are that there is generally a tendency for CO_2 and SO_2 emission intensities of energy and GDP to develop slowly in the countries in their 2000 to 2030 baseline cases. Investments in the power sector are expected to grow fast in the period, and particularly in China and India this implies a large growth in per capita electricity consumption. It is worth recognizing that none of the countries expect very large increases in the renewable share of electricity production in the period, however the absolute levels of renewable energy is projected to increase considerably in all the countries.

7.4 Conclusions on Development, Energy and Climate Synergies and Trade-offs

The 1970 to 2030 time-frame studies for Brazil, China, India, and South Africa show that there is a tendency to decouple economic growth and energy consumption over time. Energy consumption, however seems to have a stable or increasing CO_2 intensity, so all together CO_2 emissions tend to grow with about the same or a lower rate than GDP in most countries.

The power systems of all the countries except Brazil are dominated by coal and this supply structure will continue in the future. This also implies high growth rates in CO_2 emissions of between 3.6% and 2% per year from 2005 to 2030. As a result of this, the four countries are expected to contribute as much as one third of total global CO_2 emissions in 2030.

Local air pollution in terms of SO_2 emissions will also grow in the period, but there is a tendency to introduce significant control measures 10 to 15 years from now, which implies much smaller growth in this area in the future. However, CO_2 emissions do not automatically drop as a consequence of these local air pollution control measures.

Energy access is a major priority in all the countries studied, and the official development and energy policies assume almost full household access to electricity in 2030. More detailed studies of income levels and energy expenditures however show that energy is a relatively high budget burden for the poorest households. Energy expenditures contribute more than 10% of the household budget for poor households in China and India today, while the level is between 5% and 7% for high income families.

The application of SD indicators to the Brazilian, Chinese, Indian, and South African studies point to the conclusion that all the countries expect significant improvements in energy sector investment and per capita electricity consumption. This is maintained while the future growth of not only SO_2 emissions but also CO_2 emissions are kept relatively low. However, the baseline scenarios that have been examined do not deliver high GHG emission reductions and also contribute only small increases in renewable energy. So it is clear that a promotion of specific policy objectives in these areas requires special attention and policy options beyond baseline scenario perspectives.


QUAY FOUR
COBRA
Waterfront
Scenic

CHAPTER – 8

Summary and Conclusions

The methodology adopted in this study explicitly started from development objectives. Much of the contribution that this approach can make lies in considering the specific energy policies that can meet national development objectives. Reaching them in a more sustainable manner has co-benefits for climate change. The approach to climate change mitigation, then, is not one that seeks the least-cost solution to reducing GHG emissions from the energy sector. A durable approach is one which combines "win-win" policies with those that trade off some economic optimality for local and global environmental benefits. The approach explored in this study provides a possible basis for South Africa to engage in the next round of negotiations under the UNFCCC.

The case studies take as their starting point development objectives, rather than climate change targets. The form of climate action which it investigates is sustainable development policies and measures (Winkler et al., 2002a). While sustainable development measures might in practice be similar to climate policy, the motivation is different—one pursues emission reductions, while the other local development. Making development more sustainable locally is a higher policy priority for most developing countries than addressing a global problem such as climate change, particularly since the latter has been caused mainly by industrialized countries. South Africa has a rather typical emissions profile for a developing country—high emissions per capita and per GDP. A development-focused approach seems more likely to be implemented than the imposition of GHG targets by the international community—especially as the country has adopted development targets such as the Millenium Development Goals and promoted the Johannesburg Plan of Action.

The case study considers options in the electricity sector. Making electricity development more sustainable can contribute to climate change mitigation. The case studies focus both on domestic options (beyond the base case) in South Africa, and consider the climate impacts on hydroelectric imports from the Southern African region.

Climate change is projected to increase both the temperature as well as the annual rainfall in the Congo and Zambezi river catchments. The impact of this will potentially result in increase evaporation on installations with large dams, increase the volume of water per annum which could include periodic flooding, which may in turn increase the amount of sedimentation in erosion prone areas. Climate change models initially indicate minimum changes in the hydrology of the Congo River basin. Some measures to reduce siltration might be needed on the Zambezi River. Specific studies for these catchments are required to ascertain the magnitude of these impacts.

Turning to domestic options, the study found that both renewable energy and the PBMR nuclear option can contribute to diversifying the fuel mix. The base case sees electricity generation continuing to be dominated by coal over the period up to 2030. A renewables policy case increases the share of those technologies, resulting in a coal/nuclear/renewable mix. The PBMR case makes a small shift from coal to nuclear.

The policy cases reported here can avoid emissions compared to the base case. Initially, both these domestic options show similar co-benefit in terms of CO_2 emission reductions, but eventually the larger investment of the PBMR case yields greater reductions. Benefits in reducing local air pollutants, such as SO_2, are also reported for all cases. Substantial reductions around in NO_x emissions can be seen in 2025 for all of the electricity supply options. To avoid double-counting of emission reductions, a combined policy case was briefly considered.

Combined electricity supply options that move away from dependency on coal-fired plants can reduce local and global pollutants. The combined case could reduce 84 Mt CO_2 for 2030 (13% less than reference) and 579 kt SO_2 (–20% in 2030). The increases in costs for the total energy system are small, although the costing boundary in that case is particularly large.

An expedited shift from a coal dependency to a diversified energy source scenario would, however, require significant policy and regulatory upheavals. Incremental cost considerations for such change may require stronger motivation than that which would emanate from compliance to multilateral agreements and obligations. Positive incentives may be needed, through which the international community might help make a transition. While electricity supply options other than coal show potential for significant emission reductions and improvements in local air quality, they require careful trade-offs in order to take into account the implications for energy system costs, energy security and diversity of supply.

At the same time, diversifying from coal, if done for climate change policies, would not be done by South Africa alone. The overall impact from a global perspective would be to curtail coal exports from South Africa and make it more abundant and probably cheaper domestically. This would make the continued domestic use of coal in electricity generation.

Maintaining a coal-based energy option, on the other hand, would require a gradual shift toward cleaner coal technologies. In the long term, inclusion of environmental externalities could bring this option to comparatively similar capital and operating cost as other sources of energy. Continued research on nuclear Pebble Bed Modular Reactors (PBMR), for example, has indicated decreasing generating costs over time as compared to the traditional nuclear Pressurized Water Reactor (PWR) (Eskom, 2006). Whether these cost estimates are achieved in practice remains to be seen if and when the first modules are built. Similarly, the costs of renewable energy technologies are expected to decline as global installed capacity is increasing rapidly (Turkenburg, 2000; IEA, 2003).

Looking beyond the South Africa borders for natural gas and hydro based electricity would require South Africa to critically assess long-term political scenarios in the region. Risks in this regard need to be balanced against the costs of developing domestic energy sources. External energy sourcing would also call for consolidation for regional cooperation terms and an active role in contribution towards peace and political stability in neighbouring countries. In the long run this could prove to be more costly than home based coal options for energy sources.

The imports of crude oil dominate the share of South Africa's energy imports, oil as an alternative in the electricity supply sector is and will continue to be comparatively small. Imports for electricity, whether in the form of gas or hydroelectricity—obviously adds to the share of imports. For the PBMR, while fuel is imported, its potential advantage in terms of using a domestic energy source is not realized.

Generally, the implications of policy cases for energy security—as approximated by import dependency—were found to be relatively small. Impacts of individual policy cases on the total energy system are also small in percentage terms. However, they amount to substantial absolute investments. Both the PBMR and renewables case increase system costs by 0.06% over the period, or roughly R 3 billion. Taking a narrower costing boundary, we found that the PBMR needed most additional investment, while adding more capacity than renewables, but less than from gas or imported hydro. In unit cost, imported gas is cheapest, with hydro and renewables next at roughly similar levels.

Transitions that include the supply-side are important. Greater diversity of supply will need a combination of policies, since single policies do not change the large share of coal in total primary energy supply by much when taken on their own.

The various electricity supply options show potential for significant emission reductions and improvements in local air quality. However, they require careful trade-offs in order to take into account the implications for energy system costs, energy security and diversity of supply.

Annexures

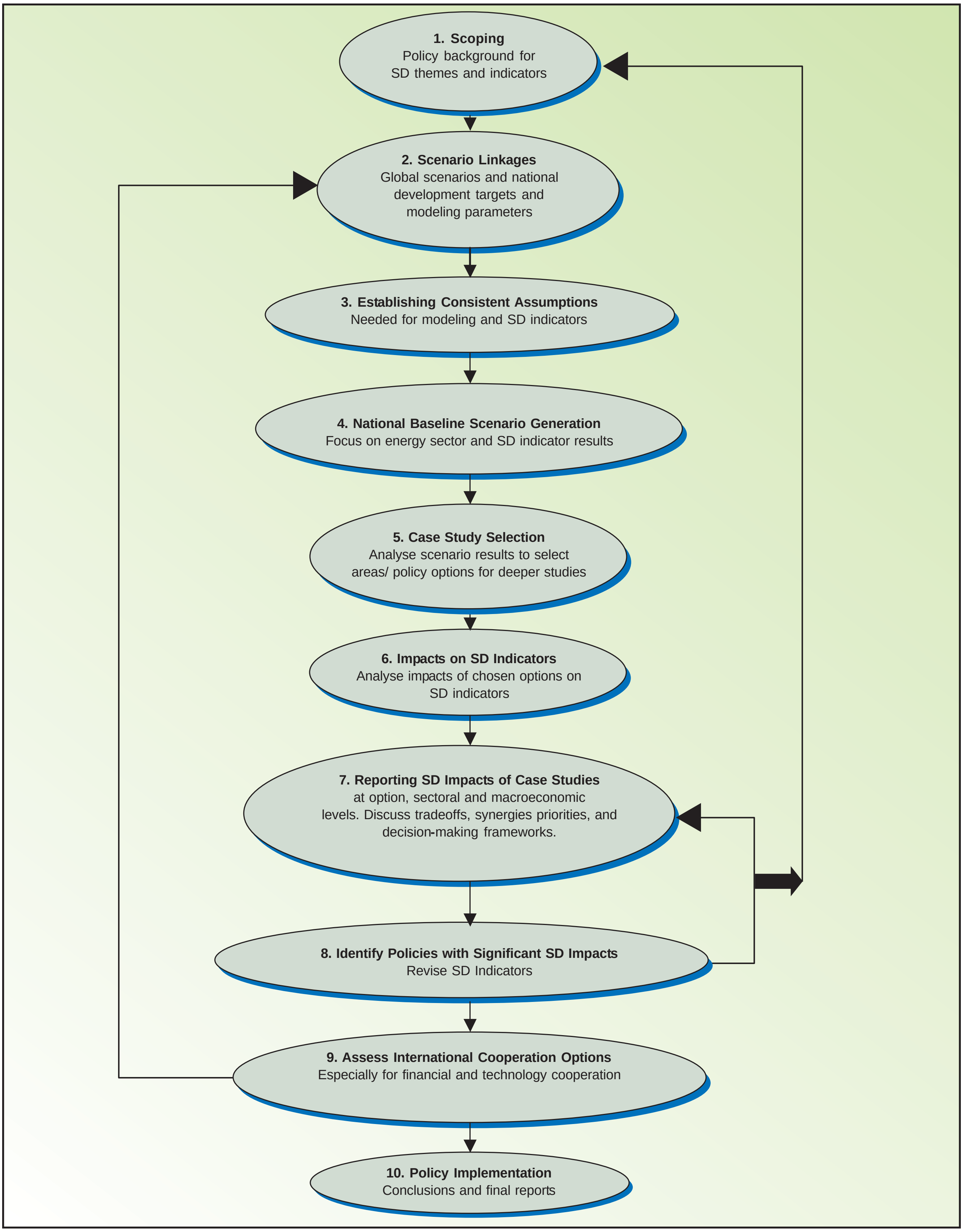

Figure 1: Analytical structure suggested for Development & Climate project
Source: Practical guidance material, first order draft (Halsnaes et al., 2005)

Table 1: Fuel prices by fuel and for selected years

Price for fuel	Units	2001	2013	2025	Source
Crude oil price	Real crude oil price local production [R/GJ]	24.8	18.0	21.4	(IEA 2004)
	Real crude oil price imports [R/GJ]	27.6	20.0	23.8	"
Petrol price	IBLC [R/GJ].	50.3	51.4	60.9	(DME 2001)
Diesel price	IBLC [R/GJ].	44.9	45.9	54.4	"
Paraffin price	Bulk [R/GJ]	58.0	59.3	70.3	"
	Drum [R/GJ]	80.5	82.3	97.6	"
HFO price	Bulk [R/GJ]	35.7	36.4	43.2	"
LPG price	Bulk [R/GJ].	112.1	114.6	135.8	"
	Drum [R/GJ].	124.4	127.2	150.8	"
Coal price	Electricity generation [ZAR/GJ].	3.02	3.02	3.02	Prevost in (DME 2002b)
	Sasol [ZAR/GJ]	2.54	2.54	2.54	"
	Domestic/commercial [ZAR/GJ]	3.45	3.45	3.45	"
	Industry [ZAR/GJ]	3.18	3.18	3.18	"
Biomass price	Wood [c/l]	30.0	30.0	30.0	See note below
	Bagasse [R/GJ]	0.0	0.0	0.0	
Natural gas price	LNG [R/GJ]	21.5	21.5	21.5	(NER 2004a)
	PetroSA [R/GJ]	20.0	20.0	20.0	(DME 2003a)
	Sasol pipeline [R/GJ]	22.1	22.1	22.1	(Sasol 2004)
Electricity price	Import [R/GJ]	5.5	Endogenous	Endogenous	(NER 2001)
	Export [R/GJ]	16.3	"	"	"
Electricity price including distribution costs	Agriculture [R/GJ]	41.4	"	"	(NER 2001)
	Commercial [R/GJ]	41.0	"	"	"
	General [R/GJ]	57.4	"	"	"
	Manufacturing [R/GJ]	10.5	"	"	"
	Mining [R/GJ]	9.8	"	"	"
	Residential [R/GJ]	44.6	"	"	"
	Transport [R/GJ]	21.8	"	"	"
Uranium price	Import [R/GJ].	3.2	3.2	3.2	(NER 2004a)

Note: The cost of fuels used in the residential sector stand out as particularly high. Per unit of useful energy service, i.e. taking into account household appliance efficiency, this would be even worse.

Biomass / fuelwood prices are in most cases low or even negative. For paper and sugar mills, biomass is a waste product. In the residential sector, most households report zero purchase costs (not couting time budgets and opportunity cost. We use an estimate of 50c per kg of wood (Cowan 2005), while acknowledging that the cost of biomass varies widely and should be treated in a locally specific way. R0.50 / kg wood, with 1 ton of wood yielding 15 GJ, gives R33.33 / GJ. This figure is of the same order of magnitude as the national average used by De Villers & Matibe (2000), and we use this as an approximation for commercially used biomass. We apply this value for urban households, but a much lower value (one-tenth) for rural households, i.e. R3 / GJ.

Table 2: Projections of electricity capacity by plant type in the reference case (GW)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Existing coal	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	32.9	32.9
Nuclear PWR	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Bagasse	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Diesel gas turbines	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Hydro	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interruptible supply	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Pumped storage	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Imported electricity	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Mothballed coal	-	-	-	-	0.4	0.8	1.5	2.8	3.6	3.6	3.6	3.6
New coal	-	-	-	-	-	-	-	-	-	-	-	-
New OCGT diesel	-	-	-	-	-	0.2	0.6	1.4	2.1	2.3	2.3	2.3
New CCGT	-	-	-	-	-	-	-	-	-	0.6	2.0	2.0
New FBC	-	-	-	-	-	-	-	-	-	-	-	-
New pumped storage	-	-	-	-	-	-	-	-	-	-	-	0.7

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Existing coal	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.2	30.3	30.3	30.3	30.3
Nuclear PWR	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Bagasse	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Diesel gas turbines	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Hydro	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interruptible supply	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Pumped storage	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Imported electricity	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Mothballed coal	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
New coal	-	-	0.1	0.9	1.7	2.5	3.3	4.2	6.1	9.2	10.2	11.2	12.2
New OCGT diesel	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
New CCGT	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
New FBC	0.8	1.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
New pumped storage	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Table 3: Electricity generation in reference scenario

	Electricity generation (TWh)			Shares (%)			Growth (%p.a.)	
	2004	2015	2030	2004	2015	2030	2004-2015	2004-2030
Total generation	**214**	**298**	**423**	**100**	**100**	**100**	**3.05**	**2.67**
Coal	199	264	372	93	89	88	2.61	2.44
Gas		15	31		5	7		
Nuclear	12	12	12	6	4	3		
Hydro	2	5	8	1	2	2	7.95	5.09
Other Renewable	1	1.2	0	0	0	0	3.75	-3.21

Table 4: Electricity generation in alternative scenario

	Electricity generation (TWh)			Shares (%)			Growth (%p.a.)	
	2004	2015	2030	2004	2015	2030	2004-2015	2004-2030
Total generation	**213**	**263**	**330**	**100**	**100**	**100**	**1.93**	**1.69**
Coal	199	228	243	93	87	74	1.26	0.77
Gas			22			7		
Nuclear	12	24	44	6	9	13	6.21	5.07
Hydro	2	2	2	1	1	1		
Other Renewable		9	18		3	6		

Table 5: Reference scenario results

	Energy demand (Mtoe)			Shares (%)			Growth (% p.a.)	
	2004	2015	2030	2004	2015	2030	2004-2015	2004-2030
Total primary energy supply	**124.3**	**160.3**	**213.2**	**100**	**100**	**100**	**2.3**	**2.1**
Coal	100.7	128.1	172.4	81	80	81	2.2	2.1
Oil	15.5	21.4	28.1	12	13	13	3.0	2.3
Gas	0.2	2.2	3.2	0	1	2	22.3	10.4
Nuclear	3.3	3.3	3.3	3	2	2		
Hydro	0.2	0.2	0.2	0	0	0		
Biomass and waste	2.5	3.0	3.6	2	2	2	1.4	1.3
Other renewables	1.9	2.1	2.4	2	1	1	1.0	0.9
Power generation and heat plants	**49.9**	**66.2**	**89.8**	**100**	**100**	**100**	**2.6**	**2.3**
Coal	46.3	61.9	85.0	93	94	95	2.7	2.4
Gas		0.7	1.4		1	2		
Nuclear	3.3	3.3	3.3	7	5	4		
Hydro	0.2	0.2	0.2	0	0	0		
Other renewables	0.1	0.1	0.0	0.1	0	0	3.8	-3.2
Other transformation, own use and losses	**16.0**	**17.6**	**17.9**	**100**	**100**	**100**	**0.8**	**0.4**
Total final consumption	**56.0**	**73.2**	**99.4**	**100**	**100**	**100**	**2.5**	**2.2**
Coal	15.8	22.4	33.2	28	31	33	3.2	2.9
Oil	19.9	24.3	30.7	36	33	31	1.8	1.7
Gas	1.1	1.6	2.5	2	2	2	3.6	3.1
Electricity	16.7	21.8	29.5	30	30	30	2.5	2.2
Biomass and waste	2.5	3.0	3.6	5	4	4	1.4	1.3
Industry	**30.0**	**42.0**	**60.4**	**100**	**100**	**100**	**3.1**	**2.7**
Coal	15.0	21.5	31.9	50	51	53	3.3	2.9
Oil	1.3	1.3	1.6	4	3	3	0.3	0.8
Gas	1.1	1.6	2.4	4	4	4	3.6	3.1
Electricity	10.7	15.0	21.1	36	36	35	3.2	2.7
Biomass and waste	1.9	2.5	3.4	6	6	6	2.7	2.3
Transport	**16.6**	**20.9**	**26.5**	**100**	**100**	**100**	**2.1**	**1.8**
Oil	16.3	20.5	26.2	98	98	99	2.1	1.8
Other fuels	0.3	0.3	0.3	2	2	1	0.2	-0.6
Residential, services and agriculture	**9.4**	**10.3**	**12.6**	**100**	**100**	**100**	**0.8**	**1.1**
Coal	0.7	0.9	1.3	8	9	10	1.7	2.2
Oil	2.3	2.5	3.0	25	24	24	0.6	1.0
Gas	0.0	0.0	0.1	0	0	1	3.6	3.4
Electricity	5.7	6.4	8.1	60	63	64	1.1	1.4
Biomass and waste	0.6	0.4	0.1	7	4	1	-3.7	-5.8

Table 6: Alternative scenario results

	Energy demand (Mtoe)			Shares (%)			Growth (% p.a.)	
	2004	**2015**	**2030**	**2004**	**2015**	**2030**	**2004-2015**	**2004-2030**
Total primary energy supply	**124.3**	**152.3**	**152.4**	**100**	**100**	**100**	**1.9**	**0.8**
Coal	100.7	118.4	103.4	81	78	68	1.5	0.1
Oil	15.5	21.0	23.9	12	14	16	2.8	1.7
Gas	0.2	2.2	3.2	0	1	2	22.3	10.4
Nuclear	3.3	5.7	16.8	3	4	11	5.1	6.5
Hydro	0.2	0.2	0.2	0	0	0		
Biomass and waste	2.5	2.8	3.0	2	2	2	0.8	0.7
Other renewable	1.9	2.0	2.0	2	1	1	0.4	0.3
Power generation and heat plants	**49.9**	**63.5**	**73.0**	**100**	**100**	**100**	**2.2**	**1.5**
Coal	46.3	55.8	50.3	93	88	69	1.7	0.3
Gas			1.4			2		
Nuclear	3.3	5.7	16.8	7	9	23	5.1	6.5
Hydro	0.2	0.5	1.8	0	1	2	8.8	9.2
Other renewables	0.1	1.5	2.8	0.1	2	4	32.2	15.2
Other transformation, own use and losses	**16.0**	**17.5**	**14.4**	**100**	**100**	**100**	**0.8**	**-0.4**
of which electricity								
Total final consumption	**56.0**	**72.2**	**74.0**	**100**	**100**	**100**	**2.3**	**1.1**
Coal	15.8	22.0	11.2	28	31	15	3.1	-1.3
Oil	19.9	24.0	29.9	36	33	40	1.7	1.6
Gas	1.1	2.0	2.0	2	3	3	5.4	2.3
Electricity	16.7	21.4	27.8	30	30	38	2.3	2.0
Biomass and waste	2.5	2.8	3.0	5	4	4	0.8	0.7
Industry	**30.0**	**41.5**	**36.9**	**100**	**100**	**100**	**3.0**	**0.8**
Coal	15.0	21.3	10.4	50	51	28	3.2	-1.4
Oil	1.3	1.3	1.4	4	3	4	0.0	0.3
Gas	1.1	1.6	1.1	4	4	3	3.5	0.2
Electricity	10.7	15.0	21.1	36	36	57	3.2	2.7
Biomass and waste	1.9	2.3	2.9	6	6	8	1.9	1.6
Transport	**16.6**	**20.9**	**30.8**	**100**	**100**	**100**	**2.1**	**2.4**
Oil	16.3	20.5	30.4	98	98	99	2.1	2.4
Other fuels	0.3	0.3	0.3	2	2	1	0.2	0.0
Residential, services and agriculture	**9.4**	**9.8**	**10.6**	**100**	**100**	**100**	**0.3**	**0.4**
Coal	0.7	0.8	0.8	8	8	7	0.2	0.2
Oil	2.3	2.2	2.4	25	22	22	-0.5	0.1
Gas	0.0	0.4	0.9	0	4	8	26.0	13.7
Electricity	5.7	6.0	6.4	60	61	61	0.5	0.5
Biomass and waste	0.6	0.4	0.1	7	4	1	-3.7	-5.8

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