Clean Energy and Development for South Africa: Background data

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Report 1 of 3

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Abbreviations and acronyms used

CCGT	Combined Cycle Gas Turbine
CO_2	Carbon dioxide
CO	Carbon monoxide
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
EE	Energy Efficiency (used in naming conventions)
ERC	Energy Research Centre
FBC	Fluidised Bed Combustion
FCO	Foreign Commonwealth Office
FGD	Flue Gas Desulphurisation
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IEP	Integrated Energy Plan
IEP2	Second Integrated Energy Plan
IGCC	Integrated Gasified Combined Cycle
IPP	Independent Power Producer
LEAP	Long-range Energy Alternatives Planning
LTMS	Long-Term Mitigation Scenarios
MARKAL	Market Allocation model
NER	National Energy Regulator
NOx	Oxides of nitrogen
NRE	Non-Renewable Energy
OCGT	Open Cycle Gas Turbine
PBMR	Pebble-Bed Modular Reactor
PF	Pulverised Fuel
PPP	Purchasing Power Parity
PWR	Pressure Water Reactor
PV	Photo Voltaic
RDP	Reconstruction and Development Program
RE	Renewable Energy
RES	Reference Energy System
SO_2	Sulphur Dioxide
StatsSA	Statistics South Africa
SWH	Solar Water Heater
Toe	Tons of Oil Equivalent
TPES	Total Primary Energy Supply
UCT	University of Cape Town

Energy Units

Power

MegaWatt (MW)	Unit of power (rate of energy consumption)
	1MW = 1000 000Watts
GigaWatt (GW)	1GW = 1000MW

Energy

KiloWatt hour (kWh)	Unit of energy consumption (used in domestic electricity billing)
GigaWatt hour (GWh)	1GWh = 1000MWh = 1000 000kWh
TeraWatt hour (TWh)	1TWh = 1000GWh = 3.6 PJ
PetaJoule (PJ)	The Joule is the basic unit of energy
	1PJ = 10^{15} Joules

1. Introduction

Energy and economic development are inseparable. Without access to affordable energy, long-term development cannot take place. Historically the most used energy sources have been those nearest and easiest to consume. This has resulted in a global reliance on fossil fuels – initially coal but with increasing amounts of oil.

South Africa has large coal reserves, and small oil and gas reserves. As a result, coal is used for electricity generation and synfuel production. It is used by households in the commercial sector, the industrial sector and in the transport sector. In addition to the reliance on coal to meet energy needs, South Africa has an energy intensive economy which has developed from, and still relies heavily on, extraction and raw materials processing. Energy intensive industries, such us aluminium smelting and iron and steel extraction, where a large amount of energy is required to generate 'value added' income form the backbone of the economy.

Although some of the local side effects of burning fossil fuels, such as thick smoke and respiratory problems, have been a global problem for some time, it was not until the end of last century that attention was drawn to the fact that by burning fossil fuels and emitting greenhouse gases (GHGs), we are contributing to a change in the planet's atmosphere and a resultant change in climate. The Kyoto protocol is a voluntary global attempt to reduce GHG emissions. South Africa signed the Kyoto protocol as an Annex 3 country in 2002. As such South Africa does not yet have an obligation to reduce carbon emissions under the Kyoto Protocol but, it is believed that after 2012, during the second commitment period, South Africa may be required to actively reduce her GHG emissions,

In an emerging economy like South Africa, development and poverty alleviation are still the primary objectives. Other concerns relate to issues such as security of supply. The pressing social needs relating to energy use and energy access must be addressed. Many people rely on 'dirty' fuels to meet their daily energy needs, transport to and from the workplace is costly due to the urban sprawl created under apartheid. The lack of access to modern energy affects health and development and government is intent on addressing unemployment and increasing GDP growth in the coming years. Economic growth is accompanied by increased demand energy.

In this study, we use energy models in conjunction with sustainability indicators to quantify future energy planning paths (or 'road maps') with relation not only to cost, energy output and emissions but also to social and environmental costs and benefits. This in turn provides planners and policy makers with options and ideas of how planning decisions may affect the economic, social and environmental well-being of the country.

The aim of modelling is not to predict the future but rather to give an idea of what could happen. No model-generated results will be 100% accurate because there are many variables that could change with time that are taken into account when projecting into the future. The benefit of modeling is rather to provide an idea of what may occur so that planning can take place and policies can be developed which provide energy solution. Computer modelling of national energy systems is useful in energy planning as it provides a means of projecting future scenarios given past, current and anticipated future development trends. Energy models provide information on capacity needed, energy demand forecasts and the costs associated with meeting demand or following policies. The models themselves do not, however, address the larger goal of sustainable development or address the development needs of communities. Combined with sustainability indicators, energy models can provide planners with an idea of where policies are most effective in helping to move towards a sustainable energy future and where future policies should be focused to avoid moving away from sustainability goals.

In a large, capital-intensive industry such as the energy sector, the government plays a vital role in planning and providing investment for power stations, transmission systems and research and development. The first Integrated Energy Plan (IEP) was published by the Department of Minerals and Energy (DME) at the end of 2003. It provided a framework for making decisions on energy policy and for the development of different energy resources and technologies throughout South Africa. The Energy White Paper (1998) outlines government's wish to continue with integrated energy planning as a means to insure energy security and improve access to modern energy services. This project builds on and updates the first integrated energy plan and provides for government a base for the second integrated energy plan.

This work forms part of a project funded by the British Foreign Commonwealth Office to develop ‘road maps’ for clean energy development. The study used both the LEAP and MARKAL energy models to run a base case and a number of scenarios between 2001 to 2030. The LEAP model is an accounting planning tool, which is used to develop projections of useful energy demand. The MARKAL model is a least cost, linear programming model, which is used to develop the least cost pathways that are then tested against the sustainability indicators. This is the first of three reports on this work and documents the assumptions and data that form the base case of the model.

A national model is used to determine the sectors in which the greatest savings in cost and energy are achievable and where policy-measures should be focused. Sustainability indicators are then used to quantify the sustainability of planning decisions. Results are used to develop ‘road maps’ for planners to choose paths towards sustainable energy development.

1.1 Objectives

The study has three main objectives, firstly to update both the models and the data developed and captured during the first integrated energy planning process. Secondly, to project future scenarios for the South African energy system and determine how these developments compare to current sustainability indicators and thirdly to develop additional capacity for energy modelling in South Africa and particularly within the DME.

The aim here is to lay out the energy system in South Africa as it is today, the options for the supply and transformation of energy that are currently used and that may be available over the planning period. The document also informs the base case for the model and attempts to clearly document assumptions that have been used to develop the economic, demand and population projections. As the model is to be made available to the DME for use by its energy modelers and planners on completion, the document serves as a guide to the model for the energy officers who will be using the model.

1.2 Methodology

1.2.1 Data collection

Previous work by the ERC, DME, StatsSA and other national energy agencies was collected and assimilated for use in the model. Additional research into specific sectors such as transport, transformation and biofuels was performed.

1.2.2 Data review

Initially the data was presented for review to the working groups and stakeholders participating in the second IEP process. When the integrated energy planning process was put on hold by the DME, data was presented to the SBT review groups reviewing data for the Long Term Mitigation Strategy study being completed by the Department of Environmental Affairs and Tourism. The working groups comprised both industry, academic and government reviewers from diverse groups such as Eskom, Anglogold, Sasol, DME, Department of Transport, Department of Environmental Affairs and Tourism etc. A complete list of participants in the review process can be found in Appendix A.

2. The South African energy system

The South African economy is dominated by energy intensive industry meaning that for every rand of economic output, a large amount of energy is required (Hughes et al. 2002). Annual per capita energy consumption in South Africa is 2.51 tons of oil equivalents (Toe) compared to a world average of 1.67. Table 1 below compares the energy intensity of South Africa to other countries.

Table 1: Energy intensity in South Africa compared with other countries

	TPES/capita (Toe/capita)	*TPES/GDP (Toe/000 1995 US$)*	*TPES/GDP (Toe/000 PPP 1995 US$)*	*Electricity consumption per capita (national average) (kWh/capita)*
South Africa	2.51	0.63	0.29	4 533
Africa	0.64	0.86	0.32	501
South Korea	4.10	0.31	0.30	5 901
Indonesia	0.69	0.70	0.25	390
Non-OECD	0.96	0.74	0.28	1 028
OECD	4.78	0.19	0.22	8 090
World	1.67	0.30	0.24	2 343

TPES = total primary energy supply, toe= tons of oil equivalent, PPP= purchasing power parity (adjusted to remove distortions of exchange rates),GDP= gross domestic product

South Africa's high energy intensity is a result of large energy-intensive industries that focus on primary extraction and low-grade processing and a low cost of energy including electricity. It is well known that South Africa has one of the lowest electricity costs in the world. This encourages the development of further energy intensive industries and means that there is little or no encouragement for sectors to improve their energy efficiency. If South Africa followed the development path of industrialized countries and moved towards more service industry, commerce and refined processing and beneficiation, the energy intensity would decrease. However, the opposite effect could also take place: as developed countries do less primary processing due to high energy costs and stringent emissions control, more external processing is brought to South Africa. An example of this trend is with aluminium smelting: South Africa has little of its own aluminium resources but has large smelters and is looking to develope another for processing of international resources.

These energy intensive industries rely on a stable, reliable supply of cheap energy. Until recently there has been no doubt that South Africa's national electricity supplier, Eskom, and plentiful coal supplies could supply this. However, there is currently a shortage of excess capacity and South Africa will need to look at increasing the generation capacity if economic growth is to continue.

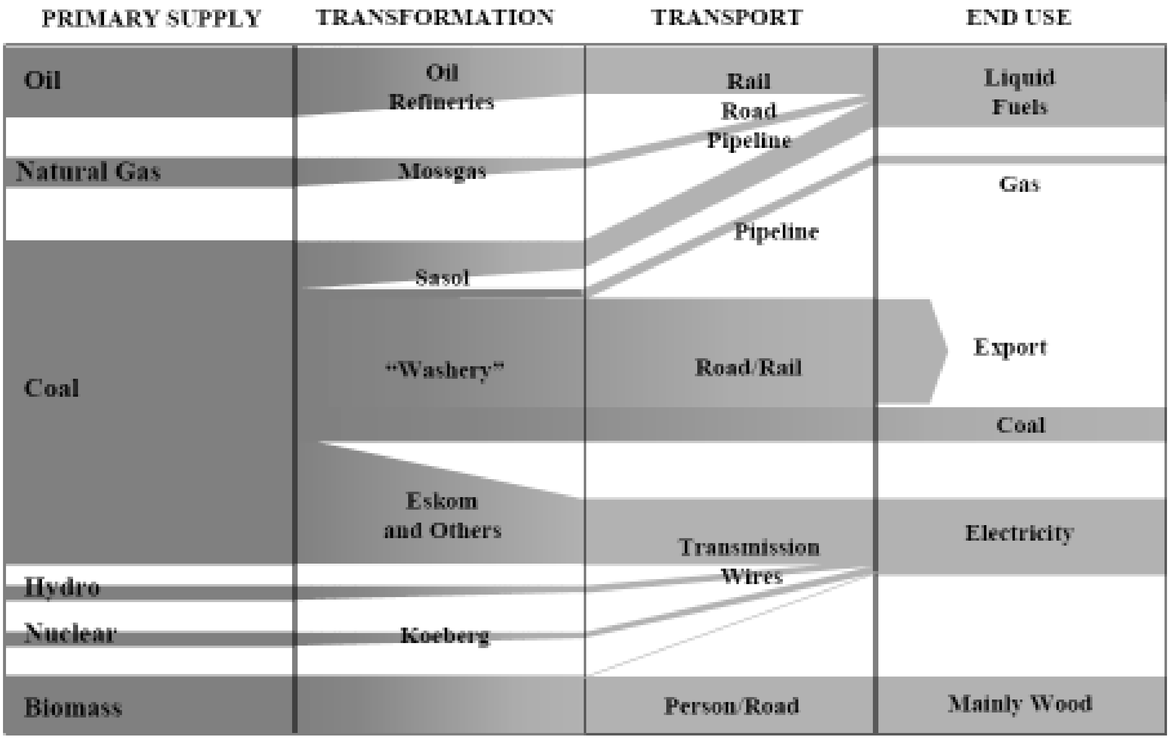


Figure 1: SA energy mix

Source: DME, 2003

A brief outline of the energy flows in South Africa is given in Figure 1, showing primary energy supply through transformation to end use. The thickness of the bar indicates the amount of energy by energy carrier. Coal clearly dominates as a primary energy source whereas liquid fuels and electricity are the major final energy carriers. Traditional biomass plays an important role in meeting energy demands in rural households. The nature of biomass use is not considered sustainable since biomass regrowth is generally slower than the rate of consumption from informal wood gathering.

2.1 Primary energy supply

Energy supply is made up of primary supply and energy transformation. Primary energy is extracted or collected as in the case of mining for coal, drilling for oil, collecting fuelwood or capturing solar radiation. These products can be used directly, for example burning wood for cooking and heating, or converted into another energy carrier such as electricity.

South Africa's large coal reserves supply over 70% of the country's primary energy. South Africa also has large reserves of uranium and small reserves of oil and gas. Potential for the use of renewable energy varies within the country but overall solar radiation is strong, wind power could be utilized in coastal regions and biomass is used for firing boilers in the sugar and paper and pulp industries. Limited large-scale hydro potential is available however there is potential for small- or micro-sized installations.

Figure 2 below shows the total primary energy supply (TPES) for South Africa between 1992 and 2004 (DME 2006). Coal dominates energy supply, but the second biggest energy carrier is imported crude oil needed for the supply of liquid fuels for transportation. Renewables in this case includes the large use of fuelwood in rural low income households. The use of biomass in the residential sector is often excluded from renewables as it is not viewed as a sustainable resource and impacts negatively on health. Moderate amounts of nuclear, gas and hydro also contribute to the energy mix.

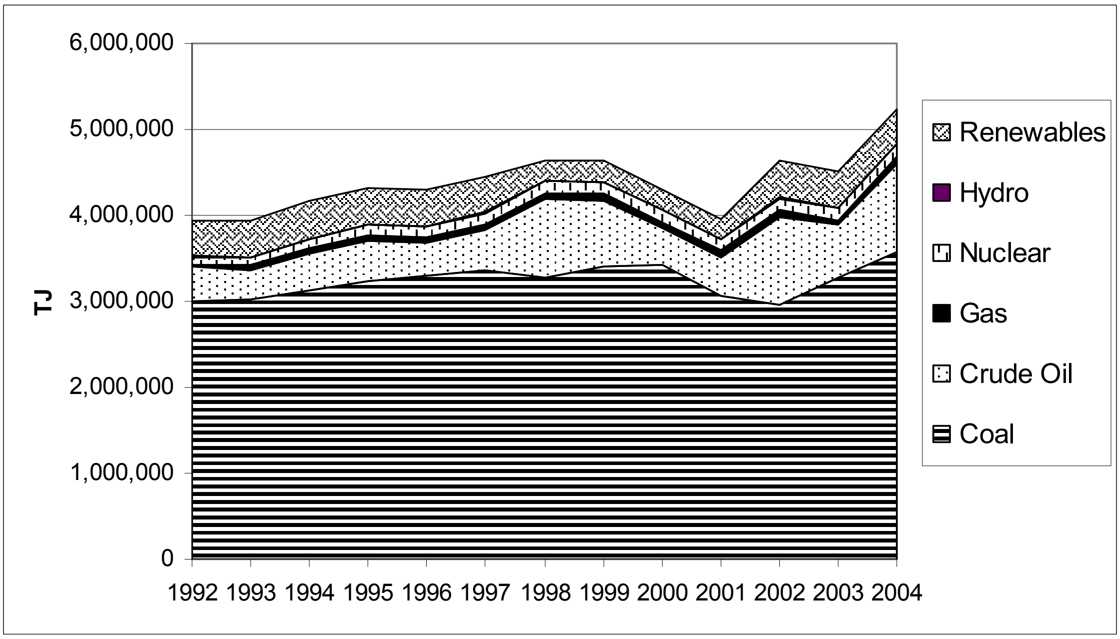
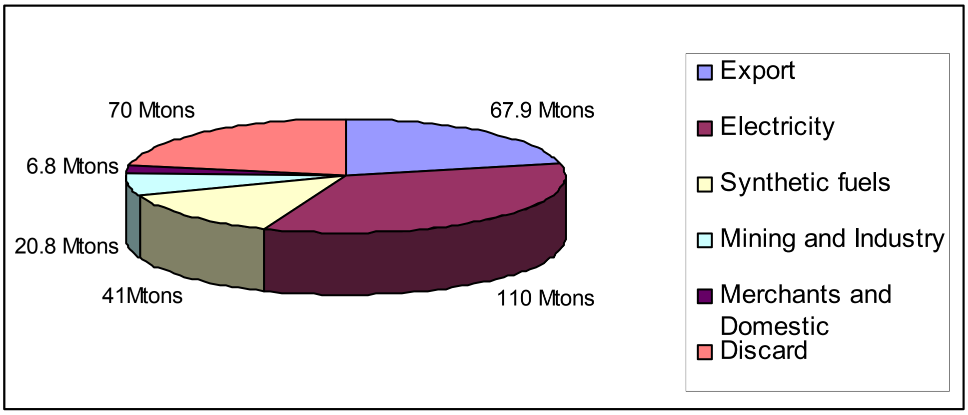


Figure 2: TPES for South Africa by energy carrier, 1992 – 2004

2.1.1 Coal

Coal mining in South Africa plays a vital role in the energy sector as well as the economic health of the country. In 2005 the total value of coal extracted, at almost R36 billion, was greater than that of gold (StatSA, DME, 2006). South Africa is the 6th largest exporter and coal exports form a significant part of foreign income. Approximately 80% of coal production comes from Mpumalanga, 11% from Limpopo Province, 7% from the Free State and 1% from KwaZulu-Natal (Prevost & Msibi, 2005). Most coal extracted from South African mines is bituminous coal with a high ash and low sulphur content. Its heating value ranges from about 27.5MJ/kg for export coal to between 22 and 15 MJ/kg for steam coal used locally for power generation and synfuel production (Winkler et al, 2006).

Of the approximately 317 Mtons of coal extracted, 28% is exported, 22% is discarded and the rest is sold within South Africa (Prevost, Msibi, 2005). As can be seen in Figure 3, the major portion of extracted coal is used in electricity production by Eskom. The second largest user within South Africa is the synthetic fuel company, Sasol, who uses coal in an advanced coal-to-liquid process. Mining and Industry use coal directly for firing boilers and the remaining coal is sold to merchants or used in domestic households and in the transport sector.



Total: 317Mtons

Figure 3: Coal use in South Africa, 2004
Source: Prevost, Msibi (2005) and Surridge (2006)

2.1.2 Oil and natural gas

While South Africa has small reserves of oil off the south coast, most of its oil requirements are imported from Saudi Arabia and other Middle Eastern countries. The proven reserves at the Oribi/Oryx Fields and Sable field amount to 49 million barrels. The newer Sable field, which is located in the Bredasdorp basin offshore about 150 km Southwest of Mossel Bay, will eventually produce 30 000 to 40 000 barrels per day which will replace up to 10% of South Africa's imported oil (Winkler et al, 2006).

Small reserves of natural gas are found off the west and south coast. The proven gas reserves are currently estimated at about 57 billion m^3 but after drilling and exploration they could be as extensive as 765 billion m^3. The only gas field currently in operation is the F-A field on the south coast. It supplies about 5.4 million m^3 of gas and 7100 barrels of condensate per day to the synfuel plant, Mossgas, in Mossel Bay where liquid fuels such as petrol, diesel and kerosene are refined (Winkler et al, 2006). This small reserve is expected to run out by 2008, but PetroSA and joint venture partners are exploring adjacent areas for more gas.

South Africa's neighbouring countries, Namibia and Mozambique also have small gas fields and plans are underway to integrate these resources, as well as gas fields in Temane, Angola, into the South African gas pipeline system.

Coalbed methane is found in varying amounts in coalfields throughout South Africa. While this resource has not yet been tapped, South Africa has reserves of 85 billion m^3 mainly in the Waterberg and Perdekop regions (Winkler et al, 2006). Latest studies estimate that the coalbed methane from the Karoo basin is unlikely to be economically attractive, however reserves in Botswana that can be economically recovered could be as high as 40Tcf.

2.1.3 Uranium

Unlike fossil fuels, the energy in nuclear energy reserves is highly concentrated therefore transport and storage costs become negligible. Uranium is a by-product of the gold mining industry since, in South Africa, uranium and gold are found together in mineral deposits. An estimated 261 000 tons of uranium are available in South Africa, of which 205 000 tons are 'reasonably assured resources' and the other 56 000 tons are 'estimated additional resources' (DME 1998). If used to generate electricity in conventional reactors, these reserves would equate to 158 EJ of energy.

In 2003 South Africa's uranium output totalled 751 tons of uranium. (Note: uranium is extracted and transported as U3O8 but the above tonnage refers to the uranium content). This is a great deal lower that its historic peak of 6 147 tons U in 1980 (Damarupurshad, 2005). During apartheid, South Africa had capabilities of enriching uranium for use at Koeberg nuclear power station, however since the early 1990s, all extracted uranium is exported and enriched fuel for nuclear power is imported from Russia. The enrichment of uranium within South Africa in the future is being investigated.

2.1.4 Biomass

Despite South Africa being an arid country with many areas that are unfavourable for biomass development, biomass is an important source of energy by households for domestic energy and in industries such as sugar refining and paper and pulp. Of South Africa's sugar cane harvest of 20 million tons, 7 million tons is bagasse (husks) with a heating value of 6.7 MJ/kg. Most bagasse is used in the refineries to raise steam for electricity generation and process heat. The sugar industry has an installed generation capacity of about 245 MWe (Winkler et al 2006).

The pulp and paper industry in South Africa produced 2.32 million tons of pulp and 2.34 million tons of paper in 2003 (PAMSA 2006). In order to fire boilers, generate electricity and produce process steam, bark from softwood such as pine as well as 'black liquor' from pulp mills is used. The pulp mills have an installed generation capacity of 170 MWe (Winkler et al 2006).

Biomass use in households is very difficult to measure since it is mainly poor households in rural areas that use biomass for heating and cooking. Biomass can be in the form of fuelwood, dung and other vegetable matter. It is estimated that 2.5 million tons (an energy value of about 38PJ) of biomass is consumed in this way. It must be made clear that while biomass is often regarded as a renewable resource and carbon neutral, this is not always the case for rural, unregulated use of natural vegetation. Forests and local plants are cut down for fuel wood and insufficient time is given for regrowth. Unsustainable practices like this lead to erosion, desertification and a lack of fuel supply for local people.

Fuels such as biodiesel, ethanol, methanol and hydrogen can be produced from biomass. Bioethanol is usually processed from wheat, sugar beet, sugar cane and sweet sorghum while biodiesel is produced from rape oilseed, sunflower oil, Jatropha and a new technology that uses a lipid-rich type of algae. The primary drawback for fuels from biomass is the cost of the feedstock. Cheaper feedstocks such as wood could reduce the cost of production and help make biofuels more competitive in relation to fossil fuels (EC 2002). Rural areas can benefit from a biofuels industry because biomass plantations can generate income and provide jobs.

Although biomass energy is usually regarded as carbon neutral and renewable there are certain concerns regarding the environmental impact of large-scale biomass-based energy generation. Particular concerns are as follows (Banks & Schaffler, 2006):

- Water: South Africa is a water-stressed country and introduced plant species are known to require more water than native species. If biomass plantations require irrigation this in turn requires water from dams or precious ground water sources, and energy to pump the water around.
- Food scarcity: If land is taken up with energy crops rather than food crops, there is a greater risk of food scarcity particularly in times of drought.
- Biodiversity: Large-scale monoculture energy crops could have significant effect on species diversity and land quality.
- Price effect on staple crops: The increase in demand for certain crops could drive up the price of food.

2.1.5 Hydroelectricity

Hydroelectric power is site-specific and relies on hydrology and topography. Given that South Africa is a water-stressed country, few of its rivers are suitable for hydroelectricity. Currently South Africa has an installed capacity of 665 MWe and while the potential for large-scale hydroelectricity is limited, there are an estimated 3 500 to 5 000 potential sites for mini-hydropower (less than 5MW) generation mainly along the eastern escarpment (Winkler et al, 2006). Other countries in Southern and Central Africa have great potential for hydroelectricity generation. South Africa currently imports hydroelectricity from the Cahora Bassa Dam in Mozambique. Potential for importing hydroelectricity from other dams on the Zambezi River, or other Southern African rivers as well as from the Inga dam in the Democratic Republic of Congo (DRC) is great. One challenge is to establish and maintain political stability and a robust transmission network. Table 2 summarises the potential for hydroelectric power in neighbouring countries

Table 2: Summary of potential for hydroelectric power in Southern Africa
Source: Winkler et al (2006)

Location	*Country*	*Potential (MWe)*
Zambezi River Basin		
Kariba North Extension	Zambia	300
Batoka Gorge	Zambian side only	800
Devil's Gorge	Zambia / Zimbabwe	1 240 – 1 600
Mupata Gorge	Zambia / Zimbabwe	1 000 – 1 200
Cahora Bassa North Bank Extension	Mozambique	550 – 1 240
Mepanda Uncua	Mozambique	1 600 – 1 700
Total Zambezi		Approx. 6 000
Other sources excluding Inga		
Angola	Including Kunene Basin	16 400
Lesotho		160
Malawi		250
Mozambique	Other than Zambezi	1 084 – 1 308
Namibia	Other than Kunene Basin	500
Swaziland		60
Tanzania		3 000
Zambia	Other than Zambezi	1 084 – 1 308
Total other sources excluding Inga		**22 000 – 23 000**
Inga		36 000 – 100 000
Total southern Africa		**70 800 – 134 800**

2.1.6 Solar

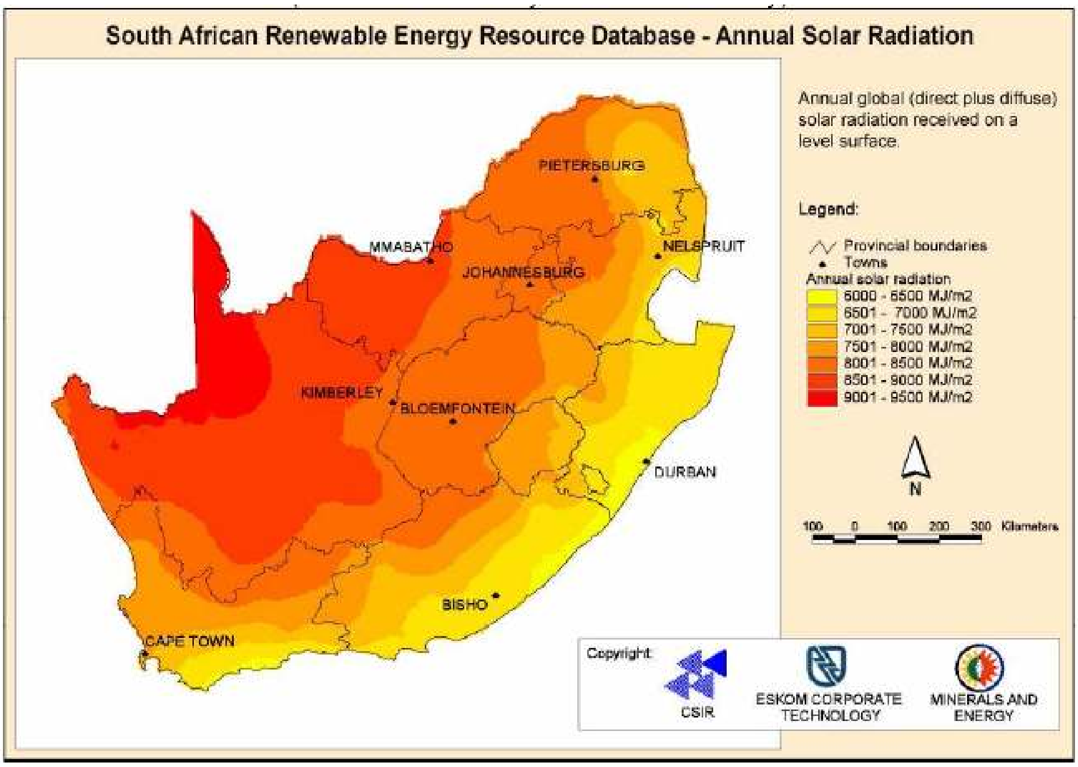
Solar radiation levels in South Africa are amongst the highest in the world. The annual 24-hour solar radiation average for South Africa is 220 W/m^2, compared with 150 W/m^2 for the USA and about 100 W/m^2 for Europe. Most of the interior parts of the country receive an average insolation in excess of 5 kWh/m^2/day with some parts of the Northern Cape averaging over 6 kWh/m^2/day.Figure 4 shows the distribution of solar energy over South Africa.

2.1.7 Wind

South Africa's best wind resources are found along the coast and in some of the more mountainous regions particularly in the west of KwaZulu Natal. Farmers in South Africa already make use of wind energy with wind powered water pumps. An estimated 30 000 systems are installed and although initially imported, they are now made locally to such a high standard that systems are now being exported (Banks & Schaffler, 2006).

Wind could also be an important source of energy for electricity generation. In 2003, a South African renewable energy strategy formulation team (DME, 2004) estimated the total wind generation potential to be 60 TWh per annum. At a capacity factor of 30%, this equates to approximately 23 GW of installed capacity. It may be claimed that this is a conservative estimate given the assumptions made for wind availability, efficiency and available land (Banks & Schaffler, 2006). The first commercial wind farm in South Africa is under construction in Darling in the

Western Cape with a first phase of 5MW installed to be completed by the end of 2007. Figure 5 illustrates that the strongest winds are in the coastal regions and certain mountainous areas.



Note: 1300 MJ/m^2/year = 1 kWh/m^2/day

Figure 4: Annual solar radiation for South Africa
Source: DME, Eskom & CSIR (2001)

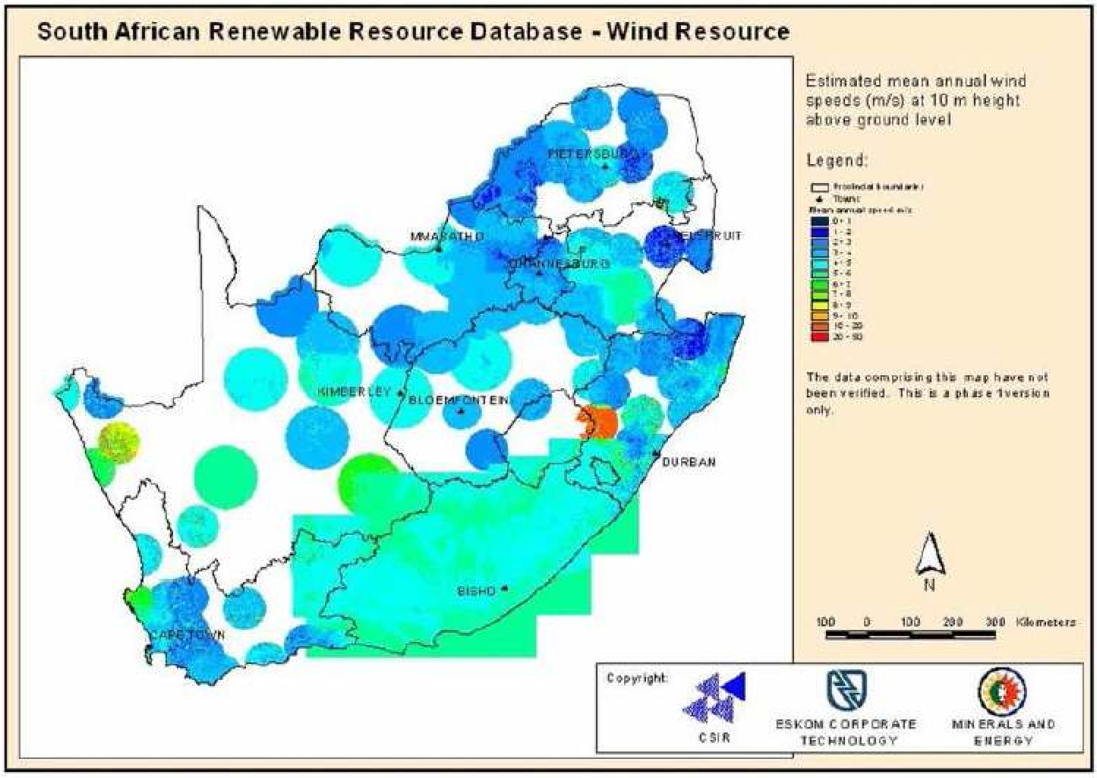


Figure 5: Annual average wind speeds in South Africa
Source: DME, Eskom & CSIR (2001)

2.2 Transformation: Electricity generation

Primary energy undergoes transformation and is converted into a final energy carrier that is convenient for human consumption. For example, crude oil is refined to petrol and diesel, paraffin and other fuels; coal is burnt in a power station to produce electricity. These along with the use of Coal for liquid fuels are the primary transformation processes in South Africa.

South Africa generates over half the electricity used in Africa. This production is dominated by the national public utility, Eskom which generates 93.5% of total production (NER, 2001). Municipal generators and certain industries like pulp mills, sugar refineries, Sasol and Mossgas also generate small amounts of electricity. Eskom has a licensed capacity of 42011 MWe which includes 3541 MWe of non-operating (mothballed) coal power stations (Eskom Annual report,2005). The mothballed stations will be brought on stream over the next few years. Table 3 shows the current licensed capacity of Eskom power stations, which is dominated by coal.

Table 3: Eskom licensed capacity

Source: Eskom (2005); Winkler et al (2006)

Coal-fired stations	*Number of units x unit capacity*	*Nominal Capacity (MWe)*	*Total net Capacity (MWe)*	*First unit commissioned*	*Cooling*
Arnot, Middelburg	6 x 350	2 100	1 980	1971	Wet
Camden, Ermelo	8 x 200	1 600	Mothballed	1966	Wet
Duvha, Witbank	6 x 600	3 600	3 450	1980	Wet
Grootvlei, Balfour	6 x 200	1 200	Mothballed	1969	Wet
Hendrina, Hendrina	10 x 200	2 000	1 895	1970	Wet
Kendal, Witbank	6 x 686	4 116	3 840	1988	Dry
Komati, Middelburg	5 x 100; 4 x 125	1 000	Mothballed	1961	Wet
Kriel, Bethal	6 x 500	3 000	2 850	1976	Wet
Lethabo, Sasolburg	6 x 618	3 708	3 558	1985	Wet
Majuba, Volksrust	3 x 657; 3 x 713	4 110	3 843	1996	Wet/Dry
Matimba, Ellisras	6 x 665	3 990	3 990	1987	Dry
Matla, Bethal	6 x 600	3 600	3 450	1979	Wet
Tutuka, Standerton	6 x 609	3 654	3 510	1985	Wet
Subtotal coal-fired stations		37 678	32 066		
Gas turbine stations					
Acacia, Cape Town	3 x 57	171	171		
Port Rex, East London	3 x 57	171	171		
Subtotal gas turbine stations		342	342		
Hydroelectric stations					
Colley Wobbles, Mbashe River	3 x 14	42			
First Falls, Umtata River	2 x 3	6			
Gariep, Norvalspont	4 x 90	360	360		
Ncora, Ncora River	4; 1 x 1,3	2	2		
Second Falls, Umtata River	2 x 5,5	11	11		
Vanderkloof, Petrusville	2 x 120	240	240		
Subtotal hydroelectric stations		661	600		
Pumped storage schemes					
Palmiet, Grabouw	2 x 200	400	400		
Drakensberg, Bergville	4 x 250	1 000	1 000		
Subtotal pumped storage		1 400	1 400		

Coal-fired stations	*Number of units x unit capacity*	*Nominal Capacity (MWe)*	*Total net Capacity (MWe)*	*First unit commissioned*	*Cooling*
schemes					
Nuclear power station					
Koeberg, Cape Town	2 x 965	1 930	1 800		

The current National breakdown of generation capacity including capacity owned by independent power producers and municipalities can be found in Table 4. The percentage of electricity supplied by each fuel can be seen in Figure 6. The mix of electricity generation capacity is dominated by coal, with nuclear electricity from Koeberg in the Cape making up an additional 6%. Other smaller stations to meet peak requirements are open cycle gas turbines (0.1%) and pumped storage and hydro stations (2%).

Table 4: Existing generation capacity including non-Eskom licensed capacity
Source: NER (2004)

Total installed capacity excl. mothballed capacity (MW)	
Coal	38 209
Nuclear	1 800
Bagasse	105
Hydro/ pumped storage	661
pumped storage	1 400
Gas turbines	342
Mothballed capacity (MW)	
Coal	3 541

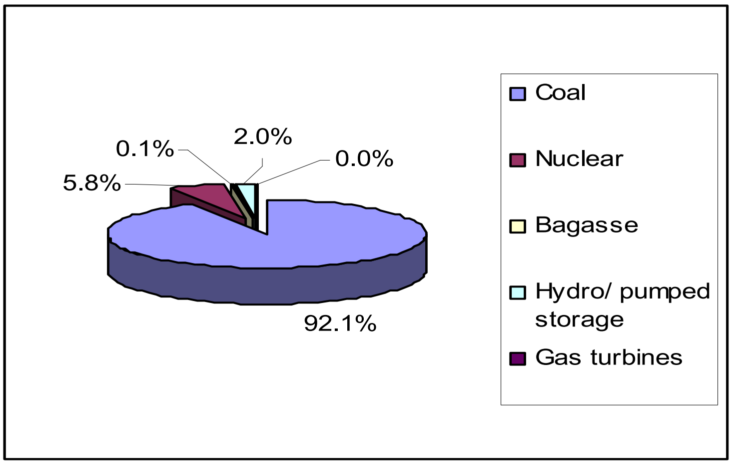


Figure 6: Output of plants as a percentage of electricity supplied
Source: NER (2004)

The demand for electricity increased rapidly towards the late 1960s when South Africa underwent a period of rapid economic growth. The South African government began a large-scale programme to build large coal powered stations. The 1960s economic boom slowed in the 1980s but the long lead times of power stations meant that the building programme continued and by the early-1990s there was a large over capacity resulting in some of the older and less economically attractive plants being 'mothballed' (put out of service for future use). Since 1994 an increased demand for electricity has closed the gap of over capacity and recent power shortages in 2005 have brought to our attention the fact that South Africa is in the process of facing a shortfall of electricity generation. New power stations will soon be required.

Currently electricity makes up 28% of final energy demand in the country (DME, 2005). Imports and exports of electricity are roughly equal at about 3% of total electricity consumed by South Africa. Electricity is imported from Mozambique and Zambia and exported to Zimbabwe, Botswana and Namibia. Alternative plants for the electricity generation options are described below.

2.2.1 Coal-fired PF

Conventional pulverized fuel (PF) combustion is common throughout the world and the majority of South Africa's electricity is generated in these types of plants. Finely ground coal particles are blown into the boiler where they are burnt. Heat from combustion is transferred through the water-cooled walls of the boiler and a number of heat-exchangers to produce high pressure steam. This steam passes through a steam turbine which in turn drives an electric generator.

Different configurations of steam plants are used to produce electricity-only or to co-generate (combined heat and power). In combined heat and power plants, the energy in the steam is also used for other applications, which increases efficiency. In South Africa, most power plants are electricity only, however in the future there may be development of more cogeneration plants.

The temperature and pressure at which the steam is generated is the key design feature of a conventional PF plant. All PF plants currently in use in South Africa use sub-critical boilers (the steam pressure is below the critical pressure of water – approximately 218 atmospheres).

Supercritical boilers are a proven technology that raise pressure above this, thus increasing the efficiency. The recorded efficiency of supercritical plants around the world varies greatly from 36 to 47%. It is estimated that these plants in South Africa which will be dry cooled will have an efficiency of between 36 and 40%. Specialised alloys are required to withstand high-pressure steam which increases the cost for components throughout the power plant. In the future, most large coal-fired plants are likely to have supercritical boilers.

Emissions control is an important cost factor of all PF plants. Current emissions control in South Africa involves basic particulates control but any future coal-plants built will include flue-gas desulphurisation (FGD). We assume all new coal plants include FGD at over 90% efficiency through bag-house filters. The predominant FGD system consists of a reaction vessel in which sulphur dioxide is absorbed from the flue gas stream by a slurry of limestone or other reagent. These systems add cost and reduce generation efficiency of the power plant, however removal efficiencies are sometimes higher than 95%. NOx control systems relate to the coal combustion itself and involve the flow of air into the combustion zone and the type of burner used.

2.2.2 Fluidized-bed combustion (FBC)

This new technology is proven in many countries, but has not yet been used in South Africa. Coal is burnt in a 'bed' or dense cloud of aerodynamically suspended particles. The airflow suspending the particles is sufficiently strong that a portion of the particles is entrained out of the boiler and recirculated back into it via cyclones. Water is heated in the same way as a conventional power plant and steam is raised to turn turbines and drive electric generators. FBCs have environmental advantages over other coal-fired plants:

- Combustion temperatures are generally lower than in a typical PF plant thus reducing the production of thermal NOx.
- The need for expensive FGD equipment can be avoided by injecting sorbent (for example limestone) directly into the fluidised bed boiler. This allows for fuel flexibility as lower grade (high sulphur content) coal can be used.

In South Africa, the use of FBCs is particularly attractive since 'discard coal' (low grade currently unusable coal) can be used. However, when discard coal is used in an FBC, efficiency is lower and the emissions are worse than from a PF station using higher grade coal. Another disadvantage is that FBCs have a lower efficiency than sub- or super- critical PF plants (Van der Riet et al, 2005). South African coal also has charisteristics which provide challenges to FBC design. This may explain why the use of FBC technology still seems far away for large-scale generation but is perhaps most appropriate for onsite generation of coal mines. In FBCs, coal can be supplemented with different types of biomass.

2.2.3 Integrated gasification combined cycle (IGCC)

Gasification technology increased the coal power-generation cycle efficiency by combining two or more energy cycles: a high-temperature gas turbine cycle and a steam turbine cycle. In most applications coal is partially combusted in an oxygen-blown gasifier to yield a synthetic gas (syngas) which is predominantly carbon monoxide and hydrogen. The syngas is cleaned before being burnt in a high efficiency gas turbine to produce electric power. The exhaust gases from the gas turbine are cooled in a heat-recovery steam generator (HRSG) and the steam is sent to a steam turbine for additional electricity generation.

The choice to use oxygen rather than air as a source of oxygen for gasification means that components can be smaller as the volume of source gas is smaller and the heating value of the gas produced is closer to that of natural gas. The gas turbine therefore requires less modification to burn the syngas produced in an oxygen-consuming gasifier. Nevertheless the need for a dedicated cryogenic oxygen production facility adds to the cost of the system.

IGCC has the following benefits:

- Cleaning of syngas can result in very low stack emissions, comparable with natural gas fired power stations
- Efficiencies of up to 48% by utilising advances gas turbine technologies and combined cycle processes.
- Sulphur removal rates are very high (98%) thus systems can be designed to handle fuels with very high sulphur content. Removed sulphur can also be used in the chemical industry.
- Produces a sintered glassy ash which locks in most chemical components found in fly ash.
- Offers the potential to remove CO_2 from the syngas for carbon sequestration.

2.2.4 Open-cycle gas-turbine (OGCT)

An OCGT power plant is basically a simple gas turbine connected to a generator and auxiliary systems such as the fuel supply system, lube cooling system, fire protection system and the control system. In South Africa all current gas turbine power plants are OGCTs run on liquid fuels such as diesel or kerosene. Of the 662MWe of gas turbine capacity in South Africa, about half are owned by Eskom and half are owned by municipalities. These plants are currently used for emergency power or for peaking power.

2.2.5 Gas-fired combined-cycle gas-turbine (CCGT)

A new type of gas turbine plant to be used in South Africa is the CCGT. In a CCGT power plant, the gas turbine is usually run on natural gas and the hot exhaust gases are used to generate steam in a HRSG. The steam is then delivered to a steam turbine for additional power generation. In a CCGT plant, about two-thirds of the electrical power is derived from the gas turbine while the steam turbine contributes the remaining third. The greatest advantage of a CCGT is the very high efficiency (50 – 60%), the low capital costs per kWh and the quick construction time.

The first CCGT in South Africa is under construction in Newcastle, KwaZulu-Natal and will produce 15MW electricity and 120 000t/h of industrial steam (Le Roux 2006). The plant is owned and operated by an independent power producer and is scheduled to start production in January. More power plants of this type could prove beneficial to the South African power mix provided that gas supply and gas prices are acceptable.

The type of fuel used by a gas turbine plant determines the emissions. Natural gas has lower emissions than liquid fuels, however both gas and liquid fuels are cleaner fuels than coal. Natural gas has little or no sulphur or particulates.

2.2.6 Nuclear power plants: pressure water reactor (PWR)

South Africa's only nuclear power plant, Koeberg, is situated 30km North of Cape Town and consists of two PWR units. Each unit has a capacity of 920MWe and it cooled by sea water. In this system, water inside a pressurised reactor is heated up by uranium fuel in the reactor. High temperature, high pressure water is passed through a heat-exchanger to a secondary water system in which steam is produced. This steam drives turbines that generate electricity. Plans for future plants of this type are underway.

2.2.7 Nuclear power plants: pebble-bed modular reactor (PBMR)

A nuclear technology in which South Africa has invested a great deal is the PBMR. This is a small, simple, inherently safe design using helium as the coolant and graphite as the moderator. The fuel consists of uranium surrounded by multiple barriers and embedded in graphite balls or 'pebbles'. The first demonstration module (165MWe) will go into production in 2013 provided that legal and political approvals are granted. Thereafter 24 modules of 165MWe each will be implemented.

2.2.8 Hydroelectric power and pumped storage

Hydroelectricity makes use of natural hydrology and topography. Water at a certain height is trapped (usually in a dam) or diverted to pass through turbines that generate electricity. Being a water-stressed country South Africa does not have vast hydroelectricity resources. There are 665MWe of installed hydroelectric power in South Africa of which most is owned by Eskom. Only two of the hydroelectric stations are over 50MWe – Gariep (360MWe) and Vanderkloof (240MWe). While potential for large hydroelectric schemes is limited, there are possibilities for small- and micro-hydro plants.

Pumped storage is not considered a regular power generation facility since it uses electricity at off-peak times to pump water from a lower reservoir into a higher reservoir. This water is then released during peak electricity demand through pump-turbines to generate power. While these stations are net users of electricity, they are important storage systems for load following. The two large Eskom owned pumped storage stations are Drakensberg (1000MWe) and Palmiet (400MWe) while the Cape Town municipality owns the Steenbras station (180MWe). A new pumped storage scheme is planned for Braamhoek on the Free State/KwaZulu-Natal border which will consist of four 333MWe units.

2.2.9 Wind

Wind turbines consist of a rotor, generator, directional system, protection system and tower. Wind spins the rotor blades which drives the generator thus turning mechanical energy into electrical energy. Gearing is some times used to increase the rotation speed for electricity generation. The directional system enables horizontal axis machines to orientate themselves into the wind for maximum power. Modern turbines are usually equipped with protection systems such as variable orientation of blades, mechanical brakes or shut-down mechanisms to prevent damage during excessive wind loads. The tower raises the rotor above the ground to capture the greater windspeeds and avoid turbulence caused by ground-interference.

Until the mid 1980s, wind turbines had typical outputs of less than 100kW and rotor diameters from 10m. In the mid 1990s turbines ranged from 0.5WM – 1.5MW and today commercial prototypes of 3.6MW with greater than 80m rotor diameters are being installed. This increase in size of turbines as well as an economy of scale in many European countries that are installing large on- and offshore wind farms, has led to significant reductions in cost.

Currently in South Africa no electricity on the national grid is generated from wind. Nevertheless wind was important traditionally, and continues to be, for water pumping on farms. An estimated 30 000 systems are currently installed (Banks & Schaffler, 2006). There are also about 500 wind turbines on farms that generate direct current electricity, usually at 36V.

In 2003, Eskom installed two 660kWh wind turbines and one 1.7MWe at Klipheuvel in the Western Cape as part of the South African Bulk Renewable Energy Generation (SABRE) programme of demonstration and research. An independent group, Darling Independent Power Producer (Darlipp), is an example of an independent power producer in South Africa. The Darling wind farm project in the Western Cape has a planned initial capacity of 5MW with intentions to expand to 10MW.

2.2.10 Concentrating solar power systems

Concentrating solar power (CSP) can be exploited though three different systems: parabolic trough, parabolic dish and power tower. All CSP systems make use of a concentrator which captures and concentrates direct solar radiation and delivers it to the receiver. The receiver absorbs the concentrated sunlight and transfers the heat to a power-energy conversion system. The parabolic trough uses linear parabolic mirrors to reflect sunlight. The parabolic dish system collects sunlight through a round parabolic solar collector and the power tower employs heliostats (large sun-tracking mirrors) to concentrate solar energy onto a central tower-mounted receiver.

The parabolic trough is the most mature of the technologies however the power tower is looking more attractive with its potentially lower cost and more efficient thermal storage. The dish/engine systems can be used in smaller applications.

CSP systems can also be 'hybridised' or operated in combination with conventional fossil fuels. For example parabolic troughs can be combined with gas combined-cycle systems.

In South Africa, as part of the SABRE programme initiated in 1998, a 25kW solar dish with a Stirling engine was installed at the Development Bank of Southern Africa in Midrand in 2002. Eskom is also studying the feasibility of building a 300MWe solar thermal power station near Uppington in the Northern Cape. If built, this station would have three 100MWe units concentrating sunlight via heliostats onto a central power tower in which molten salt would absorb the heat. The salt is able to store heat thus allowing the station to deliver electricity 24 hours a day.

2.2.11 Solar photovoltaic systems

Photovoltaic (PV) technology transforms the energy of solar photons into direct electric current using semiconductor materials. When photons enter the photovoltaic cell, electrons in the semiconductor are freed, generating direct electric current. The process of converting sunlight to electricity has very low efficiency: Laboratory tests achieve up to 32% efficiency but in practice it is much lower than this. There are many different solar cell designs but the most common semiconductor materials are single-crystal silicon, amorphous silicon, polycrystalline silicon, cadmium telluride, copper indium diselenide and gallium arsenide. The most important PV cell technologies are crystalline silicon and thin films, including amorphous silicon (NEA et al,2005).

PV cells are connected to form a PV module or panel. PV modules come in standard sizes ranging from less than a watt to around 100 watts. PV modules can be connected together to form an array. In order to obtain useful electricity from the PV array, a number of other elements such as an inverter, batteries, charge controller are required. PV systems can either be used as stand-alone off-grid systems (often applicable in remote areas when extension of the grid is too expensive or infeasible), grid-connected systems in buildings or large utility-scale systems.

In South Africa no electricity from solar power is generated for the national grid but PV systems are widely used in rural areas. It is estimated that about 70 000 households, 250 clinics and 2 100 schools have PV panels. Programmes are in place to increase the number of these systems (Winkler 2006).

2.2.12 Biomass

Much biomass is used in South Africa for heating, lighting and cooking in low-income households. The industrial use of biomass is small but significant. Annually South Africa's sugar industry produces about two million tons of sugar from about 20 million tons of cane. Approximately seven million tons of bagasse is burnt in boilers to make steam for electricity generation and process heat.

The paper and pulp mills in South Africa also use biomass to generate electricity with an estimated capacity if 170MWe. The mills burn sawdust and bark to make steam for electricity generation and process heat. In chemical pulp mills, 'black liquor' is separated from wood fibres after passing through digesters. This black liquor is burnt in recovery boilers to make steam. The pulp and paper industry is expanding and there is room for expansion of generating capacity both for onsite use and for sale to the national grid.

Biofuels from biomass such as ethanol (both liquid and gel) and biodiesel are receiving considerable attention particularly for use in the transport sector (ethanol and biodiesel) and residential sector (ethanol gel). Ethanol gel is a possible replacement to paraffin for domestic use in households (Banks & Schaffler 2006). These energy carriers are most appropriate for direct combustion and not for electricity generation.

2.2.13 Municipal waste

It has been estimated that South Africa's total domestic and industrial waste disposed in landfill sites has an energy content of about 11 000 GWh per annum. This could be directly combusted or converted into biogas and methane for electricity production. A project currently underway in the Durban metropolitan municipality consists of enhanced landfill gas capture from three of the city's landfill sites and use of this gas to generate up to 10MW of electricity. This project is supported by the World Bank's Prototype Carbon Fund which will purchase the greenhouse gas reductions of 68,833 metric tonnes CO_2 equivalent per annum (DSW & PCF 2006; ENS 2004).

2.3 Transformation: Refineries

South Africa makes liquid fuels in the following ways: refining of crude oil, conversion of coal to liquid fuels, conversion of natural gas to liquid fuels and more recently, the process of producing biofuels such as bio-ethanol from maize or sugarcane and biodiesel from vegetable oil, has added to the mix of liquid fuels. Liquid fossil fuels come from four refineries: Sapref, Genref, Calref and Natref; from Sasol's two coal-to-liquid plants at Secunda; and from the PetroSA natural gas-to-liquid plant at Mossel Bay.

2.3.1 Oil refineries

Oil refineries are categorised into coastal or inland plants. South Africa has three coastal oil refineries: Genref (Engen) and Sapref (BP/Shell) in Durban; and Calref (Caltex) in Cape Town; and one inland refinery in Sasolburg (Sasol/Total). Since inland refineries do not have a market for the heavy residual oil used for marine bunkers at the coast, the refining process is modified to produce less heavy oil, which increases the costs.

2.3.2 Coal-to-liquid fuel plants

Sasol is a world leader in converting liquid fuels from coal. The first plant was built in Sasolburg in 1955 and is now only used for chemical manufacture. Two larger plants were built at Secunda in the 1970s and produce about 150 000 barrels of crude oil equivalent per day. The plants consume 40 million tons of coal a year, mined from Sasol's own coalfields. The coal is first gassified to form 'syngas' (a mixture of hydrogen and carbon monoxide) after which it undergoes the Fischer-Tropsch process to be built up into hydrocarbons such as petrol, diesel, other fuel and chemicals. These fuels are very clean and contain no sulphur.

A by-product of the synfuel process is methane-rich gas (heating value of 35MJ/kg) which is sent by pipeline to industrial and commercial markets in Gauteng, Durban and Richard's Bay. The synfuel plant at Secunda also includes the world's largest oxygen plant (3550 tons of oxygen a day). The Sasolburg chemical plant produces methane-rich gas which has a heating value of about 18MJ/kg and is used in steel mills and other industries.

2.3.3 Natural gas-to-liquid fuels

Producing liquid fuels from natural gas rather than coal is both cleaner and easier and South African technology is being used all over the world with plants under construction in places such as Quatar in the Middle East. The PetroSA plant in Mossel Bay (Mossgas) makes liquid fuels from natural gas piped from the offshore F-A field, producing about 45 000 barrels a day of crude oil equivalent. The field is predicted to run out of gas in about 2008, so new gas will have to be found to keep the plant in operation. Either gas will have to piped in from neighbouring fields currently under development, or it will have to be imported in the form of LNG (liquefied natural gas).

2.3.4 Biofuel plants

Ethanol Africa, a South African-based biofuels company, has recently broken ground in Bothaville in the Free State, for the first bio-ethanol plant of its kind in Africa. The plant will be in full production by the end of 2007 with a capability of producing 473 000 litres of alcohol per day, using 1126 tons of maize daily. The company plans to erect eight R700-million plants in the Free State, North West and Mpumalanga (25 Degrees in Africa, 2006). A large biodiesel plant recently opened in Naboomspruit by De Beers Fuel and several other biodiesel plants production facilities are in the planning stages. Sasol is investigating the economic feasibility of building a 400 000 ton/year soybean to biodiesel plant (Creamer, 2004).

2.4 Energy demand

The abundant availability of cheap coal has enabled South Africa to develop energy-intensive industries reliant on inexpensive energy. Figure 7 shows how the industrial and transport sector dominate the fuel consumption. (Non-energy in the chart refers to resources such as coal, oil, gas and wood which could be used for energy but are converted to other products like chemicals and paper.)

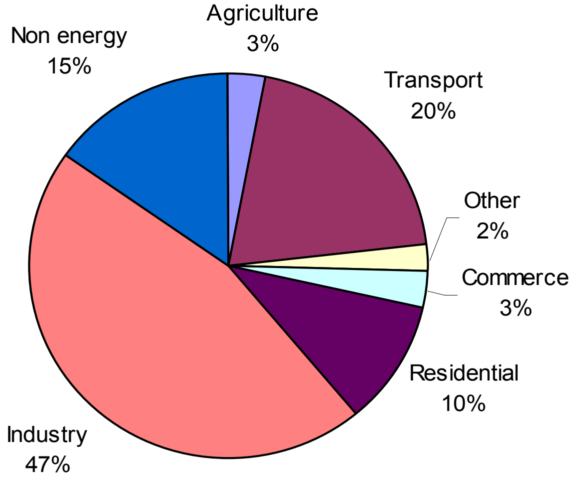


Figure 7: Share of final energy consumption in South Africa, 2000
Source: Based on SANEA (2003)

Electricity plays a very important role in the South African economy for both industrial and social development. Many industries reply heavily on electricity which is supplied in South Africa at a very low cost, less than half the cost of electricity in the UK. Electricity also represents a clean, modern energy service to those who have been denied access in the past. A rigorous electrification plan is underway to bring electricity to many rural and low-income households. Ninety-one percent of the country's electricity is generated from coal with small amounts from hydro (4%) and nuclear (5%) (Eskom 2004). Figure 8 shows the dominance of electricity and coal as well as South Africa's dependence on liquid fuels mainly for transport. The large portion of biomass may be misleading as this is traditional biomass used inefficiently in rural households. It is often collected in an unsustainable manner leading to land degradation and can therefore not necessarily be considered a renewable resource.

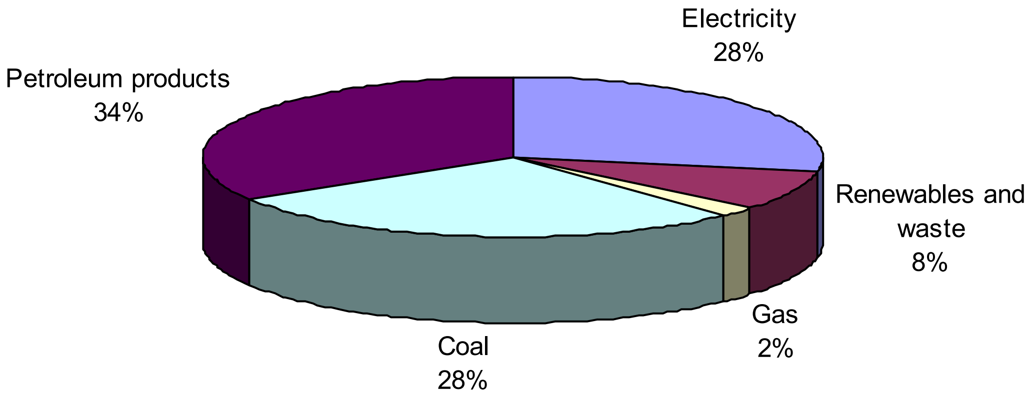


Figure 8: Share of final energy demand by energy carrier
Source: DME, 2005

2.4.1 Electricity demand

Electricity use varies during the day and throughout the year as seasons change and demand for energy services varies. In 2001, peak demand was 30 599MW, which is almost 50% above the average demand during the year of 20 000MW (NER 2001a). By 2005 the peak demand had increased to 34 195MW (Eskom, 2005). The weekly electricity demand profile for 2004 is shown in Figure 9 below. There are two peaks in demand resulting largely from increase in residential demand during those periods, these occur between 7:00 and 11:00 am and again between 18:00 and 21:00pm.

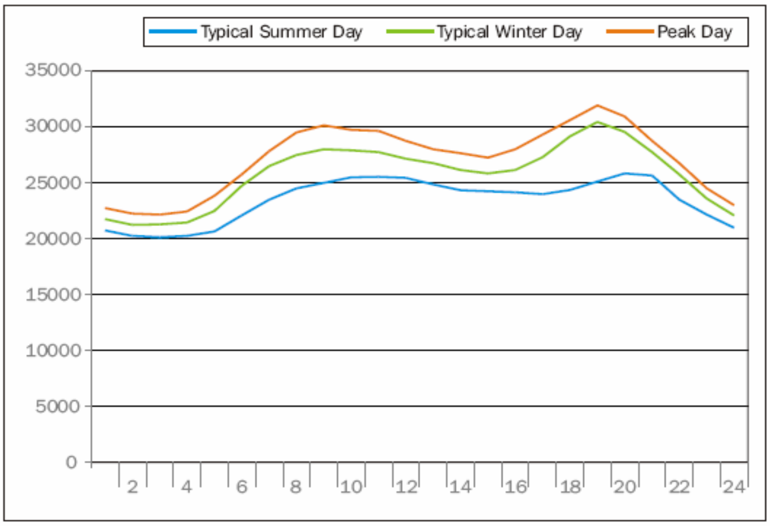


Figure 9: Weekday electricity demand profile, average across all seasons
Source: NER (2004)

Electricity consumption has been increasing over the past decade, largely driven by increasing demand in the industrial sector. The sectoral change in consumption between 1986 and 2000 is shown in Figure 10 below. Both energy distributed and peak demand have been increasing since 2000.

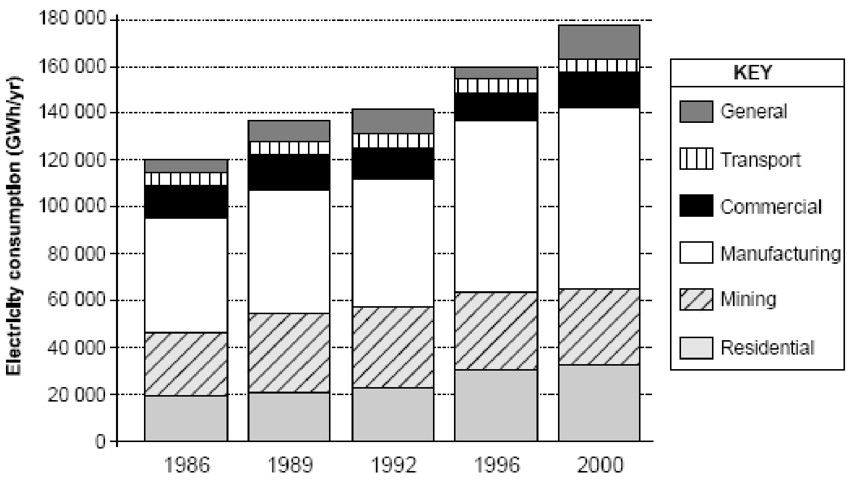


Figure 10: Sectoral increase in consumption, 1986-2000

Figure 11 shows the increase in electricity distributed by Eskom between 1987 and 2004, it also shows the increase in peak demand over that period and the increased peak demand relative to distributed demand. Currently Eskom are having difficulty meeting peak demand due to the lack of investment in new generation capacity.

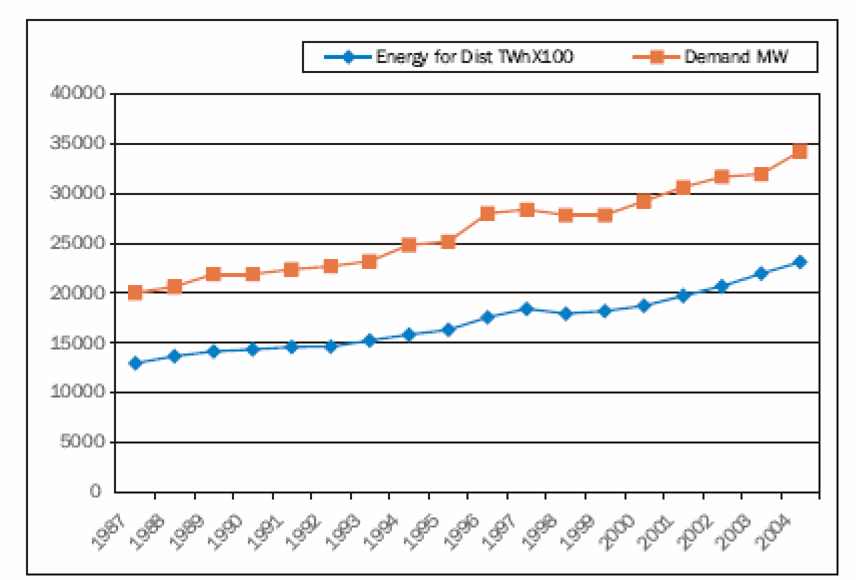
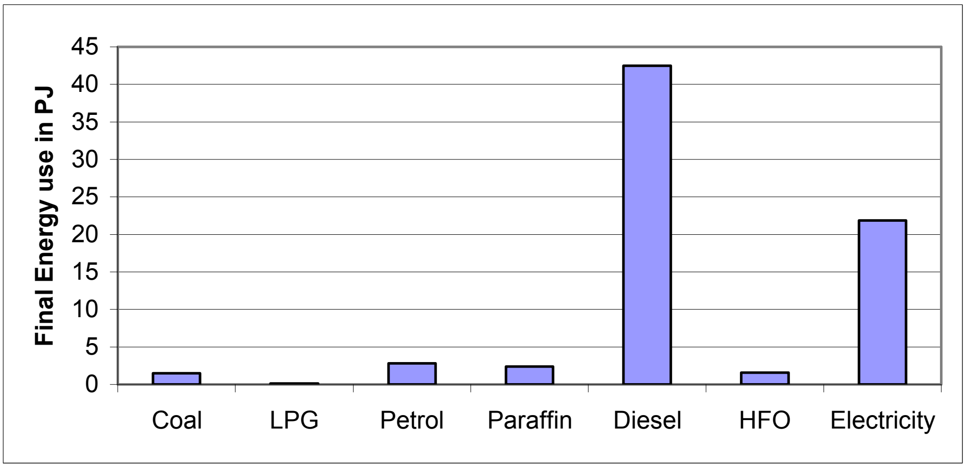


Figure 11: Energy distributed and peak demand
Source: NER (2004)

2.4.2 Agricultural energy demand

The agricultural sector includes demand from agriculture, forestry and hunting as well as ocean, coastal and inland fishing. Agriculture is dominated by large commercial farmers that make up 40% of the output but only account for about 5% of the farms. The agricultural share of GDP has steadily declined over the past few decades. In 1965 the agricultural share of GDP was 9.1% but by 1998 it was only 4.0% (NDA 2000). This trend is likely to continue in the future. Total 72.8PJ

Figure 12 below shows the final energy use by fuel type in this sector.



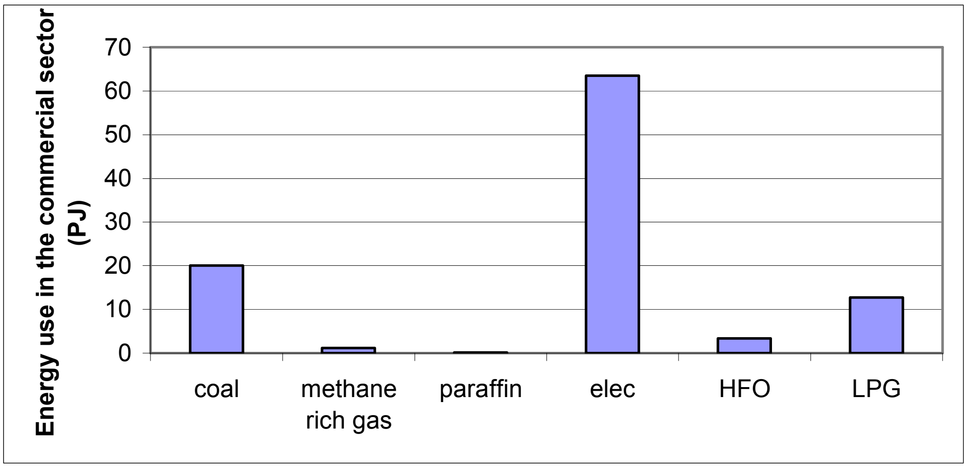
Total 72.8PJ

Figure 12: Final 2001 energy use in the agricultural sector
Source: Winkler et al (2006)

2.4.3 Commercial energy demand

The commercial sector includes economic sectors such as trade, catering and accommodation, finance, property, business services, community, social and personal services. Most activity in the commercial sector is confined to buildings such as offices, warehouses, shops, education facilities etc. thus most of the energy use is energy for running the buildings. The commercial sector makes up only 6% of the national total final energy consumption, 63% of which is electricity, 20% is coal and the remainder is made up of methane rich gas, HFO and LPG (see Total: 101PJ

Figure 13 below).



Total: 101PJ

Figure 13: Final 2001 energy demand in the commercial sector
Source: Winkler et al (2006)

Six energy service demands are identified:

- Cooling
- Lighting
- Refrigeration
- Space heating
- Water heating
- Other (computers, printers, cooking etc)

2.4.4 Industrial and mining energy demand

Industry has the largest energy demand of the sectors. Due to its size and the difference in demand for fuel and intensity when producing different products, the industrial sector is divided into sub-sectors within industry. The major sub-sectors are: Mining, iron and steel, pulp and paper, non-ferrous metals, non-metallic minerals, chemicals and petro-chemicals, food and tobacco and other. Figure 14 below shows the distribution of final energy demand between the different sub-sectors.

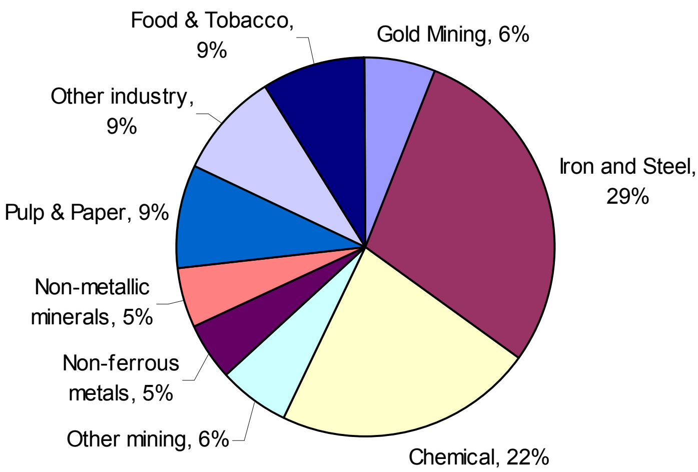


Figure 14: Final industrial energy consumption by sub-sector, 2001
Source: Winkler et al (2006)

The iron and steel and chemical industries are large energy-consumers. These sectors have developed due to abundant iron ore and coal supplies. The chemical sector includes the Sasol processes. Mining is often split into gold mining and 'other mining'. This is due to the decrease in quantities of gold mined, which although accompanied by an increase in the energy needed to extract the ore is resulting in a decrease in demand from gold mining whilst the demand from 'other mining' is increasing. Mining is expected to grow more slowly than other industries as it becomes more difficult and costly to extract minerals.

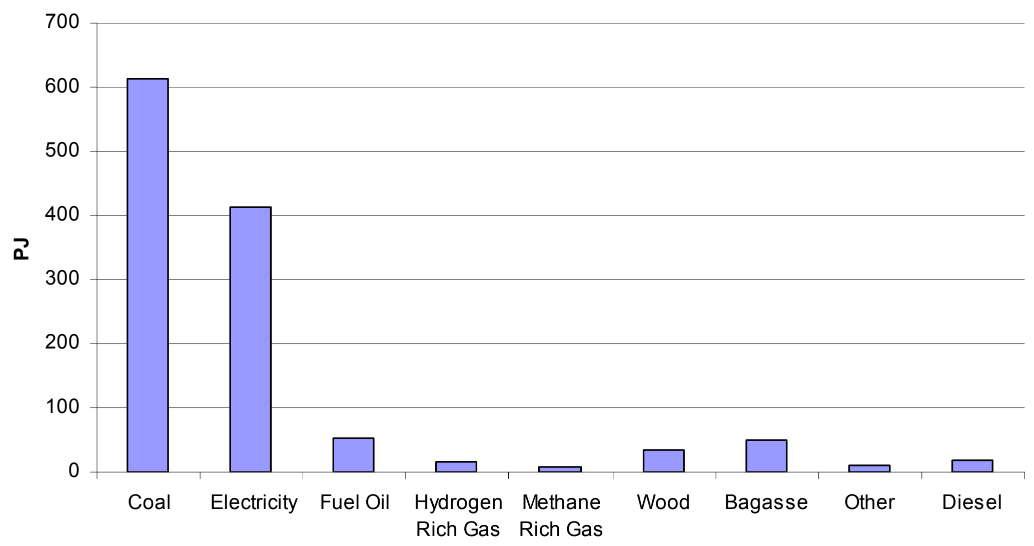


Figure 15: Final energy demand in industry by energy carrier, 2001
Source: Winkler et al (2006)

Figure 15 shows the final energy demand by energy carrier and it is clear that electricity and coal dominate the fuel mix.

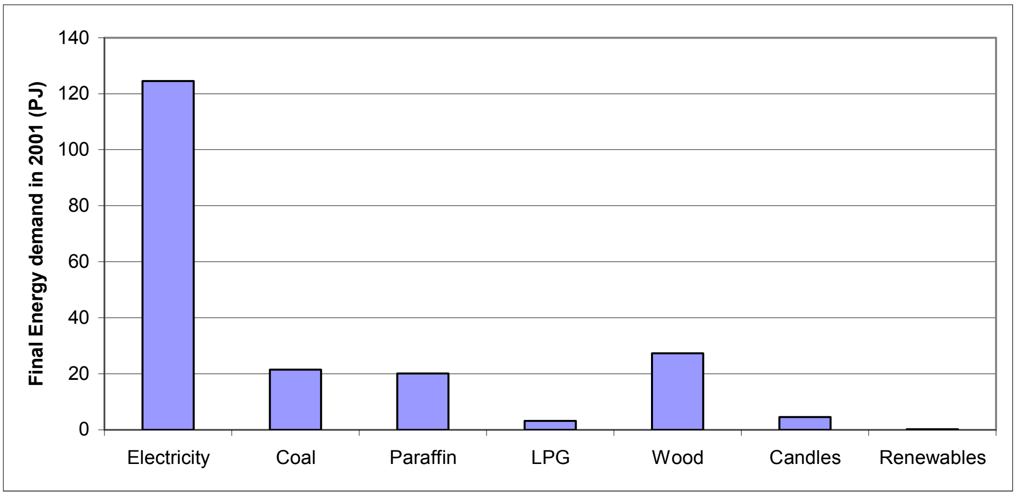
The low cost of energy has given South Africa a competitive advantage on global industrial processes. This has encouraged the growth of energy-intensive industries such as mining and aluminium smelting. However, this energy is used inefficiently and there are many opportunities in which significant energy savings are possible. Improving efficiency would reduce the cost of energy for production and decrease resulting emissions and environmental impacts. This will move the economy towards better practice and increased profitability (Laitner 2004).

2.4.5 Residential energy demand

There is a wide range of household income and household types in South Africa. The type of fuel used by households varies greatly according to their location and socio-economic position. In order to represent the household energy demand data is needed that defines energy use and appliance use in each income group and household type. Collection of this data requires large detailed surveys and for these reasons domestic energy demand data by household type and income is fairly unreliable and assumptions are made to fill in the gaps.

The major end uses considered in this study were: cooking, lighting, space heating, water heating and electrical appliances for other uses. A wide variety of fuels are used to meet these demands with a significant difference between the types of fuels used in urban areas versus the types of fuels used in rural areas. Electricity dominates energy demand throughout the residential sector whereas fuel wood is mainly used in rural areas. In Total 201PJ

Figure 16 below, the final energy demand is given by energy carrier. The reason for the large energy use by wood is because of its low efficiency when burnt. Significantly more wood is needed for a particular output than, for example, electricity.



Total 201PJ

Figure 16: Final energy demand in the residential sector by energy carrier:
Source: Winkler et al (2006)

2.4.6 Transportation energy demand

The transport sector has shown the fastest growth over the last few years and this trend is likely to continue. We are currently in a transport boom with record breaking sales of new vehicles in 2005. In 2005, 618000 units were sold compared with 481000 in 2004 and 381000 in 2003 (Venter 2006). This increase was particularly prevalent in commercial vehicles which is a good indicator of fixed investment in the country (Venter 2006):

- Light commercial vehicles increased 25.9% from 2004
- Medium commercial vehicles increased 41.8%
- Heavy commercial vehicles increased 24.5%

Transport energy is dominated by liquid fuels (97% of final energy consumption) especially petrol and diesel with electricity (3%) and coal (0.2%) making up the remainder (DME 2005). Diesel use has been increasing rapidly over the past few years.

Passenger transport over land is the largest consumer of energy followed by land freight. Road transport is a larger sub-sector than rail and air (DME 2001). Energy intensities are high in this sector due to an ageing vehicle fleet, low occupancy rates and poor maintenance of vehicles. Historically segregated residential patterns result in large commuter communities which increases fuel consumption and resultant emissions. Loading and maintenance regulations are poorly enforced and public transport systems are crowded and unreliable. This leads to high smog levels, road damage, increased road fatalities and reduced productivity as people spend more time and money on commuting.

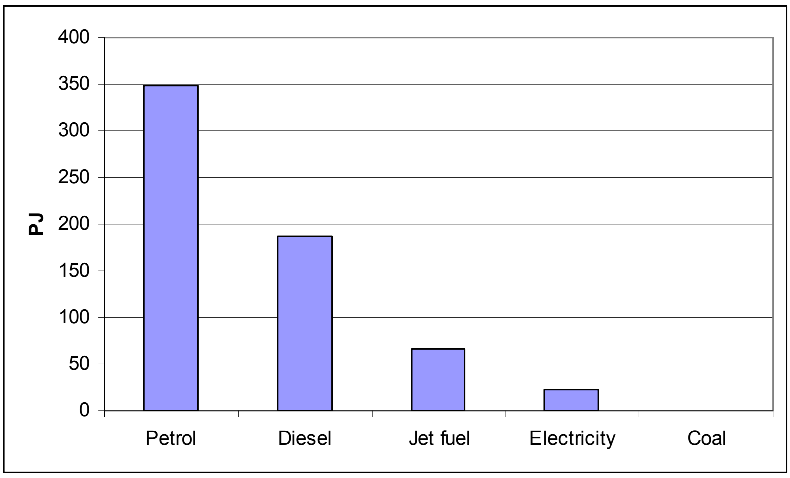


Figure 17: Final energy demand in transport by carrier, 2001

The Taxi Recapitalization Plan for South Africa was launched by the Department of Transport in 2000 to address the problem of an ageing taxi fleet and the potential risks to passengers due to poorly maintained vehicles, lack of seat belts and bad vehicular emissions. At the time the taxi fleet was approximately 126 000 taxis large and the average age of a taxi was ten years. (Cambridge, 2000). Since taxis carry over 60% of public transport users and 30% of all workers nation wide, the impending problem of the taxi industry failing due to ageing vehicles would lead to a serious lack of transport as well as the loss of more than 80 000 jobs (Cambridge 2000; NDT 2000). Part of the taxi recapitalisation plan is also to generate a fuel switch from petrol to diesel in order to balance petrol and diesel use and also to improve overall efficiency in the taxi fleet.

The South African government recently presented a Draft Biofuels Strategy (DME, 2006) in which biofuels, particularly bioethanol and biodiesel were punted as an effective way to meet growing transport demand, reach the Renewable Energy Target, decrease reliance on imported liquid fuels and reduce transport related emissions. A petrol-ethanol blend with 8% bioethanol and a diesel blend with 2% biodiesel is proposed for the national fuel supply (DME 2006). This equates to an average market penetration of 4.5% of liquid transport fuels by 2013 and will contribute 75% to the Renewable Energy Target (DME 2006). Biofuels are currently not widely used in South Africa but the flexibility of the model allows for various blends to be simulated and the recent interest in the biofuels industry suggests that biofuels will play an important role in the South African energy supply chain.

3. Modelling: The LEAP and MARKAL tools

This project makes use of two energy models to generate future scenarios and optimize for least cost. The Long-range Energy Alternatives Planning system (LEAP) is used initially to generate a time series of useful energy demand developed from base year data. Assumptions are made as to how each sector will grow according to GDP and or population growth. The output from LEAP in Petajoules of useful energy demand or demand for other end uses such as passenger km or tonne km over the planning period is then used as input for the Market Allocation model (MARKAL) which optimizes for least cost.

3.1 LEAP

The LEAP model as we know it today developed in 1997 out of a collaboration between the Stockholm Environment Institute – Boston (SEI-Boston) and other leading international research and training institutions. The LEAP initiative was funded by the Netherlands Ministry of Foreign Affaires (DGIS) and the aim of the project was to address the needs of energy professionals around the world. The major output of the project was the vastly improved version of the LEAP software as well as a Technology and Environmental database (TED) and appropriate training materials (SEI-Boston, 1995).

LEAP is a user-friendly model that can be used to simulate future energy trends and patterns based on assumptions and data input by the user. It also maintains a fairly detailed database of energy information. Given the flexible data structures, a LEAP analysis can be as detailed or as cursory as the user requires. As already suggested, LEAP does not generate a market-equilibrium scenario but can be run in conjunction with other models (such as MARKAL) to determine least-cost alternatives.

The May 2005 User guide (SEI-Boston, 2005) summarises the main functions of LEAP as follows:

- Maintains a database of energy information
- A forecasting tool to project energy supply and demand in long-term planning
- A policy analysis tool that simulates the effects (physical, economic and environmental) of alternative energy programs, investments and actions

3.2 The MARKAL model

MARKAL has an objective function to minimize the cost of the energy system (Loulou et al 2004). Sectoral demand projections are entered into the model along with an array of supply-side options that can meet the demands. Estimates of demand, existing technology stocks, information on technology choices that can be used to meet demand are input by the user. With a demand projection based on GDP and population growth (developed in LEAP in this case), MARKAL computes least-cost energy balances at all levels of the energy system. The model aims to supply energy services at a minimum global cost by simultaneously making decisions about capital investment in equipment, operating costs and primary energy supply. By taking all these factors into account, MARKAL is a vertically integrated representation of the entire energy system.

In MARKAL the energy system is represented by a set of energy carriers that link primary energy resources through transmission, transport modes and transformation to final energy demand technologies. A simplified figure of the electricity Reference Energy System (RES) in South Africa is shown in Figure 18. Fuels from refineries or mines, in the case of coal, flow along fuel paths to meet specific demands.

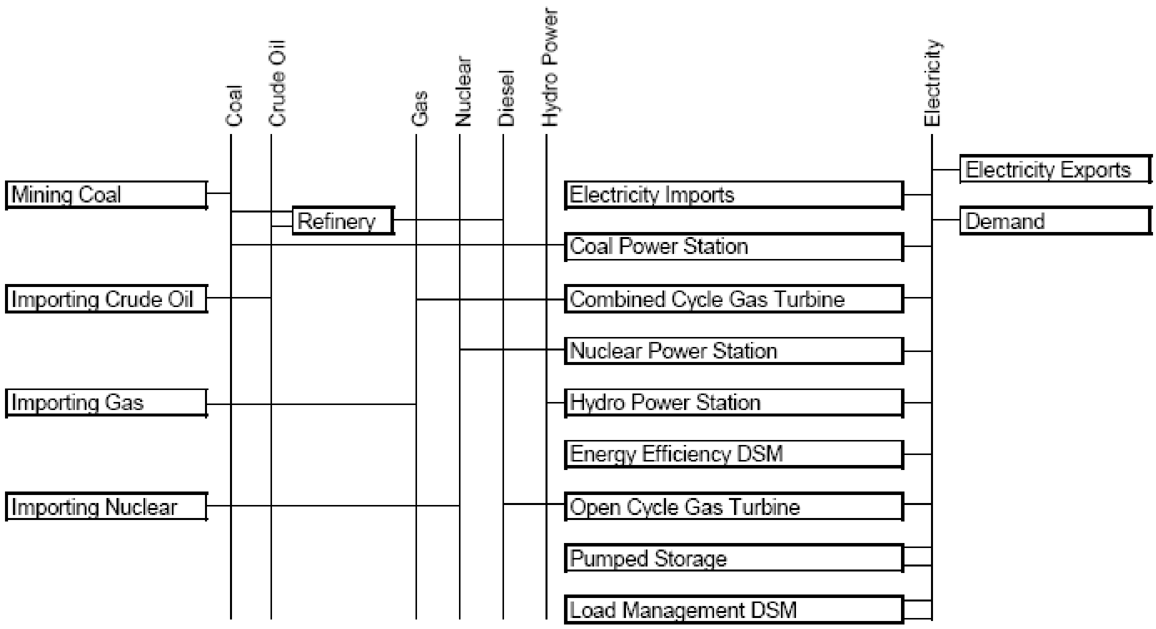


Figure 18: Simplified RES for the electricity sector of South Africa

Source: Schultz (2003)

4. Model structure and assumptions

In developing a model, there are many ways in which the structure of the energy system can be represented. The goal is to create a structure that is robust with sufficient flexibility to allow for all possible outputs that may be demanded of the model. Although an attempt has been made through assumptions and drivers to capture the changing structure of the economy, as the IPCC (2001a) so aptly puts it:

> The current state of modelling long-term economic growth is not well developed, not least because the dominant forces of long-run productivity growth, such as the role of institutions and technological change remain exogenous to models.

An example of how the structure of economies changes within countries as they develop over time is given by the IPCC, see Figure 19 below. It seems obvious that some attempt should be made to include this change over time in the modelling. This is done and is discussed in Section 4.1.2

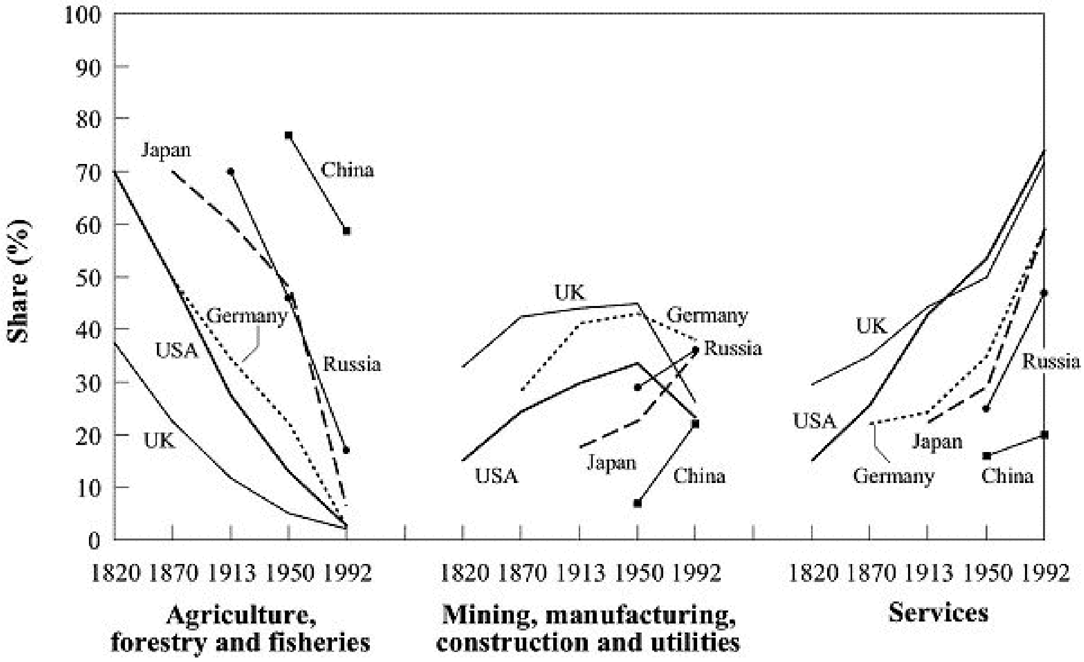


Figure 19: Change in economic structure of economies
Source: IPCC (2001a)

4.1 Major drivers

4.1.1 Population growth

Population projections are a topic of much debate in South Africa given the high rate of HIV infection and how this will impact the growth of the population. Many believe that the population will level off and even decline in the future. No model can perfectly simulate this population growth as there are many unknown variables around which assumptions must be made. Nevertheless, a study by Professor Dorrington of the University of Cape Town Commerce Faculty for the Actuarial Society of South Africa is well respected for its population projections which include the influence of HIV/AIDS (ASSA 2002). This is the model used for population growth this study. Figure 20 below shows the simulated population growth over the study period: 2001 – 2030 using the ASSA model. Previous studies such as the first integrated energy plan have included a higher population growth over the period, for example, in the integrated energy plan population grows to 57 million in 2025, in this study the population in 51.5 million in 2025.

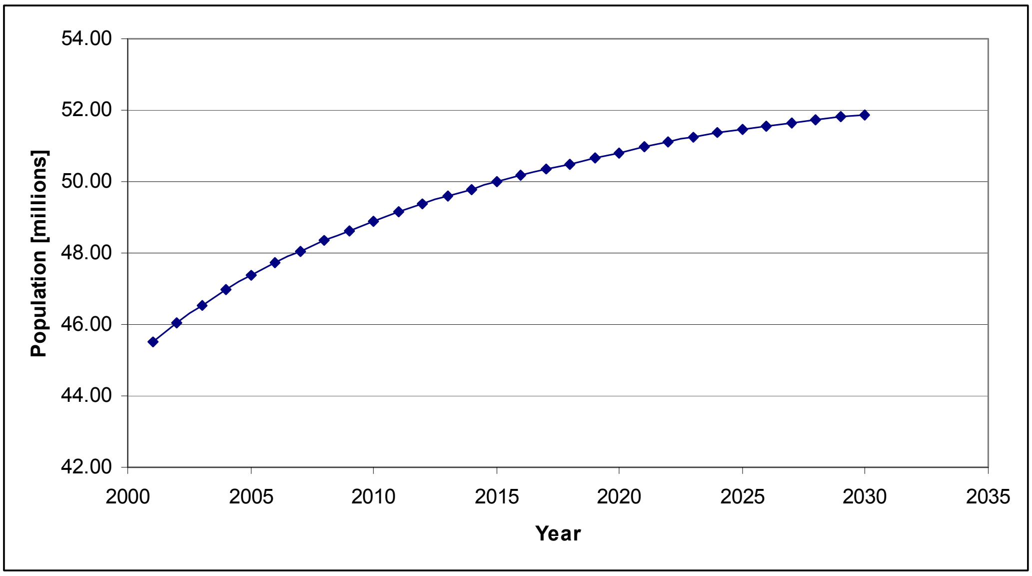


Figure 20: Population projection from ASSA model: 2001–2030

4.1.2 GDP

Together with population, GDP is the most influential driver of energy demand. South Africa is a developing economy reliant on heavy industry that requires much energy. Industry drives GDP growth, therefore as GDP is projected to increase, we assume this is accompanied by an increase in final energy demand in the industrial and commercial sectors. In the residential sector, as the poorer section of the population becomes more affluent they may acquire more appliances thus demanding more energy or they may move towards increased private vehicle ownership and use. In long-term modelling of energy and Green-House Gas (GHG) emissions, per capita income is often the major development indicator.

The task of projecting GDP growth is difficult and decisions on growth rates are often politically bias as governments would like to project a continuously high GDP growth when, in fact, this is unlikely to occur. GDP growth is seldom, if ever, exponential over a long period of time; however this is how GDP has been modelled in South Africa in the past (NER 2004a; IEP 2003). If one examines other developed regions of the world, it is easy to see that GDP growth increases, reaches a peak and then declines.

Figure 21 shows the percentage GPD growth per capita over time for Western Europe, Australia, Canada, New Zealand, the US and Asia. Although growth patterns occur at different times, all regions show a period of rapid growth followed by a period of slower growth.

The IPCC describes this pattern in five major stages of economic development (IPCC 2001):

- First, the *pre-industrial economy*, in which most resources must be devoted to agriculture because of the low level of productivity.
- Second, the phase of *capacity-building* that leads to an economic acceleration.
- Third, the *acceleration* itself (about two decades).
- Fourth, *industrialization* and catch-up to the ‘productivity frontiers’ prevailing in the industrialized countries (about six decades).
- Fifth, the period of *mass-consumerism and the welfare state*.

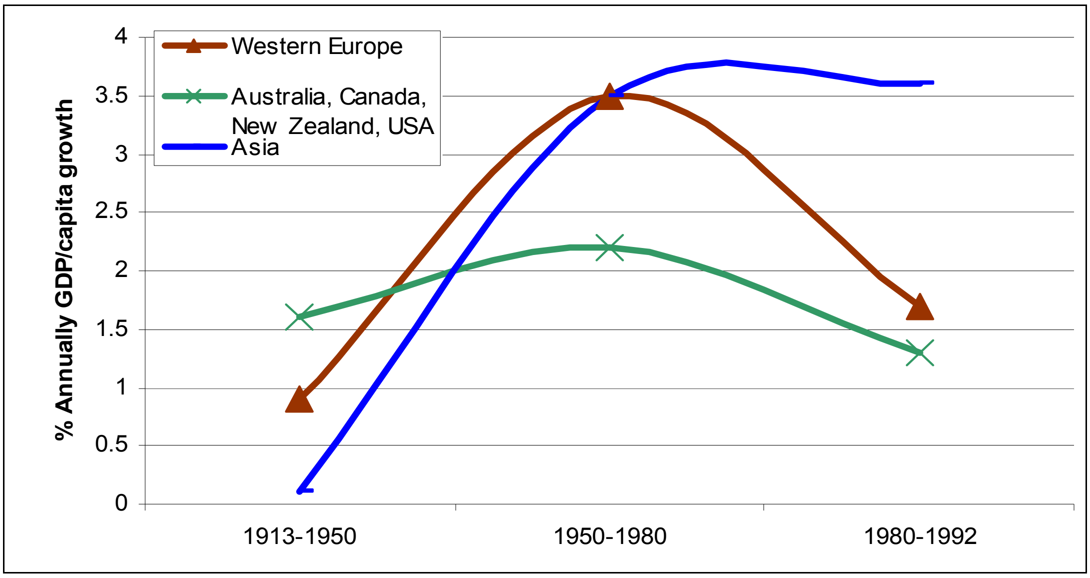


Figure 21: GDP growth rates for different world regions

South Africa is unique in that its apartheid history created a huge disparity between different ethnic groups and the areas in which they live so that today parts of the country represent developed nations while large parts of the country fall into what would be classified as 'developing'. South African could be described as being an accelerating economy (stage 3).

Another factor when developing a GDP growth projection for South Africa, is that the impact of HIV/AIDS could play a significant role in the GDP of the country. If we assume that the population will stabilize and actually decrease over time (as mentioned in section 4.1.1 above), then we question if it is possible for GDP to continue to follow an exponential growth. We assume that GDP will follow population trends to some extent.

Over the past 12 years, GDP growth in South Africa has fluctuated between 0.5% and the growth reported for 2006 of 5%. GDP growth is has shown a positive upwards trend during the 1990s as illustrated in Figure 22. As part of the Accelerated and Shared Growth Initiative for South Africa (AsgiSA), targets for GDP growth rates have been established. (AsgiSA 2006; National Treasury 2005). The targeted growth rate for AsgiSA is broadly defined as 6%. In the long-term GDP growth rates might settle at around 3%, consistent with the IPCC's recommendation of discount rates of 3% to be applied for long-term, inter-generational studies. (IPCC 2001).

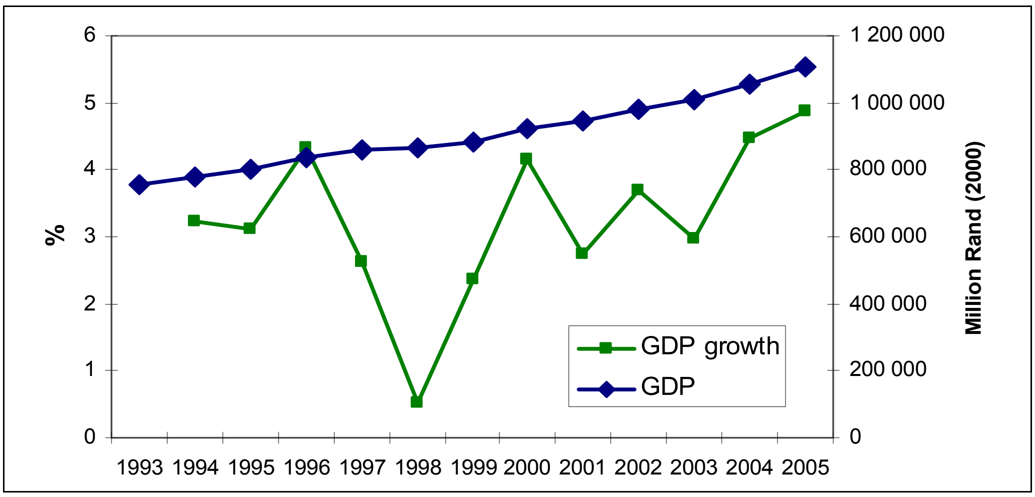


Figure 22: Annual GDP and growth rate for South Africa, 1993 – 2005
Source: StatsSA (2006)

To include all these factors, a time-dependent GDP growth projection (which we will refer to as GDP-E) that peaks at around 2015 and then declines thereafter has been developed for this study.

Figure 23 below shows the actual GDP growth rate, the corresponding trend line and the projected GDP-E growth rate. Figure 24 shows how these growth rates translate into a monetary increase in GDP over the planning period. The average growth rate over the planning period is 4.74%, peaking at 6% in 2016.

Previous studies using the year on year increase of 2.8% result in a GDP at the end of the period of less than that anticipated in this study. It is worth noting that it is felt that the average growth rate of 4.7% will only be realised if government manage to achieve the 6% growth rate through ASGISA and other policies. Due to the uncertainties around GDP growth rate projections, it was decided to run a sensitivity analysis using a slightly lower growth rate. This is discussed further in the second report.

The GDP-E growth is developed from the function below:

$$GDP(y) = \varphi \cdot y + \alpha(\arctan(\beta(y - \lambda)))$$

Where:

α	= -55	(Amplifier)
λ	= 2015	(Peak growth year)
β	= -0.07	(Parameter governing the gradient of the curve)
φ	= 1.4	(Linear constant)
y	= {1993, 2060}	(Year)

GDP growth rate is the derivative of the function.

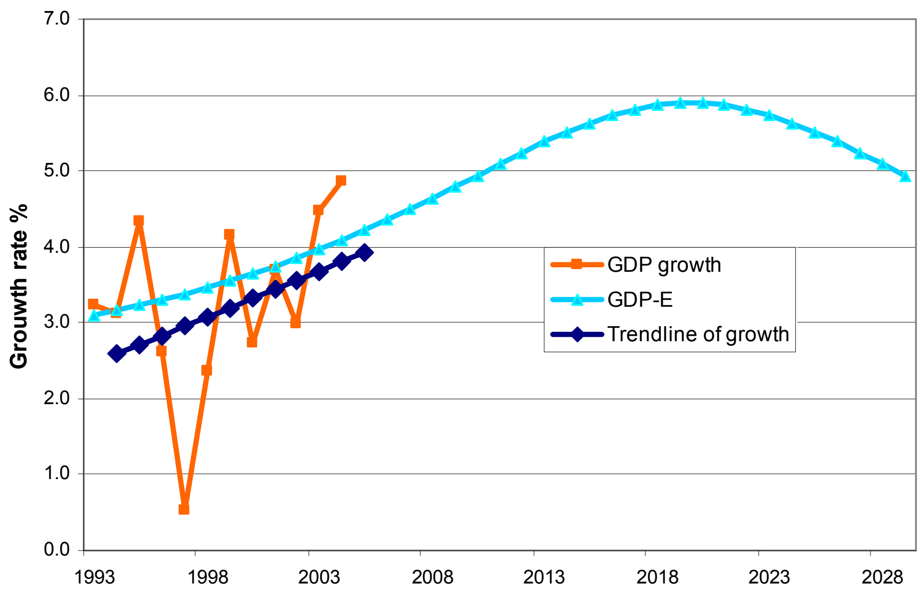


Figure 23: South Africa's GDP growth, the trend line and projected GDP-E growth

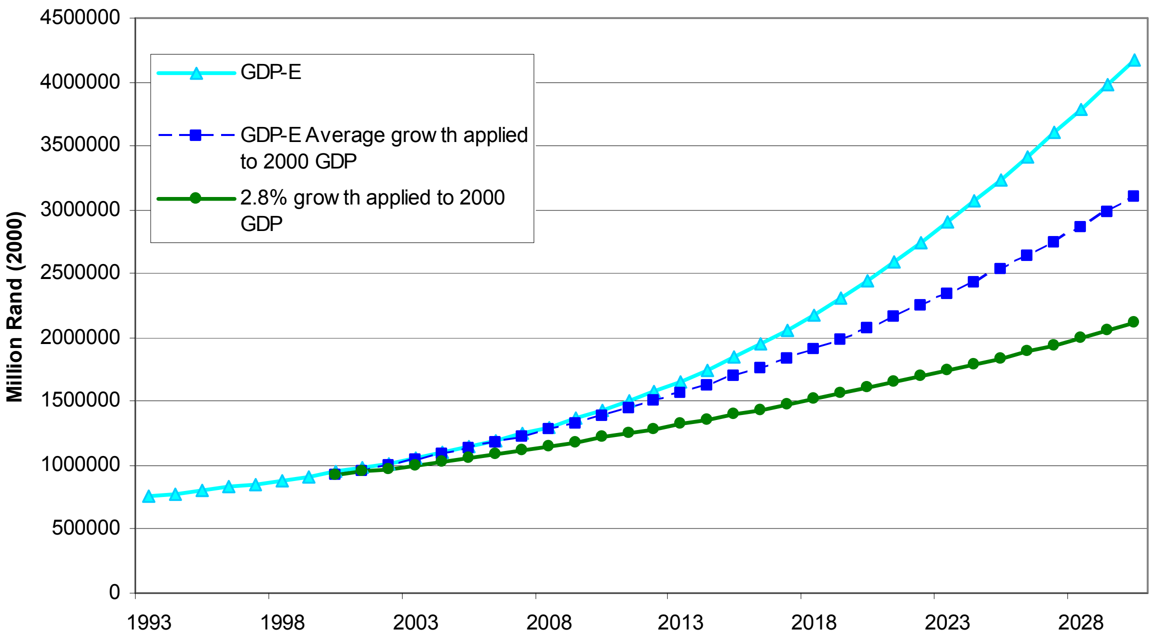


Figure 24: GDP-E and GDP at 2.8% growth

4.1.3 Exchange rate

The strength or weakness of the South African Rand compared to international currencies is another factor that can influence model outputs. Imported fuels such as crude oil are quoted in US dollars since their price relies on a global price. Investment costs of most power stations are also given in US dollars since many of the parts and certain expertise must be imported. The fluctuating Rand-dollar exchange rate is therefore important and can have a large influence on the model results and the total costs of certain scenarios. The exchange rate is a highly volatile factor and very difficult to predict. For this study an assumed exchange rate of R7.50 to the US dollar in 2003 was decided on and is kept constant in the base case.

It has been suggested that a 2% decrease in exchange rate per year is likely (Personal communication Kalie Pauw, UCT Economics Department, October 2006). Initially it was decided to include a decrease in exchange rate in the model. This was to be applied to the investment cost of generation technologies. Exchange rate variations were not applied to variable operation and maintenance costs, or fixed operation and maintenance costs. After witnessing the results, which favour those technologies with a lower investment cost such as OCGTs, it was decided to exclude the anticipated decrease in the exchange rate over the planning period from the base case, as it was felt that results were unrealistic. The results from running the base case with the exchange rate variation are included in the third report as a sensitivity analysis for the purpose of demonstration. If exchange rate is to be included in the base case, it is felt that further work is required to determine what portion of generation costs (fixed and variable operation and maintenance and investment cost) the change should be applied.Table 5 shows the projected exchange rate of the rand to the dollar from 2003 to 2030 used in the sensitivity analysis.

Table 5: Projected rand-dollar exchange rate over the study period

2003	R7.50
2005	R7.80
2010	R8.62
2015	R9.51
2020	R10.50
2025	R11.59
2030	R12.80

4.1.4 Technology learning

Technology learning assumes that as technologies are more widely used and more of a technology is produced, so its cost will decline over time. This is particularly applicable to new renewable technologies such as wind and solar technologies, but is also applied to new coal technologies such as supercritical coal and integrated gasification combined cycle. Costs of technologies decline depending on technical innovations, the global installed capacity and the rate at which the installed capacity is growing.

Again technology learning has a large affect on results. Due to the uncertainty around technology learning it was decided to adopt the same approach that was used for the exchange rate. Technology learning is excluded from the base case, but for the purpose of demonstration is included as a sensitivity case study.

4.1.5 Seasonal variation in electrical demand

As demonstrated through Figure 9 in section 2.4, demand for electricity changes throughout the day. Demand also changes seasonally. This change in the demand profile affects the type of generation capacity that is used to meet the demand. Stations with low investment costs, but which may have higher O&M and fuel costs and can be brought on line quickly, are used to meet the peak demand which occurs for a short time during the day. Stations which have lower fuel costs and O&M costs are used to meet base load demand. These base load stations are generally not technically suitable to run for short periods and therefore are not used to meet the additional demand required at peak times.

In the model and attempt is made to include the seasonal and daily variation in demand through the use of time slices. These allow us to divide the year into six time periods:

- Intermediate day
- Intermediate night
- Summer day
- Summer night
- Winter day
- Winter night

The distribution of electrical demand over the time periods as it is represented in the model is shown in Figure 25. Although the use of the time periods, along with reserve margin, does encourage the building of stations to meet peak demand only, the time periods are not small enough to allow for a full optimisation of the electrical generation system.

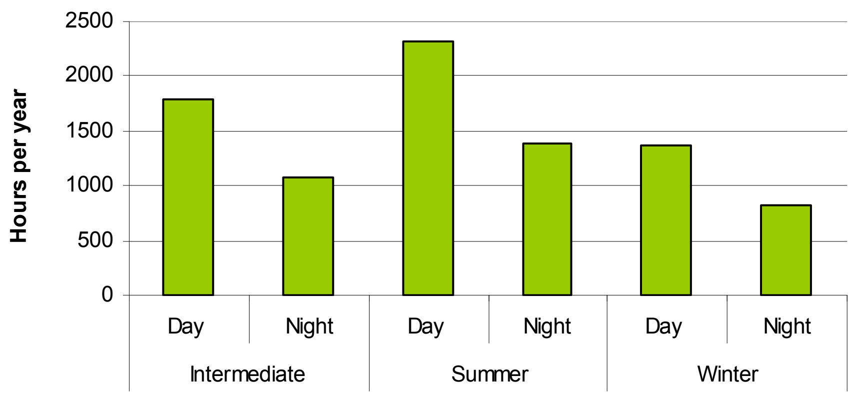


Figure 25: The distribution of electrical demand by season

4.1.6 Resources and fuel prices

Predicting future fuel prices is virtually impossible and different theories come up with very different results. Fuel prices vary with availability and demand, exchange rate (if the fuel is imported) and other factors. The fuel prices used in this study are discussed in this section.

Crude oil price
The global price of crude oil is very volatile and accurate forecasts into the future are virtually impossible. For this study a stable price (in real terms) was estimated at $55/bbl over the study period. This equates to $97/bbl in nominal terms. These figures are supported by the EIA and OECD in their projections of future oil prices (EIA 2006; OECD 2006). Table 6 describes how this is converted into a rands per giigajoule value. Local crude oil production is assumed to be 90% of the price of imported crude oil.

Table 6: Oil price assumptions over the study period

	Units	
Assumed oil price in 2030	2005 $/barrels	55
	2005 ZAR/barrel	429.17
	2003 ZAR/bbl	395.76
Conversion factor	bbl/tonne	7.33
Energy density	GJ/tonne	41.9
Imports	2003 ZAR/GJ	69.23
Local extraction	2003 ZAR/GJ	62.31

Coal price
Local coal price has been somewhat stable over the past few years however it is believed that as demand for coal increases and resources become more difficult to extract, the price of coal will increase dramatically. In this study different coal prices are used for current power stations, new power stations, synthetic fuels and other uses. Table 7 shows the price of coal to the different consumers in 2005 given in 2005 rand/ton and in 2003 million rand per petajoule.

Table 7: Coal prices for various activities in 2005
Source: Prevost (2006)

	2005 R/ton	*2003 million R/PJ*
Current Eskom power stations	65	2.80
New power plants	90	3.54
Synthetic fuel	90	3.81
Other	125	4.29

Predicting the way in which these prices will increase is very difficult although it is assumed that they cannot stay at this level indefinitely. In this study we assume that the prices of coal begin at the levels shown in Table 7 and then rises to R6 per GJ (the same as R6 million per PJ) in 2030. Discard coal remains at R2.83/GJ over the period.

Distributed electricity price
The following prices (Table 8) are assumed for the distribution of electricity to the sectors.

Table 8: Distributed cost of electricity

Distribution cost	*R/GJ*
Commerce	41.0
Industry	10.5
Mining	9.8
Residential	44.6
Transport	21.8

4.1.7 Emissions

The most important emissions that we are focusing on are: carbon dioxide, carbon monoxide, sulphur dioxide, and oxides of nitrogen. These are modelled for the entire energy system. Local air pollutants such as total suspended particulate solids (TSPSs) are only modelled in the residential sector as this is where the greatest risk to health is.

In the model, emission factors are placed on the primary energy carriers at the point where the fuel is combusted. For example emissions from petrol are placed on the petrol going into a vehicle and not on the crude oil going into a refinery. Excess emissions from the refining process itself, are placed on the refinery. Coal being burnt in power stations has emissions factors associated with it, but electricity does not have emission factors. As of now, biofuels do not have carbon dioxide emissions associated with them in the model since they are regarded as carbon neutral. Life-cycle analysis of biofuel production may show in some cases that biofuels have substantial emissions (Von Blottnitz & Curran in press) and perhaps in a future version of this model, this can be taken into account. It should be noted, that while ethanol gel fuel is considered a biofuel, we have included emission factors to provide an accurate comparison of indoor particulate emissions with paraffin.

Table 9: Table of CO_2 emission factors

Fuel	Sectors to which the emission factor is applied	CO_2 Ton/GJ
Coal mining	Electricity	96.25
	Other uses	94.6
	Sasol	94.6
	Discard Coal	94.6
Local crude oil extraction		73.33
Coal	Electricity	96.25
	Commerce and Industry	94.6
	Sasol	94.6
	Discard Coal	94.6
	Residential	87.001
Diesel	All users	74.07
HFO	All users	77.37
LPG	Commerce, Industry and Agriculture	63.07
	Residential	65.0
Paraffin	Commerce, Industry and Agriculture	71.87
	Residential	69.94
Petrol	All users	69.3
Gas	All users	56.1

4.2 The Base Case

The Base Case describes an energy scenario projected from 2001 to 2030 in which the future is a continuation of current trends. Policy measures that are currently in place are projected at their current rate of implementation but targets are not forced in. For example the model is not forced to use 10 000 GWh of renewable energy by 2013 inline with the DME's Renewable Energy target as described in the White Paper (DME, 2003). However, all projects underway and solid future plans are included in the Base Case. This primary scenario gives a platform from which other scenarios and policy interventions can be compared. Most assumptions in the Base Case are carried through to other scenarios unless explicitly defined as a targeted policy.

4.2.1 The commercial sector

The commercial sector is modelled with disaggregated demand for cooling, lighting, refrigeration, space heating, water heating and 'other'. These demands are met by various demand technologies using different energy carriers. The energy demand in the commercial sector is based on the intensity of demand per area of floor space for a given commercial activity (MJ/m^2). The useful and final energy demand for each activity are given in Table 10. Useful energy intensity is assumed to remain constant throughout the time period 2001 – 2030 for all end uses except for the services grouped as 'other' in which the energy intensity is expected to grow by 0.5% per year. Useful energy is kept constant because the base case does not include any improvement in commercial building design that would affect the thermal performance of buildings or the demand for lighting and behaviour patterns which affect energy demand are not expected to change.

Table 10: Useful energy intensity in the commercial sector

	Final energy intensity ([MJ/m^2)	*Useful energy intensity (MJ/m^2)*
Cooling	356.17	1331.01
Lighting	217.51	799.70
Water heating	273.87	239.65
Space heating	205.36	178.96
Refrigeration	48.10	48.10
Other	206.37	206.37

The increase in energy demand over the planning period (2001 to 2030) is driven by an increasing floor space area. Commercial floor area is assumed to increase at a fraction of 1/0.7 of the increase in economic activity, ie a 1% increase in trade activity raises floor space demand by 0.7%. Floor space projections are generated using regression analyses with the GDP sales growth projections for various commercial buildings (warehouses, offices etc). These are then summed up to give the total floor space projection. Figure 26 shows, graphically, the projected floor area growth by commercial building type. The total floor space in 2001 is estimated at 77 million square metres and is assumed to depend on total sales in the commercial sector (De Villiers 2000). For this study, the Industrial Development Corporation's projections of future sales were used to 2015, after which an average growth over the period was used to extend the time series (IDC 1999). The floorspace growth was then considered proportional to sales growth in a ratio of 0.7 (Winkler et al 2006).

Like the transport sector, the commercial sector shows higher growth rates in energy consumption in comparison to other sectors (SANEA 2003). This trend is expected to continue in the future.

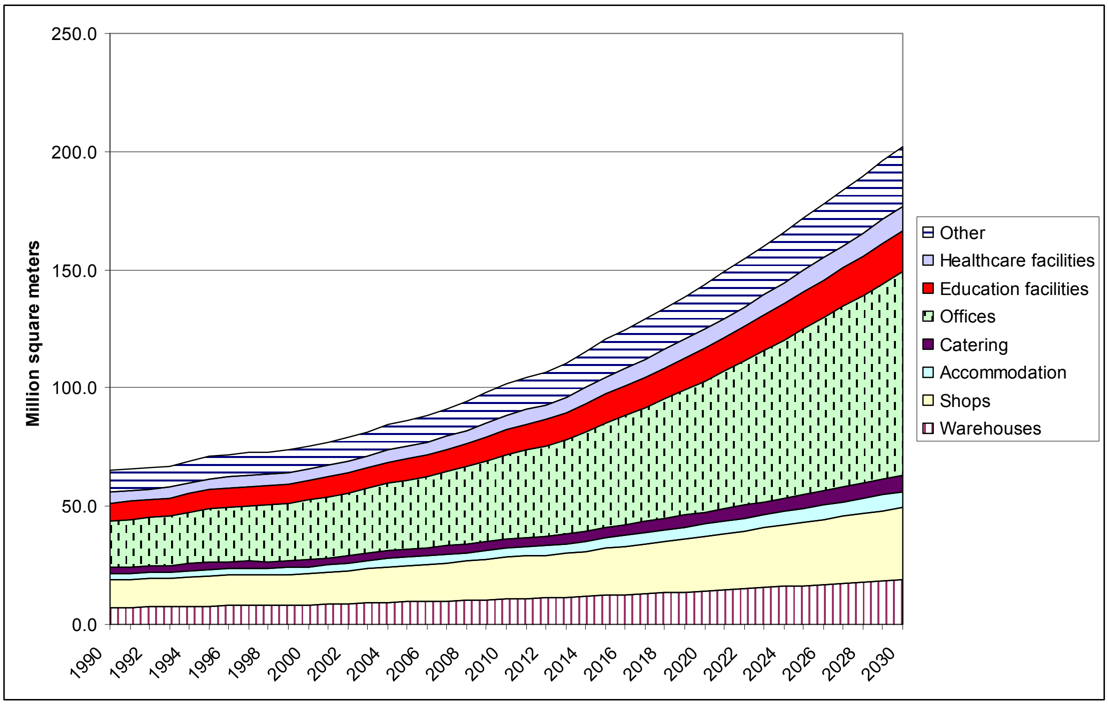


Figure 26: Floor space growth projection by type

Since most energy use in the commercial sector takes place during business hours, the time of use is very important for modelling the sector. Residual capacity must be sufficient to meet the demand. Much of the energy is used for heating or cooling, thus the seasonal dependence also plays an important role. The percentage of each demand that occurs in a particular time of use period is shown in Figure 27.

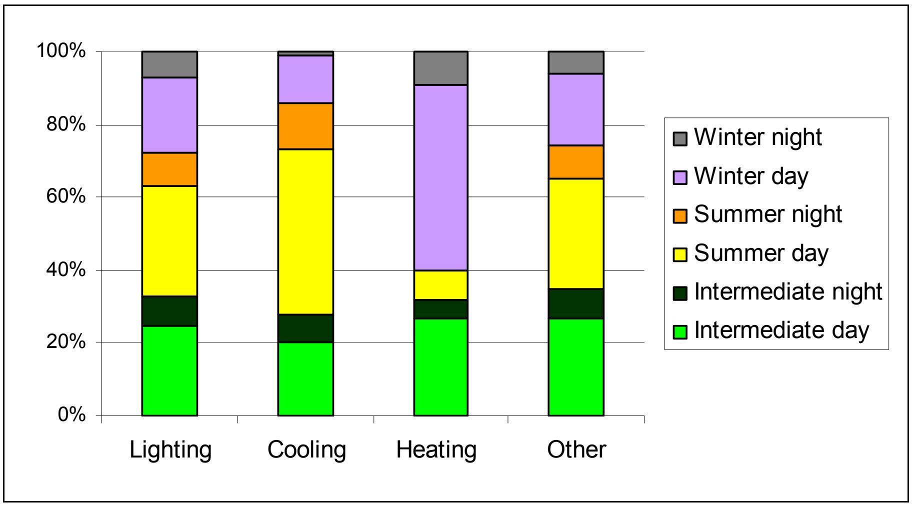


Figure 27: Time of use for the commercial sector

The demand technologies included in the model are shown in Table 11, along with their assumed operating cost and efficiency. These include technologies that supply lighting, cooling, water heating, space heating and refrigeration.

Table 11: Technical and economic assumptions for commercial sector demand technologies

		Efficiency/COP	*PJ/a*	*R/GJ/a*	*R/GJ*	*years*
		Cooling				
Electricity	air cooled chillers	2.98	5.23	199.10		15
	central air conditioners	4.23	59.30	122.52		15
	heat pumps	3.28	20.92	321.62		15
	room air chillers	3.23	16.98	168.47		15
		Lighting				
Electricity	CFL	4.00	3.69	37.70	14.70	15000 hrs
	Fluorescents	4.50	43.08	74.80	8.40	15000
	Halogen	2.00	1.23	13.60	10.40	5000
	HID's	7.00	9.23	5.50	15.40	18000
	Incandescent	1.00	4.31	45.20	11.20	2000
		Refrigeration				
Electricity	refrigeration	1.00	3.70	50.00		15
		Heating				
Coal	heaters/boilers	0.80	7.17	382.88	0.98	15
Electricity	heaters	1.00	5.09	229.73	0.98	15
HFO	heaters/boilers	0.85	1.20	382.88	0.74	15
Methane rich gas	heaters/boilers	0.92	0.31	382.88	0.74	15

		Efficiency/COP	*PJ/a*	*R/GJ/a*	*R/GJ*	*years*
Water heating						
Coal	boilers	0.80	4.89	60.00	0.98	15
Electricity		1.00	2.04	40.00	0.98	15
HFO	boilers	0.85	1.43	60.00	0.74	15
Heat pump		3.03	0.11	160.00	8.00	15
LPG		0.91	0.01	60.00	0.74	15
Methane rich gas	boilers	0.92	0.62	60.00	0.74	15
Paraffin		0.91	0.11	60.00	0.74	15
SWH		10.00	0.11	475.00	14.25	15
Other appliances						
Coal	appliances	0.75	2.64			15
Electricity	appliances	1.00	8.52			15
HFO	appliances	0.85	0.38			15
LPG	appliances	0.90	0.00			15

Currently HVAC systems are the biggest consumers of energy and are thus the targets for potential mitigation scenarios however the lack of thermal efficiency design codes in South Africa leaves little incentives for developers and building owners to implement energy efficiency measures. Mandatory efficiency standards, retrofits of HVAC systems or new efficient HVAC systems could all contribute in energy (and money) saved as well as pollution and GHG emissions reduction. Other energy policies will include efficient lighting systems, heat pumps or solar water heaters for water heating and fuel switching to maximise the use of a particular fuel.

4.2.2 The industrial sector

In the model, the industrial sector is disaggregated into the following industries:

- Chemical and petro-chemical
- Food and tobacco
- Gold mining
- Mining and quarrying
- Iron and steel
- Non-ferrous metals
- Non-metallic minerals
- Pulp and paper
- Other

End use demands are disaggregated into heating (boilers and process heating), cooling, compressed air, HVAC, facility support, lighting, and a few other end use demands. All these demands, besides boiler heat, are met with electricity only. Boilers are fed with an assortment of fuels such as coal, bagasse, heavy fuel oil, as well as electricity for electrode boilers.

Table 12: Percentage of total electricity to meet demand

	Industry	***Gold mining***	***other mining***
Process heating	15.01%	2.00%	2.00%
Process cooling and refrigeration	2.98%	7.00%	7.00%
Compressed air	9.79%	20.00%	20.00%
Other Machine drive	37.61%	45.00%	45.00%
Electro chemical processes	25.13%	0.00%	0.00%
Other process use	0.50%	10.00%	10.00%
Facility HVAC	3.65%	8.00%	8.00%
Facility Lighting	4.44%	4.00%	4.00%
Facility support	0.88%	4.00%	4.00%

The energy intensities of each of the industrial subsectors are indexed from 2001 to 2030. They change with time as the industry or processes are expected to change. This is shown in Table 13.

Table 13: Intensities of mining and industry indexed to 2001

Sector/sub-sector	*Year*	*1995*	*2000*	*2001*	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
	Activity measure	*Intensity data with 2001=100*								
Mining										
Gold	Physical output	85.47	97.58	100	109.69	121.80	133.90	146.01	158.12	170.23
Rest of mining	Value added	101.37	100.20	100	99.29	98.55	97.92	97.38	96.90	96.47
Industry										
Food bev & tobacco	Value added	91.21	98.99	100	103.23	106.16	108.40	110.22	111.74	113.06
Pulp and paper	Physical output	95.72	99.54	100	101.43	102.70	103.65	104.42	105.06	105.61
Chemicals & petro-chem	Value added	103.78	100.43	100	98.61	97.35	96.39	95.60	94.95	94.38
Non-metallic minerals	Physical output	90.78	99.01	100	103.09	105.82	107.87	109.52	110.90	112.09
Iron & steel	Physical output	89.85	98.91	100	103.40	106.40	108.67	110.49	112.01	113.31
Non-ferrous metals	Physical output	96.67	99.64	100	101.11	102.10	102.84	103.44	103.94	104.37
Other	Value added	98.73	99.85	100	100.46	100.89	101.21	101.47	101.69	101.88

It is assumed that the structure of the industrial sector will evolve slightly over time. Table 14 shows the assumed level of contribution to GDP by each subsector between 2001 and 2030. It has been normalised to give 2000 a value of 1. A constant value would indicate a constant contribution to GDP over time. An increasing value indicates increased contribution to GDP by that sector over time.

Table 14: Normalised assumed sectoral contribution to GDP

Sector/Sub-sector	*2000*	*2010*	*2020*	*2030*
Mining				
Gold	1.00	0.60	0.33	0.19
Platinum	1.00	1.03	1.06	1.08
Coal	1.00	0.92	0.85	0.79
Iron ore	1.00	0.95	0.89	0.84
Copper	1.00	0.75	0.53	0.37
Diamond	1.00	1.03	1.03	1.03
Chrome	1.00	1.02	1.00	0.97
Asbestos	1.00	0.52	0.34	0.25
Manganese	1.00	0.90	0.83	0.77
Rest of mining	1.00	0.97	0.86	0.76
Industry				
Food bev & tobacco	1.00	0.96	0.92	0.90
Textile, cloth & leather	1.00	0.75	0.66	0.62
Wood & wood prod	1.00	0.99	0.97	0.96
Chemicals	1.00	1.05	1.07	1.08
Non metallic minerals	1.00	0.96	0.92	0.89
Iron & steel	1.00	0.95	0.91	0.86
Precious & non-ferrous metals	1.00	1.03	0.95	0.88
Rest of basic metals	1.00	0.90	0.85	0.83
Rest of manufacture	1.00	1.01	1.01	1.01

Figure 28 shows the seasonal distribution of industrial demand for electricity. Electricity demand is highest on summer days. This daily and seasonal demand distribution is assumed to remain constant between 2001 and 2030.

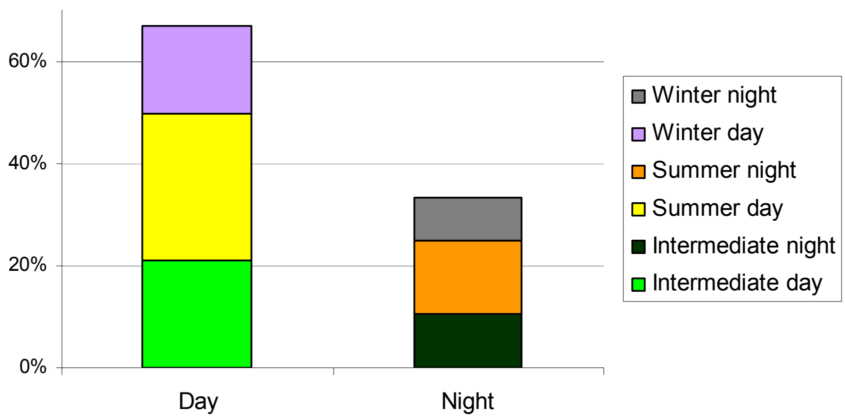


Figure 28: Electricity time of use for industry and mining

The useful energy demand of industrial end uses as well as their assumed efficiencies are recorded in Table 15. Useful energy demand increases over the planning period as industrial sectors grow. The efficiency of end uses requiring electricity are either an index or coefficient of performance (COP) or are included, as in the case of lighting and compressed air, as the energy required to produce a certain amount of light or compressed air. And useful energy demand is then for lighting or for compressed air and not for energy.

Table 15: Efficiency and useful energy demand for industrial end uses, 2001

			Useful energy demand		
End use	*Efficiency*		*Industry*	*Gold mining*	*Other mining*
Electricity end uses					
Process heating	1	Index	44.33	1.34	0.96
Process cooling	3.22	COP (PJ/PJ)	28.37	15.09	10.77
Compressed air	516.37	PJ/l of useful air	14938.52	6914.89	4933.12
Other machine drive	0.85		94.44	25.61	18.27
Electrochemical processes	1	Index	74.25	0.00	0.00
Other process	1	Index	1.49	6.70	4.78
HVAC	2.61	COP (PJ/PJ)	28.09	13.97	9.97
Lighting	4.17	Gluminhrs/PJ	54.67	11.16	7.96
Facility support	1	Index	2.60	2.68	1.91
Thermal demand					
Coal	0.64		380.90	1.27	10.41
Electricity	0.76		1.42	0.00	0.00
HFO	0.68		34.94	0.07	0.41
Methane and hydrogen rich gas	0.72		15.99	0.29	0.22
Wood	0.64		22.54	0.00	0.00
Bagasse	0.64		32.50	0.00	0.00
Other	0.64		6.35	0.00	0.00
Diesel	0.68		0.00	2.23	10.57
LPG	0.72		0.00	0.00	0.07
Paraffin	0.68		0.00	0.00	0.28

4.2.3 The residential sector

The vast range of income in South Africa means that the energy demand of households can differ significantly. Higher income households tend to demand more electrical energy and own more appliances, whereas lower income households use more traditional energy sources via inefficient means. Whether a household is situated in an urban or rural setting also impacts on the energy use and particularly the type of fuel used to meet energy demands. In many rural areas wood is available whereas a similar economic bracket in the city, may be using coal. In order to capture these differences within the model, the residential sector is divided into six different household types. Table 16 below shows the different housing types included in the model, the number of households in each type in 2001 and the projected number of households in 2030.

Table 16: Household type and number of households of that type in 2001

Source: Winkler et al (2006)

	2001	*% share*	*2030*	*% share*
Rural rich electrified	1 181 279.238	10.54	1 852 596.721	13.75
Rural poor electrified	1 095 449.288	9.78	2 315 745.901	17.19
Rural poor non-electrified	2 249 570.731	20.08	463 149.1802	3.44
Urban rich electrified	4 074 437.503	36.36	6 190 668.426	45.94
Urban poor electrified	1 255 728.28	11.21	2 564 705.491	19.03
Urban poor non-electrified	1 349 239.96	12.04	88 438.12037	0.66

South African cities have already seen an explosion in population due to urbanization as rural people move to the cities in search of jobs and an improved quality of life. Many of these people live in large informal settlements which spring up around the city limits. It is believed that this trend of urbanisation is will continue into the future. In the nine largest South African cities, population grew by 2.8% per year between 1996 and 2001 but the number of households increased at 4.9% per year (SACN 2004: 179). This is due to increased urbanisation and establishment of new households as income increases. The number of residents her household has also decreased: Household sizes have decreased from an average 4.5 persons per household in 1996 to 4.0 in 2001 (StatSA 1996; 2003). It is assumed that this trend will continue and will result in a decrease in the number of people per household between 2000 and 2030. The number of residents per household is assumed to drop from 4.06 in 2000 to 3.85 in 2030.

The assumed change in number of households by household type as well as the increase in the total number of households between 2001 and 2030 is shown in Figure 29 below. There is a shift towards electrified households which results from a government drive for electrification, in which government intends to achieve 98% electrification by 2012 and a continued movement of people from rural to urban areas.

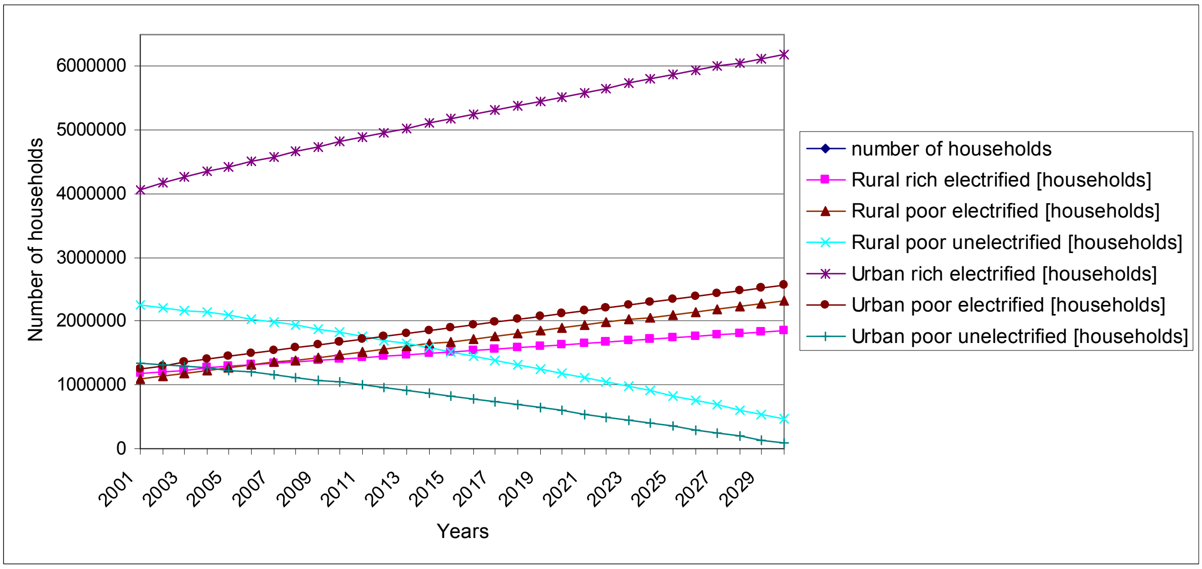


Figure 29: Number of households in each subsector (2001 to 2030)

In this study, 'poor' households, with regard to energy consumption, are considered to be those in the bottom two quintiles of income (an annual per capita income of less than R4 033). Households that fall into a 'middle income class' have been included in the 'rich' category (Winkler et al 2006) due to the similar fuel and appliance availability and use. The Final energy demand by each household type in 2001 is shown in Figure 30.

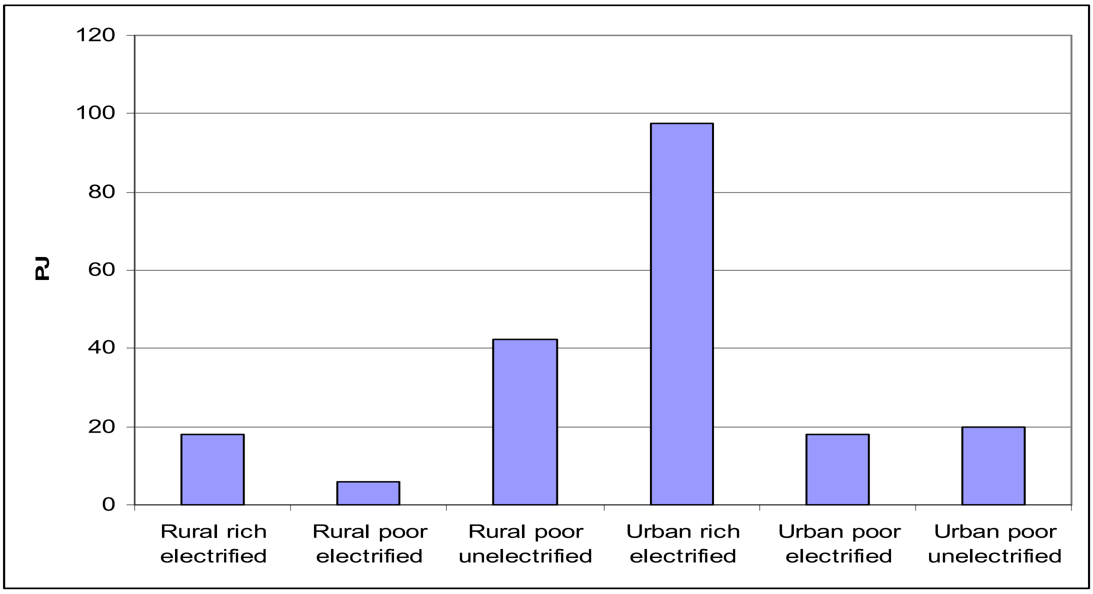


Figure 30: Final energy demand for each household type, 2001

Energy demand in the residential sector is disaggregated into a demand for cooking, lighting, space heating, water heating and other electrical demands for each household type. Originally refrigeration and laundry were included as separate demands, however national data is not available for such a high level of disaggregation. Data collection in the residential sector is a difficult and expensive task thus most of the information used in the model is calculated from census data. Census 2001 provides the numbers of households that use a particular fuel to meet a specific demand. From these numbers of households, an energy use is calculated given a fuel use per household. The factor for fuel use per household is an approximation and leads to some inaccuracies. In areas that figures look highly unlikely, numbers were adjusted, keeping total fuel use similar to what was reported in the DME National Energy Balance for 2001.

A number of appliances are used to meet the demand for cooking, space heating, water heating, lighting and other requirements such as laundry. The type of fuel and percentage of demand that each appliance meets as well at the efficiency of appliances are shown in Table 17.

Table 17: Final energy intensity by end use for each household type

Final energy intensity [PJ/Mill households]	*Cooking*	*Water Heating*	*Space Heating*	*Lighting*	*Other*
Rural rich electrified	2.941	5.422	3.947	3.506	3.70
Rural poor electrified	2.247	4.512	4.448	1.849	0.094
Rural poor non-electrified	1.246	4.644	4.735	1.853	0
Urban rich electrified	6.032	8.098	4.016	1.814	4.115
Urban poor electrified	2.593	5.855	4.004	2.141	0.115
Urban poor non-electrified	3.807	3.297	5.508	1.740	0

The useful energy demand of households in each category is assumed to remain constant. Therefore changes in final energy demand in the residential sector are a result of changes in the number of households of each type, the fuel and appliance used by the household and the appliance efficiency. Only the energy intensity of 'other electricity' changes over time and increases with a 0.5% annually. The energy use for the different household types by end use in 2001 is shown in Figure 31.

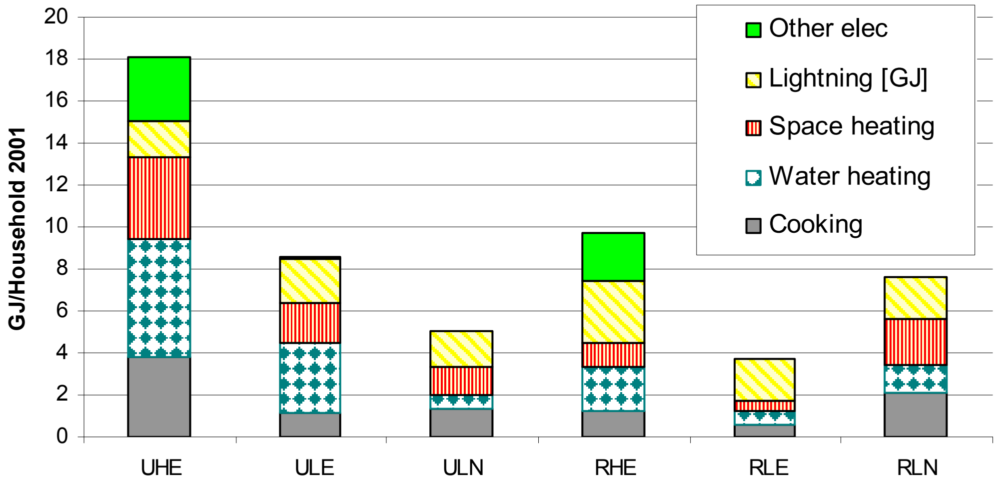


Figure 31: The energy use for the different household types

It is clear that urban high income households use the most energy, but the difference between the household is not only energy use but also type of fuel. As rural households switch from fuel wood to electricity for cooking, the final energy demand decreases due to the increased efficiency of electrical appliances. The same would be true for a switch between wood or coal and gas, ethanol gel or paraffin.

The range of appliances used for cooking in each household type is shown in Figure 32. In each case U and R represent urban and rural households, LE low income electrified, LN low income non-electrified, and HE high income electrified. Heat for cooking is supplied by five different fuels from eight appliances. Electrified high income urban households (UHE) and low income non-electrified rural households (RLN) use fewer fuel and appliance types. Urban high income households use electricity and a small amount of gas and wood. Low income rural households supply most of their energy needs for cooking with wood stoves. The other household types use a more varied mix of appliances and fuels. The low efficiency of wood stoves is reflected in the high energy demand by RLN households to meet their energy needs for cooking.

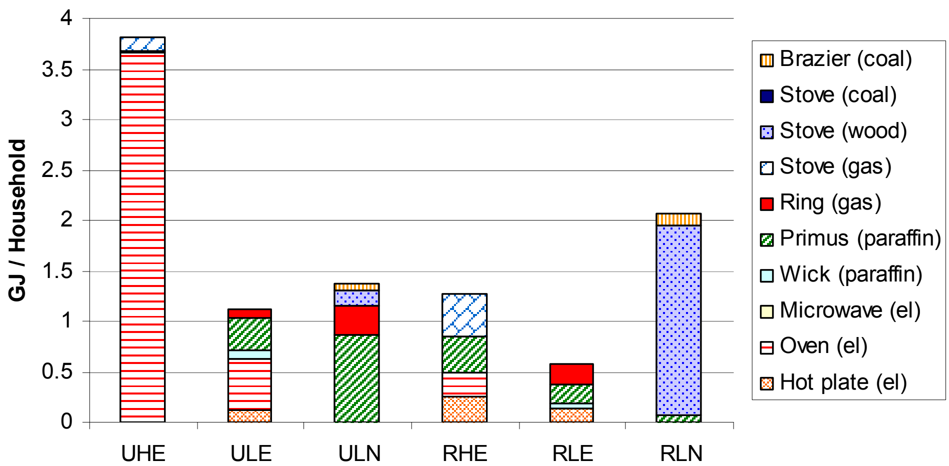


Figure 32: The energy carriers used for cooking

Figure 33 on the following page shows the energy demand for water heating by household type. Poorer households tend not to use much fuel for water heating. There is currently very little use hot water supplied by solar water heaters, the majority of hot water is supplied by electric geysers. It is possible to increase the efficiency of these geysers by covering them with what is often called a 'geyser blanket'. This is a layer of additional insulation that covers the geyser reducing standing losses.

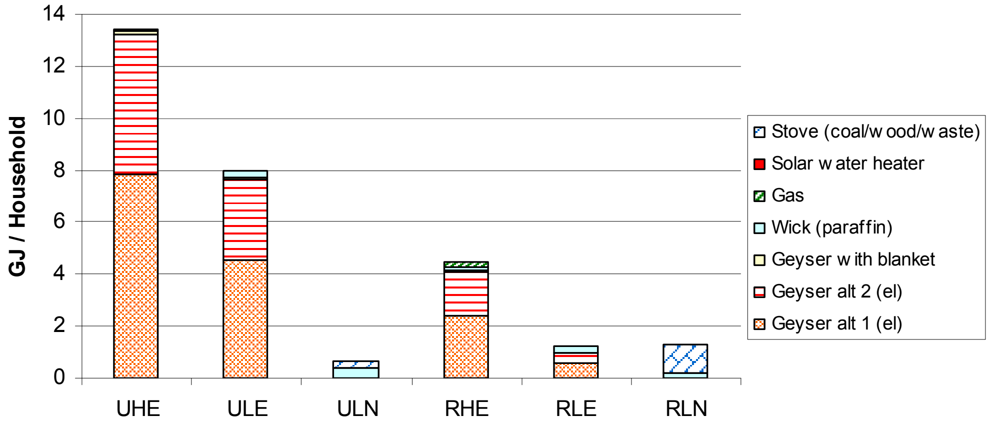


Figure 33: The energy carries used for water heating

The following figure (Figure 34) shows demand by fuel for space heating in households. Whilst there is a large demand for wood in the rural low income non electrified households (RLN), the heating provided is small due to the inefficiency of the appliances being used by those households.

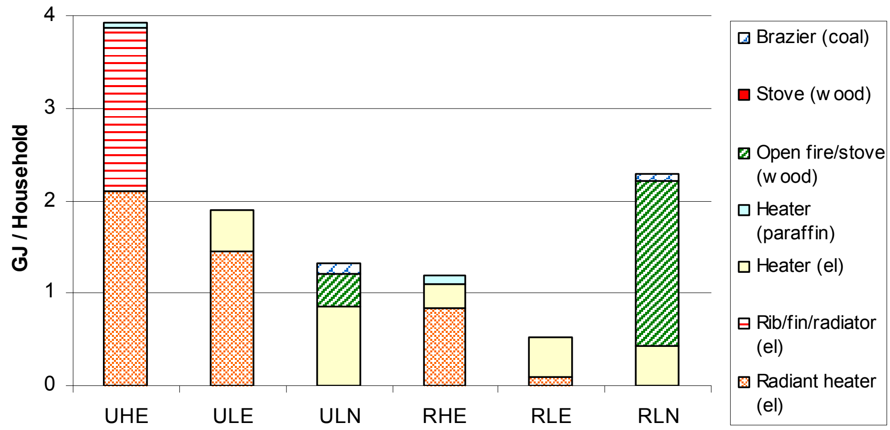


Figure 34: The energy carriers used for space heating

Lighting demand is dominated by electricity, paraffin wick lanterns and candles. Again the RLN household are using appliances to supply lighting which have a lower lumen output per energy input and as a result, although they may have fewer lights and lower lux levels within the home, the final energy demand increases. Currently incandescent lights meet most of the lighting demand in electrified households. There are several campaigns underway, including an aggressive DSM campaign by Eskom in the Western Cape, to increase the percentage of compact fluorescent lamps (CFL) used to meet lighting demand due to their significantly improved efficiency. CFL's use approximately one quarter of the energy required by an incandescent lamp to supply the same amount of light.

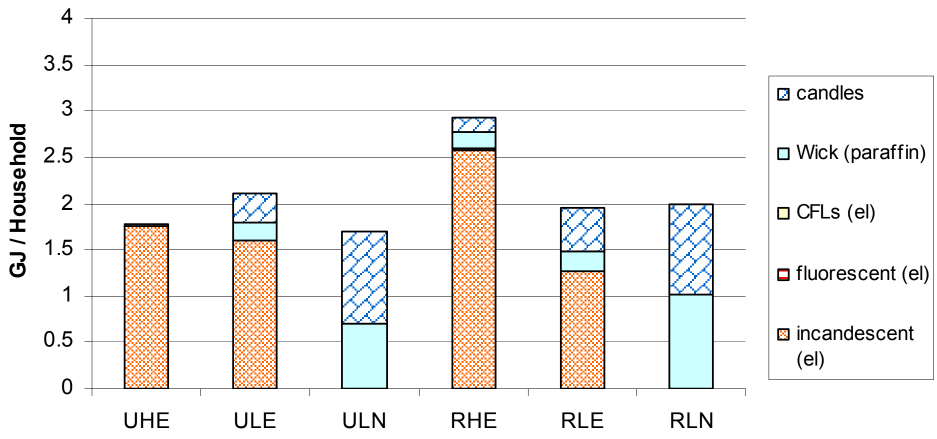


Figure 35: The energy carriers used for lighting

The following efficiencies, lifetimes, residual capacity and investment costs (Table 18) are applied to appliances in the residential sector. In the base case it is assumed that there is no improvement in the efficiency of appliances although there is a shift towards more efficient appliances such as the "Basa Njengo Magogo" (BNM) method for cooking with coal, and a shift towards the use of CFL's to meet lighting demand.

Table 18: Energy efficiency of appliances used in the residential sector in 2001 and 2030

Fuel consumed	*Device*	*Efficiency 2000*	*Adjusted cost (2003 Rand)*	*Lifetime (years)*	*Res. capacity (PJ)*	*Investment cost (R/GJ)*
			Cooking			
Coal	BNM method	0.11	0.00	1	0	
	Brazier	0.08	0.00	1	0.18	
	Stove	0.33	4823.38	11	-	
Electricity	Hot plate	0.65	211.18	5	1.5	116
	Microwave	0.6	805.97	5	0.10	3037
	Stove/oven	0.65	2166.16	9	15.86	529
Gas	Ring	0.58	229.62	5	0.32	119
	Stove	0.57	4606.21	9	0.91	427
Gel Fuel	Stove	0.41	147.55	9		36
Paraffin	Primus	0.43	34.33	6	1.85	47
	Wick	0.4	98.69	3	0.82	11
Wood	Stove	0.25	782.06	9	1.01	1141
			Lighting			
Candles	Candles	0.02	1.07	0.01		6.8
Electricity	CFL's	4.9	16.13	10	0.4848	59
	Fluorescent	7.1	11.94	4	-	
	Incandescent	1	2.76	1	14.28	9.5
Gas	Pressure	0.06	230.54	4	-	
Gel Fuel	Lamp	0.06	46.11	4		77
Paraffin	Pressure	0.07	177.06	4	-	
	Wick	0.02	4.60	4	0.08	25

Fuel consumed	*Device*	*Efficiency 2000*	*Adjusted cost (2003 Rand)*	*Lifetime (years)*	*Res. capacity (PJ)*	*Investment cost (R/GJ)*
			Space heating			
Coal	BNM method	0.79	0.00	1	0	0
	Brazier	0.59	0.00	1	3.58	0
	Stove	0.4	4823.38	11	0	
Electricity	Fin/rib/radiator	1	892.66	9	7.38	209.67
	Radiant heater	1	92.21	6	11.14	23.16
Gas	Heater	0.75	915.94	5	0.30	197.64
Paraffin	Heater	0.73	54.14	9	4.26	25.25
Wood	Open fire	0.925	782.06	9	16.81	87.86
			Water heating			
Coal	BNM method	0.11	0.00	1		
	Brazier	0.08	0.00	1		
	Stove/pot	0.33	36.89	1	3.79	8.90
Electricity	Geyser blanket	0.80	138.32	22	0.60	20.97
	Geyser (no blanket)	0.7	2002.94	22	29.17	303.60
Gas	Geyser	0.84	3963.46	22	0.33	2861.72
Gel fuel	Stove	0.41	147.55	5		35.99
Paraffin	Wick	0.4	34.12	3	2.06	36.01
Solar	Solar Water Heaters	1	6593.48	17	0.19	698.84
Wood	Stove	0.25	782.06	9	3.98	179.45

Figure 36 shows the time of demand assumed for each end use in the residential sector. Time of use in the residential sector is important as the sector is one of the main contributors to the increase in electricity demand at peak times. As is shown, space heating is only used during winter months, and the demand occurs largely during day. Cooking and water heating demand are greatest during winter nights. The time of use shown below is assumed to be the same across all households types, this is simplified view of what occurs in practice, but there is little data at present to substantiate changing the time of use profile between households types.

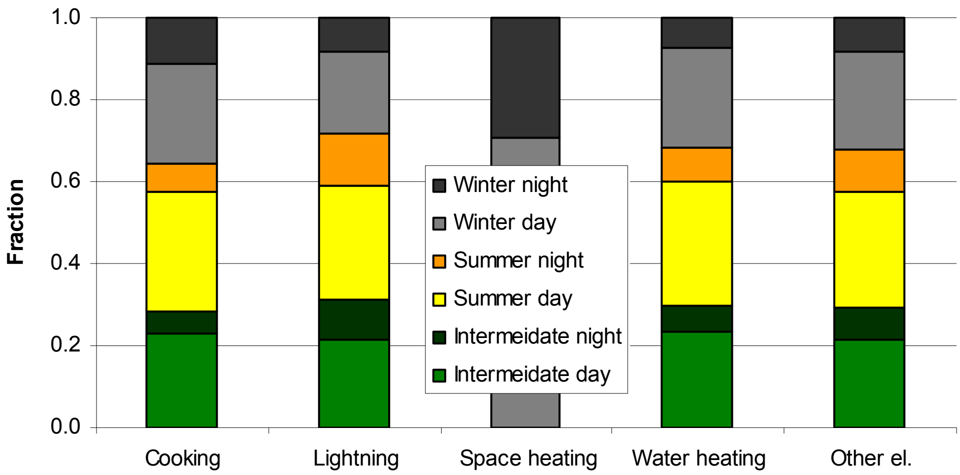


Figure 36: Time of demand for the different demand types

4.2.4 The transport sector

The transport sector includes passenger transport, freight, aviation and piped fluids (gaseous and liquid). Marine freight is not included in the model since it is largely international travel and the effects are not restricted to South Africa. Passenger transport is further split into public and private transport.

The road transport sector in South Africa is a sector has traditionally received the least attention although if forms some 20 percent of final energy demand. We have attempted in this study to improve on all previous attempts to model the transport sector in South Africa. Improvements in data as well as method have been made. Data relies heavily on the paper 'Road transport in South Africa – 2030' and 'Key results of the national household travel survey 2003'.

Useful energy demand for passenger and freight transport is now modelled in passenger –km and tonne –km. This allows flexibility for modal shifting, however with this method one has to assume an occupancy rate or tonnage per kilometre for each type of vehicle. These assumptions as well as the desegregation of road transport within the model are shown in Table 19 below.

Table 19: Assumptions for occupancy and load for passenger and freight vehicles

Passenger vehicles	*Occupancy (persons/vehicle)*
Diesel buses	35
Petrol taxis (minibus)	10
Diesel Taxis (minibus)	15
Petrol Cars	2.1
Diesel cars	2.1
Hybrid cars (diesel)	2.1
Hybrid cars (petrol)	2.1
SUV's diesel	2.1
SUV's petrol	2.1
Motorcycles	1
Diesel freight vehicles	*Load (ton/vehicle)*
Light commercial vehicle	3
Medium commercial vehicle	10
Heavy commercial vehicle	15
Petrol Freight vehicles	
Light commercial vehicle	3

Currently 52% of passenger-kilometres are met by public transport and 48% are met by private vehicles. When calculating the efficiency for freight vehicles it is assumed that the vehicle is full for half of the journey (ie half the kilometres) and empty for the other half. New vehicles are assumed to have an efficiency of 90% of the efficiency quoted by suppliers to account for city- versus open-road driving as well as a decrease in efficiency with increased vehicle age. As new vehicles enter the fleet, it is assumed that design changes will result in improved vehicle efficiencies. This assumption is based on a British study, which suggests that new passenger vehicles and light commercial vehicles will have an improved vehicle efficiency of 0.9% per annum (Kwon, 2006).

As technology advances and the characteristics of the South African vehicle fleet changes, so too must a model that describes such a system. In this study, we have included hybrid vehicles and sports utility vehicles (SUVs) as a separate category of private passenger vehicles in order to determine the effect increased use of these types of vehicles may have on the fuel consumption and emissions by the transport sector. Unfortunately data on these vehicle types is very difficult to obtain so a number of simplifications and assumptions have been made. The cost for SUVs is averaged from the cost of the following Toyota vehicles for both petrol and diesel: Land Cruiser GX, Land Cruiser Pickup, Land Cruiser Pickup Brutus and Land Cruiser Prado VX. It is assumed that in 2001

Hybrid vehicles meet 0.0024% of the passenger-kilometres travelled while diesel and petrol SUVs meet 0.32% and 0.35% respectively. In 2030 hybrids meet 0.1% of demand in the base case while SUVs increase to meet 4% of the demand for passenger-km (1.7% of diesel vehicles and 2.3% for petrol vehicles). The main implication for these types of growth patterns is that a very efficient vehicle such as a hybrid will reduce the demand for fuel while maintaining the same passenger-kilometre output whereas an SUV due to its larger size and decreased fuel efficiency uses a great deal more fuel and thus emits far more GHGs per kilometre driven than a smaller passenger car.

Due to the ageing taxi fleet, the National Department of Transport has instigated a Taxi Recapitalization Plan (described further in section 2.4.6). This is represented in the base case by increasing diesel taxis from 0% of passenger-kilometres in 2001 to 1.2% in 2030.

Demand for passenger and freight transportation is met through a number of technologies with varying costs and efficiencies. Less is known about pipeline and aviation transport therefore the demand for these forms of transport is given in kilo-tons and Petajoules respectively. No modal shift between types of pipeline pumps or types of aviation is simulated in the model.

The various transportation technologies meet transport demand using an assortment of energy carriers with liquid fuels such as diesel and petrol being the most dominant. The model has the flexibility to include bioethanol and biodiesel into the transportation fuel mix to simulate what may occur as a result of the new draft biofuels strategy (DME 2006). The use of bioethanol and diesel in the fuel mix is included in the base case, with the ethanol petrol blend being 4% and the biodeisel diesel blend being 1% in 2015. This percentage is increased to 8 and 2 respectively in 2030. Calculations based on the 'Biomass study- Maize from South Africa, 2006' indicate that biofuel can be supplied to meet this demand without negatively impacting on food security.

The increase in demand for passenger km, by vehicle type, over the planning period is shown in Figure 37.

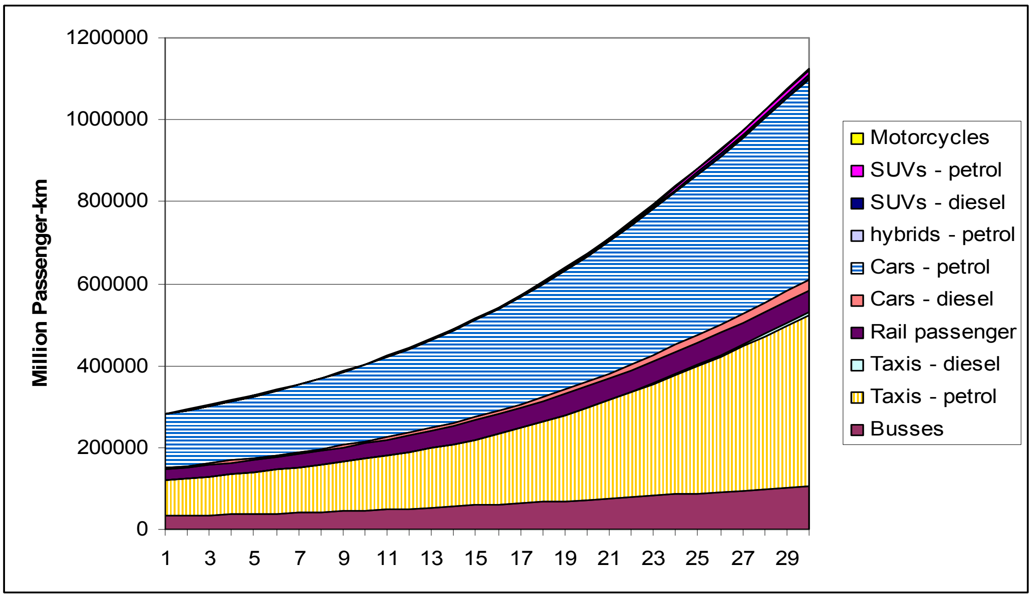


Figure 37: Demand for passenger km, public and private

The increase in demand for tonne km, by vehicle type, over the planning period is shown in Figure 38.

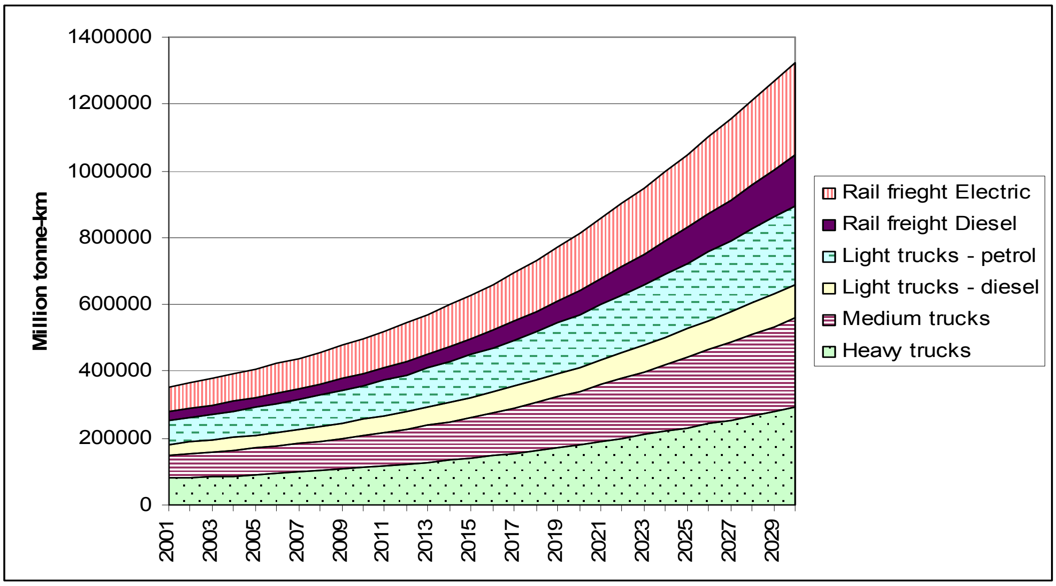


Figure 38: Demand for tonne km road and rail

The intensity or demand for fuel changes with each transport mode. The energy intensity of travel is recorded in PJ/passenger km. The assumed total mileage travelled by each vehicle type is recorded in Table 20 below along with the intensity. Lifetimes of vehicles are based on scrapping curves for vehicles in the South African transport fleet. The assumed life of vehicles is 18 years for all cars, 25 years for trucks, 14 years for buses and 11 years for taxis.

Table 20: Intensities of passenger and freight transport

Transport intensities (road)			
Passenger transport	***Intensity*** *(MJ/pass-km)*	***Total mileage*** *(billion vehicle-km)*	***Total fuel use*** *(PJ)*
Diesel buses	0.39	0.92	12.66
Petrol taxis (minibus)	0.44	8.82	38.46
Diesel Taxis (minibus)	0.29	0.00	0.00
Petrol Cars	1.51	62.00	197.23
Diesel cars	1.40	1.82	5.36
Hybrid cars (diesel)	0.59	0.00	0.00
Hybrid cars (petrol)	0.70	0.00	0.00
SUV's diesel	2.04	0.21	0.88
SUV's petrol	2.39	0.23	1.14
Motorcycles	1.80	1.58	2.84
Freight	*(MJ/tonne-km)*		
Light commercial vehicles	1.59	11.34	54.00
Medium commercial vehicles	0.70	6.89	47.92
Heavy commercial vehicles	0.84	5.28	66.62

4.2.5 The agricultural sector

Demands for heat, processing energy, irrigation, tractors, harvesters and other energy needs (all in Petajoules) are met through various technologies and fuel sources. Technologies using liquid fossil fuels (tractors, harvesters and pumps using diesel or petrol) are able to use a bio-fossil fuel blend. Tractors and harvesters are also able to run on pure bio-ethanol or bio-diesel for a case in which farmers may be producing biofuel on site for use in their own vehicles. Demand for energy increases in time with respect to the agricultural GDP.

Most energy in the agricultural sector is used for traction in the form of diesel or other liquid fuels. Other energy demands include irrigation, preparing the land, processing, transport etc. While there is no accurate data for these splits in energy demand a best guess is made for useful energy demand in 2000 and projected to 2030 and seen in Table 21 below.

Table 21: Useful energy demand by end use in the agricultural sector

Useful energy demand	*2001*	*2030*
Heat	3.85	5.22
Irrigation	6.63	13.89
Other	9.84	20.63
Processing	5.69	8.92
Traction	14.98	23.50

4.2.6 Transformation: Electric conversion and refineries

Electric conversion

All major existing Eskom plants are included explicitly in the model and smaller plants such as the hydro plants Gariep and Van der Kloof are included collectively as Eskom Hydro plants. Moth-balled Coal-fired plants that will be brought online in the coming years, such as Groot Vlei and Komati are included as existing capacity, and are allowed to generate electricity in the year in which they are due to be commissioned. New plants that are under construction, such as the New Braamhoek plant, the CCGT plant planned for Coega, and the OCGTs currently under construction are also included explicitly. Existing municipal plants are collectively included as one single unit for each fuel type.

Proven technologies such as certain renewable energy technologies, clean coal technologies or PBMR nuclear technology are allowed to be commissioned after the year in which it is likely that the capacity could be brought on line. Ceilings are set for investment in new capacity for each technology.

Transmission costs are not included for either existing or new plants. However certain types of plants that do not need to be built near a fuel source, for example nuclear power plants and gas turbines, are given a 'transmission benefit' in the form of slightly reduced cost.

Availability factors and forced outage rates are included along with a reserve margin. Table 22 includes all investment and operation and maintenance costs assumed for all new types of generation capacity included. The availability factor indicates the percentage of the year that each plant is available to run i.e. when it is not undergoing maintenance, whilst the capacity factor, which is included for renewable technologies only, indicates the percentage of the year that the plant can generate electricity based on resource availability. All costs are in 2003 Rands.

Table 22: Characteristics and costs of new power plants (2003)

	CapeX: PV Capital expenditure (R/kW)	*Fixed O&M costs (R/kW/yr)*	*Variable O&M costs (R/MWh/yr)*	*Capacity per unit (MW)*	*Operating lifetime (Years)*	*Effic-iency (%)*	*Lead time*	*Avail-ability factor (%)*	*Capacity factor (%)*
Coal-fired									
PF dry-cooled with FGD	9 980	125	7.5	642 x6	30	34.6	4	88	
Cleaner coal									
Fluidized bed combustion, greenfield with FGD	11 511	205	19.5	233 x 2	30	36.7	4	86	
Supercritical coal with FGD	11 015	227	16.9	600 x 4	30	38.0	4	88	
Integrated gasification combined cycle	10 564	141	19.1	550 x 4	30	46.3	5	88	

	CapeX: PV Capital expenditure (R/kW)	Fixed O&M costs (R/kW/yr)	Variable O&M costs (R/MWh/yr)	Capacity per unit (MW)	Operating lifetime (Years)	Effic-iency (%)	Lead time	Avail-ability factor (%)	Capacity factor (%)
Gas turbines									
CCGT (w/out transmission benefits), LNG	4 171	175	10.6	387 x 5	25	50.0	3	85	
Open cycle gas turbine 1	2 753	80	65.9	120 x 5	25	33.0	2	85	
Imported electricity									
Imported hydro-electricity (Cahora Bassa)			92.2			n/a			n/a
Imported hydro-electricity (Mepanda Uncua)			161.3			n/a			n/a
Imported hydro-electricity (Inga)			126.7			n/a			n/a
Imported coal-fired electricity (Mmamabula)			–			n/a			n/a
Imported gas-fired electricity (Kudu)			235.4			n/a			n/a
Solar thermal									
Central solar receiver ('power tower')	22 200	178	0.1	100	30	n/a	3		60
Parabolic trough	22 500	147	0.1	100	30	n/a	3		50
Photovoltaic	49 000	69		5	30	n/a	2		15
Wind									
Wind turbines	7 768	167		5	20	n/a	2		30
Other renewables									
Landfill gas	4 287	156	0.4	3	25	n/a	3		89
New biomass co-generation	23 000	154	22.9	8	30	n/a	4		57
New small hydro	10 938	202		2	25	n/a	1		30
Nuclear									
PBMR (excl transmission benefits)	18 707	158	6.7	165	40	40.5	4	95	
PBMR later series multi-module	10 761	158	6.7	165	40	40.5	4	95	
PWR (excl trans benefits)	15 290	507	25.0	874	40	31.5	4	79	
Storage									
Pumped storage (Braamhoek)	4 619	37	9.0	333	35	76.0	7	97	
Pumped storage (generic)	4 822	49	9.0	333	40	76.0	7	97	

Refineries

All existing refineries are included in the model as a single unit of refining capacity. The proposed refinery at Richard's Bay is included separately as are generic refineries of 15000bbl/day and 30000 bbl/day for future capacity requirements. Existing synfuel plants are included separately as well as a new coal-to-liquid (CTL) plant is for future developments.

Inputs to refineries include locally extracted crude oil and imported crude oil. Synfuel plants use coal specifically for that purpose.

The bioethanol plant currently under construction in Bothaville is included explicitly in the model but further bioethanol plants as well as small and large biodiesel plants are included as generic plants with estimated capacities and investment costs. The investment costs are based on current economic analyses for biofuel plants. As described in section 2.4.6, a biofuels strategy has recently been released by government and will have great impacts on the biofuels industry in South Africa.

Assumed costs for new refinery capacity, new coal to liquid, gas to liquid, bio ethanol and bio diesel plants are given in Table 23

Table 23: Characteristics and costs of new refinery capacity (2003 Rands)

Capex: PV capital expenditure (2003 Rm/ GJ)	*Fixed o&m costs (R/GJ/yr*	*Variable O&M costs 2003R/GJ/yr*	*Capacity (bbl/day)*	*Capacity (PJ/yr)*	*Expected operating lifetime (Years)*	*Capacity factor (%)*	*Process efficiency (%)*
Crude oil							
35.946644	1.68	1.86	150000	313	25	0.92	
30.195181	1.68	1.86	250000	522	25	0.92	
Gas-to-liquid							
148.70	10.94	11.45		94	25	0.93	0.89
Coal-to-liquid							
272.16	9.45	3.43		313.0	25	0.96	0.35
Maize-to-ethanol							
159.83	33.360	40.773		3.64	25	0.96	0.52
Biodiesel							
52.91	6.00	9.70		3.8636	25	0.96	93-99% by volume
234.90	18.21	29.71		0.04896	25	0.82	

5. Final Comments

This report covered the base case data for primary energy supply, transformation (for both electricity and liquid fuels), and energy demand. It also covers the model structure and assumptions for the base case including the major drivers. Following on this report are two additional reports, the first covers in detail the scenarios included in the model, the second presents and examines the model results.

Many assumptions have been made whilst assembling this data, not only in the drivers, but also where data was lacking in certain sectors. Much of the end use data, although referenced post 2000, is based on data collected in the 90's and the split of fuels and end uses during that time. It is possible that, for instance, the use of fuelwood in households may have changed in the last decade. Whist we have tried to make assumptions about the way fuel use has changed, where recent data is not available, accuracy is lost through this process.

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Appendices

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2. The integrated energy planning process

Worldwide, the rapid increase in demand for energy has necessitated an innovative and far-reaching planning process for energy infrastructure. In the past planning usually occurred within each separate energy carrier with little view of the larger picture: for example oil, coal, electricity were all planned separately. Analysis of the energy sectors was restricted to the technical aspects of supply. It was only after the 1970s oil shock that governments started looking at end uses and demand side management in their energy planning (Eberhard, 1992). Nevertheless a basic market equilibrium of supply and demand failed to take into account all aspects of energy demand and utilization and often the poorest people, using local biomass as an energy source, were left out of the analysis and thus no planning was made to improve energy supply to these people.

The omissions in past energy planning, coupled with a growing concern for the environment, led to what is currently known as Integrated Energy Planning (IEP). Given the nature of most energy sectors in which very large investments are made for centralized power stations and vast distribution networks, governments are the only groups capable of controlling this sector. And it is vital that they do so effectively since the energy sector directly influences all other sectors and the economic growth of the country.

What is IEP?

The goal of an IEP process is to determine the least expensive energy mix that provides energy for economic growth as well as reaching environmental, socio-economic and development targets.

Munasinghe (1990) says of integrated national energy planning:

> Energy planning, broadly interpreted, denotes a series of steps of procedures by which the myriad of interactions involved in the production and use of all forms of energy may be studies and understood within an explicit analytical framework. (1990:2)

The traditional top-down approach to energy analysis which started at the specific energy source and moved down to the consumer has been replaced by a bottom-up approach that starts with the consumer. Integrated energy planning involves comprehensive analysis of the energy sector and the linkages to all other sectors, as well as formulating and evaluating energy policies and the impact they have on society and the economy of the country. Demand- and supply-side management strategies are implemented and examined as policy instruments to achieve certain goals. (Eberhard, 1992). Throughout the IEP process, research is essential in supporting the planning procedures.

The key aspect to IEP is efficiency in both the production of energy (technological and economical efficiency in optimization of energy planning and system operation) and consumption of energy (efficient technologies and price signals to ensure optimal energy use and resource allocation) (Munasinghe 1990). Economic and Energy efficiency, while linked in the energy planning process, are distinctly different in their definitions and goals. The IEP process allows one to analyze and prioritize different goals.

The steps that go into IEP are usually as follows, although the order is not necessarily rigid (Eberhard, 1992):

1. Definition of goals and scope:
2. Database development/description of energy system
3. Demand analysis and projections (ie modelling)
4. Supply analysis
5. Balancing supply and demand and constructing future scenarios
6. Policy options
7. Impact analysis
8. Iteration

IEP in South Africa

The goals in energy planning differ from country to country depending on the energy, economic and social conditions specific to that country. Energy policy literature points this out by highlighting Africa:

> The building of energy policies in Africa must be based on a development trajectory which strives towards growth which is sustainable in environmental and economic terms and takes account of constraints imposed by an unfavourable economic climate and environmental resource limits. (ETC 1989)

As well as energy for economic growth and general development, the South African government requires selective intervention in the energy sector in an attempt to rectify some of the gross disparities of energy provision between different population groups. Through an IEP, the future energy infrastructure can be optimized for these multiple goals. The South African government first initiated the program of IEP in the White Paper on Energy (DME 1998) in 1998 where it was stipulated:

> The Department of Minerals and Energy will ensure that an integrated resource planning approach is adopted for large investment decisions by energy suppliers and service providers, in terms of which comprehensive evaluations of the economic, social and environmental implications of all feasible supply and demand side investments will have to be undertaken.

The first Integrated Energy Plan, based primarily on techno-economic modelling, was released in 2003 by the Department of Minerals and Energy (DME) and claimed to 'address energy demand balanced with energy supply, transformation, economics and environmental considerations in concourse with available resources' (DME 2003). The energy modeling in the IEP used the LEAP and MARKAL modeling tools to simulate and optimize two scenarios from 2001 to 2020: A baseline, 'business-as-usual' scenario and a 'Siyaphambile' ('we are going forward') scenario in which diversification of supply and environmental improvement are priorities (DME 2003). While the IEP took many factors into account, we are warned in the documentation:

> The integrated energy and resource planning process takes into account physical, technical, resource and economic considerations. The modelling process cannot by itself account for matters pertaining to sociological effects, political imperatives, global changes etc. (DME 2003)

The results of the first IEP focused heavily on fossil fuels and suggested that South Africa will continue to use coal in the near term as it is the most economical of available energy sources. Coal may be burnt in both in traditional power plants or in 'clean coal' technologies such as Fluidised Bed Combusters. Imported natural gas from neighbouring countries (such Namibia and Mozambique) will also play a more significant role in electricity generation and provision of industrial heat and household cooking. The Pebble-Bed Modular nuclear Reactor (PBMR) is a likely candidate for electricity generation and oil will continue to be imported from the Middle East for the transport sector. Imported hydro-electricity electricity from Central Africa is also a possibility for the future. The results from the IEP highlighted the need for enforced efficiency measures especially in the industrial sector.