South African energy policies for sustainable development

Phase 2
Final report

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EXECUTIVE SUMMARY

This report models a range of energy policies for sustainable development in South Africa and evaluates the results against energy indicators of sustainable development. Demand- and supply-side policies exist that can contribute both to energy objectives, and also to broader sustainable development goals. The report builds on previous work on a South African profile on energy for sustainable development (ERC 2004a), identifying, modelling and evaluating future policy options. The purpose of the report is to present possible energy futures for the country and to demonstrate how indicators of sustainable development can be used to assess options. This method, we argue, provides the means for policymakers to identify synergies and trade-offs between options, and to evaluate them in economic, social and environmental dimensions.

The policy options considered in the present report include both on the demand side (industry, commerce, residential and transport sectors) and supply side (electricity and liquid fuels). Types of policy instruments which are investigated include both economic and regulatory instruments. The analysis is conducted by scenario modeling, in which the energy policies are implemented in the Markal framework. The model is a least-cost optimising tool, rich in technologies and capable of including environmental constraints. The implications of the policy cases are assessed against energy indicators of sustainable development.

The report is structured as follows. The introductory section reviews background to the South African energy system and its resource base. Section 2 provides background on key economic sectors, and identifies policy options for the scenario modeling. The modeling framework and the key drivers of the reference case (close to government policy) are elaborated next. The modeling results are reported for each policy options in section 4. Section 5 consolidates the assessment against indicators of sustainable development, before concluding in section 6.

Reference case

The base case presents ‘current development trends’ or a base case which is close to the Integrated Energy Plan (DME 2003a).and for electricity, the second National Integrated Resource Plan (NIRP) (NER 2004a). On the demand side, fuel consumption in industry and transport dominates, with the latter growing most rapidly among sectors. On the supply-side, electricity generation continues to be dominated by existing and new coal, supplemented by gas turbines and new fluidised bed combustion, using discard coal. Smaller contributions come from existing hydro and bagasse, electricity imports, existing and new pumped storage and interruptible supply. Liquid fuel supply is met mostly from existing refineries and some expansion, little by imports of finished petroleum products. Emissions of both local and global air pollutants increase steadily in the reference case, over the period. Carbon dioxide emissions increase from 337 Mt CO_2 in 2001[1] to 591 Mt CO_2 in 2025 – an increase of 75% over the entire period.

Policies identified

A set of energy policy cases are modelled and compared to the base case.

- Industrial energy efficiency meets the national target of 12% less final energy consumption than business-as-usual. This is achieved through greater use of variable speed drives; efficient motors, compressed air management, efficient lighting, heating, ventilation and cooling (HVAC) system efficiency and other thermal saving. Achievement of this goal depends on forcefully implementing the policy.
- New commercial buildings are designed more efficiently; HVAC systems are retrofitted or new systems have higher efficiency; variable speed drives are employed; efficient lighting practices are introduced; water use is improved both with heat pumps and solar

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[1] The base year number is fairly close to the CO_2 emissions reported in the Climate Analysis Indicator Tool (WRI 2005).for 2000 – 344.6 Mt CO_2. It is somewhat higher than the 309 Mt CO_2 from fuel combustion reported in the Key World Energy Statistics for 2001 (IEA 2003a).

water heaters. In addition to specific measures, fuel switching for various end uses is allowed. Achievement of this goal depends on forcefully implementing the policy.

- Cleaner and more efficient water heating is provided through increased use of solar water heaters and geyser blankets. The costs of SWH decline over time, as new technology diffuses more widely in the SA market. More efficient lighting, using compact fluorescent lights (CFLs) spreads more widely, with a slight further reduction. The shell of the house is improved by insulation, prioritising ceilings. Households switch from electricity and other cooking appliances to LPG. The subsidy required to make interventions more economic for poorer households.
- Biodiesel production increases to 35 PJ by 2025, at a maximum growth rate of 30% per year from 2010, displacing petroleum. Energy crops do not displace food production, and sustainable production means the fuel is effectively zero-carbon.
- The share of renewable electricity increases to meet the target of 10 000 GWh by 2013. Shares of solar thermal, wind, bagasse and small hydro increase beyond the base case. New technology costs decline as global production increases
- Production of PBMR modules for domestic use increases capacity of nuclear up to 4,480 MW (32 modules). Costs decline with national production and initial investments are written off
- Share of hydro-electricity imported from SADC region increases from 9.2 TWh in 2001, as more hydro capacity is built in Southern Africa.
- Sufficient gas is imported to provide 5 850 MW of combined cycle gas turbines, compared to 1 950 MW in the base case.
- The use of economic instruments for environmental fiscal reform is being considered by Treasury {National Treasury, 2006 #2551}. We analyse the option of a fuel input tax on coal used for electricity generation. The policies could potentially be extended to coal for synfuel production and industrial use, or alternatively, the environmental outputs could be taxed directly, e.g. in a pollution tax (not analysed in this study).

Key results of policy cases

Key results are presented in sections 4, 5 and 6 of the report, and a summary of quantitative results can be found in the Appendices (see Table 60). The following text summarises some important findings and conclusions.

On the demand-side, energy efficiency policies were found to be particularly important. The overall strategy of reducing final energy demand by 12% compared to business-as-usual can be implemented most effectively in the industrial sector. Industrial energy efficiency is effective both in lowering the cost of the energy system by 18 billion Rand, and reducing global and local air pollution. Carbon dioxide emissions are reduced by 770 Mt CO_2 over 25 years. Greater efficiency has benefits in delaying the need for investment in power stations, with new base load power stations postponed by 4 years, and peaking power plant by 3 years.

Realising the potential for industrial energy efficiency requires forceful, even aggressive implementation. Current practice is often not economically optimal and clear signals are needed to induce industry to 'pick up the $20 bill'. The agreement between industry and government to implement the energy efficiency strategy (DME 2005a) and the recent announcement of that a dedicated Energy Efficiency Agency is to be established bode well in this regard.

A strong legal and institutional framework is needed for the commercial sector. The modeling suggests that a 12% energy efficiency target is achievable and can save R 13 billion over 25 years. However the results also suggest that the cost optimal energy efficiency improvements are 2-3% lower than the 12% and that these savings thus come at a cost (about 5% of investment costs). Government leading in making its own buildings and practices more efficient can play an important role.

The residential sector is particularly important for social sustainability. A sustainable development approach aims to deliver services meeting basic human needs, but in a cleaner and more efficient manner. Policy interventions focus on all end uses, using solar water heaters and geyser blankets (SWH / GB), LPG for cooking, efficient housing shell, and compact fluorescent lights (CFLs) for lighting. Making social housing more energy-efficient through simple measures such as including insulating ceilings, should be adopted as a general policy.

All policy cases assume near-universal electrification, and we find that the share of other commercial fuels (LPG and paraffin) also increases. Overall fuel consumption, however, is lowered compared to the base case (8.13 PJ less in 2025), with increasing efficiency and use of solar energy for water heating. Not all interventions are used by all household types – for example, efficient houses are only taken up by urban higher-income electrified households. Design of appropriate measure for poorer households is required, for example considering geyser blankets as well as solar water heaters. The lower cost – both upfront and per unit of energy saved – suggests that geyser blankets are appropriate policy interventions in poor electrified households.

Access to energy in physical terms needs to be accompanied by affordability in economic terms. While this issue deserves further analysis (translating it into an 'energy burden'), our findings suggest that a relatively small subsidy can make interventions economic for poorer households. The order of magnitude of the subsidy required to make efficient housing as affordable for poorer households as for richer ones is in the hundreds of Rands, but less than a thousand Rand.

On the supply-side, four policy cases focused on electricity supply – imported gas or hydro-electricity, or generating electricity domestically from PBMR nuclear or renewable energy technologies. Imported hydro potentially reduces investment costs, but increase the share of imported energy as a percentage of TPES. Imported gas increase the share of imports, while making little difference to total energy system costs. The PBMR case with imported fuel also shows an increase in this regard up by 4.3% of TPES in 2025. Domestic supply options, including renewable energy technologies, perform better in this regard. However, domestic supply options include substantial imported components. A sustained move to greater diversity, however, will require more than a single policy.

Investing in the PBMR and renewables options increases the costs of the energy system, while imported gas has a small effect and hydro imports reduce costs. While the increases are only 0.06% of energy system costs, they are nonetheless over R 3 billion in both the PBMR and renewables case over the period. In unit costs (R/kW of new capacity), gas is significantly cheaper than other options, followed by a mix of renewable energy technologies, hydro and the PBMR. However, the options do show quite substantial emission reductions – 246 Mt CO_2 for the PBMR and 180 Mt CO_2 for renewable energy technologies, both over the 25-year horizon. Both reduce local pollutants, notably sulphur dioxide, by 3 and 1.6% relative to the base case, respectively.

A key policy option addressing liquid fuels for transport is the supply of bio-diesel. The potential to produce 1.4 billion litres of biodiesel was modeled as starting in 2010, reaching a biodiesel reach market share of 9% of transport diesel by 2025. An average of 4,500 barrels/day of oil refining capacity can be avoided. Total reduction in carbon dioxide emissions reaches 5 Mt CO_2 per annum in 2025 and cumulative savings are 31 Mt CO_2 for the entire period. There are also smaller reductions in local pollutants. Present value of total system cost for this scenario is 2.4 billion Rands higher than for the reference scenario.

The results for a tax on coal for electricity generation show that the reductions of CO_2 emission from coal for electricity generation are small relative to the reference case. The economic difference lies less in system costs (R67 million over 25 years), but more in the tax revenues. These revenues both impose added costs on producers, but could also generated economic benefits if recycled. More detailed analysis is required of this policy option, possible extending the tax to coal for synfuels and industry as well, and quantifying the indirect economic effects of tax recycling and impacts on other policy objectives.

Combined, the emission reductions achieved by all the policies analysed here add up to 50 Mt by 2015 and 142 Mt CO_2 for 2025, 14% and 24% of the projected base case emissions for each respective year. One important conclusion is that significant emission reductions compared to business-as-usual are possible (or 'avoided emissions'). This should be understood together with a second conclusion, however, namely that stabilising emissions levels (e.g. at 2010 levels) would require some *additional* effort from 2020 onwards. The tools used in this analysis – a modeling framework combined with indicators of sustainable development – provide a useful way of examining trade-offs, as well as the room for compromise.

Over the 25-year time-frame considered here, energy efficiency makes sense against indicators of sustainable development. Industrial efficiency in particular shows significant savings in energy, costs and air pollution, with commercial energy showing a similar pattern at slightly smaller scale. Residential energy efficiency is particularly important for social sustainability. Even small energy savings can be important for poorer households. In the short-term, then, energy efficiency is critical to making SA's energy development more sustainable.

In the longer-term, transitions including the supply-side becoming important. Greater diversity will need a combination of policies, since single policies do not change ¾ share of coal in TPES by much on their own. The various electricity supply options show potential for significant emission reductions and improvements in local air quality. However, they require careful trade-off for the implications for energy system costs, energy security and diversity of supply.

The global costs (discounted total energy system costs) for the combined scenario are lower than for the base case by some R16 billion over the full period. This suggests that the savings of the combined efficiency measures outweigh the additional costs of investing in a diversified electricity supply.

GLOSSARY OF TERMS

BFP: Basic Fuel Price
CH_4: Methane
CO_2: Carbon dioxide
COP: Coefficient of Performance
DME: Department of Minerals and Energy
DSM: demand side management
EJ: etajoules (10^{18} joules): unit of energy
FBC: fluidised bed combustion
GDFI: Gross domestic fixed investment
GEAR: Growth Employment and Redistribution
GJ: gigajoule (10^9 joules): unit of energy
GTL: gas-to-liquids
GWh: gigawatt-hour (10^9 watt-hours): unit of energy
HFO: heavy furnace oil
IBLC: In-Bond-Landed-Cost
IPP: independent power producer
kW: kilowatt (10^3 watts): unit of power
kWh: kilowatt-hour (10^3 watt-hours): unit of energy
LPG: liquid petroleum gas
mcf: million cubic feet
MJ: megajoule (10^6 joules): unit of energy
Mt/a: million tons per annum
MW: megawatt (10^6 watts): unit of power
MW_e: megawatt of electrical power
MWh: megawatt-hour (10^6 watt-hours): unit of energy
NEPAD: New Partnership for African Development
NER: National Electricity Regulator
N_2O: nitrous oxide
NO_x: nitrogen oxides
NPA: National Ports Authority
PJ: petajoule (10^{15} joules): unit of energy
RDP: Reconstruction and Development Programme
RES: Reference energy system
SAEE: The Southern African Association for Energy Efficiency
SAPIA: South African Petroleum Industry Association
SEMA: South African Energy Management Association
SO_2: sulphur dioxide
tcf: trillion cubic feet (1 tcf of natural gas has an energy value of about 1,130 PJ)
TJ: terajoule (10^{12} joules): unit of energy

1. Introduction

This report presents analysis of South African energy policies for sustainable development. It builds on the final report of a previous phase of work, which presented a profile of South Africa in relation to the economic, social and environmental dimensions of sustainable development. The present report identifies future policy options for a range of sectors, both on the demand side (industry, commerce, residential, transport) and supply side (electricity and liquid fuels). Types of policy instruments investigated include both economic and regulatory instruments. The analysis is conducted by scenario modeling, in which the energy policies are modeled in the Markal framework. The model is a least-cost optimising tool, rich in technologies and capable of including environmental constraints. The implications of the policy cases are assessed against energy indicators of sustainable development.

The report is structured as follows. The rest of this introductory section reviews background to the South African energy system and its resource base. Section 2 provides background on key economic sectors, and identifies policy options for the scenario modeling. The modeling framework and the key drivers of the reference case (close to government policy) are elaborated next. The modeling results are reported for each policy options in section 4. Section 5 consolidates the assessment against indicators of sustainable development, before concluding in section 6.

1.1 Overview of the SA energy sector [2]

South Africa is a collage of diversity and contrast. Economically and culturally there is a distinct mix of the developed and developing world. As part of the national-building process it is essential to develop tools for effective growth. Among the challenges is the implementation of economic, self-perpetuating, sustainable energy systems.

1.2 Energy and resources

A sustainable energy system is one that provides for present national energy needs without compromising the ability of future generations to satisfy their energy requirements (Goldemberg & Johannson 1995). This also implies a system optimised in terms of delivered cost affordability to users and socio-economic development potential. As an input for economic activity, the lower the real cost of energy to the national socio-economic system, the more competitive the system. South Africa as a developing country is in urgent need of advancement, both in terms of education, living conditions and environmental protection. In order to make this energy system effective, it is important to establish the real costs of energy (including environmental costs) and to integrate this system with national development goals. Influencing energy supply and use, in the residential sector, for example, is integral to addressing key issues, such as housing, disposable income, fauna depletion, lighting and health impacts.

To improve the sustainability of a national energy system, three important approaches must be adopted to form a context in which an energy system can be technically optimal. Firstly, an evaluation of potential technical options for future energy scenarios and technology options and associated impacts must be established, which is the aim of this work. Secondly, clear information dissemination must take place in order for the market to optimally drive the energy system. Thirdly, until there is an empowering of concerned parties, fiscal steps should be taken to encourage external cost accountability and longer-term energy planning. At present Government is probably the best equipped institution to establish or coordinate all of these steps. However, over time, they should be self-perpetuating.

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[2] This section draws extensively on previous work by Andrew Kenny of ERC (SANEA 2003).

Technical energy scenarios and their impacts on the economy, resources, society and the environment for the medium to longer term are important. From such analyses, information vital for policy construction and investment may be derived (DME 2003a). Areas of specific interest and research direction include:

- the possibility of current energy sector development leading to future over-dependence on finite resources or on imports;
- the potential for longer-term national savings that could be brought about by extending local, national and regional resources;
- the technical potential of power pooling in the region, taking cognisance of the various energy demand growth rate predictions for neighbouring countries;
- the potential for distributed power generation, especially where piped gas supply may be cheaper than electricity distribution;
- the impact of novel technologies;
- case studies to establish the applicability of technologies and energy strategies for the South African situation done nationally or internationally, depending on the nature of the challenges involved for economic reasons. For example, Indian and South African coal reserves are similar, thus a joint Integrated Gasification Combined Cycle (IGCC) pilot plant project holds potential savings. (Currently the national electricity supply body ESKOM is completing the construction of a Fluidised bed plant together with an Indian consortium.) Also, biomass depletion and the health impacts from biomass-burning represents a common theme in African rural energy supply. Coordinated research offers further potential savings and African-specific solutions;
- the determination of energy efficiency potentials, and technological options for the demand-side as a function of cost must be established;
- the establishment of the real cost of energy and externality costs in the context of national development goals.

An externality cost is the change in utility or welfare of an agent, brought about by another, where this change in welfare is not compensated for, or appropriated (Van Horen 1996), by the latter. This externality may be either positive or negative. Thus where the eternality costs of energy are added to the supply costs, the figure that results is the real cost of this energy to society. This allows for a meaningful comparison of different energy forms where the real cost and costs of energy supply are different. It derives a possible basis for penalising or reimbursing energy users that impact on the environment (or society). Due to the often subjective nature of evaluating impact costs or potential impact costs, methodologies used for externality derivation must be both transparent and derived in the context of economic growth and needs in the short, medium and longer term. The data produced will then provide important elements for constructing an optimised energy system.

Information dissemination is vital for the establishment of a national, sustainable energy system. The most effective driver for the system may be the free market. However, players in the economy must be able to base decisions on clear authoritative data. Currently this is not the case. It is estimated, for example, that energy savings are possible for industry and commerce with significant medium-term financial gains. Such options are not being perused primarily due to lack of accessible authoritative data. The lower the real cost of the energy, the more competitive the economy becomes - an essential prerequisite for economic growth. Energy efficiency information and externality costs, as well as the potential impacts of carbon dioxide emissions restrictions on production must be made known. Meaningful databases should be built up for fuel use for all energy cycles, from generation to efficient demand-side consumption and information made accessible. This would include, for example, all feasible options for rural electrification and energy supply. Such information may then encourage optimal energy development and form the basis for sensible policy.

In the short term Government ‘encouragement’ of a sustainable energy development is essential, with an analysis of the most socially economic development paths. The tools used for the implementation of this integrated energy planning could include:

- physical controls, such as short-term supply rationing;
- investment policies;
- education policies;
- taxes or subsidies;
- market controls, such as regulating residential coal prices;
- establishing energy efficiency agencies.

Careful consideration must be given in such regulation implementation to ensure that the externality costs are borne by the responsible parties and that the controls do not restrict free market activity (Spalding-Fecher & Matibe 2003). Such measures should be seen as temporary and, with time, these controls should be diminished. In the case of externalities, as development progresses and with the empowerment of parties affected by energy externality costs, a laissez-faire situation will ideally evolve. Here, for example, the affected party and the polluter will bargain to establish an optimum pollution level and any associated cost compensation. Thus energy supplied will be at the lowest real cost to society.

With the necessary information and market forces, the current energy system, subsequently described, should evolve. A short description follows of major national energy carriers, reserves, fuel supply and demand sectors. Mention is also made of shortcomings in terms of potential efficiency improvements and impacts. Of special interest are the energy options for the residential sector, characterised by important needs as well as the industrial sector where energy efficiency hold special potential. These needs are discussed and possible technical solutions presented.

1.3 An introduction to the national energy system

The South African economy is energy-intensive, using a large amount of energy for every Rand of economic output (Hughes et al. 2002). It requires 0.24 tons of oil (equivalent) to produce 1000 international[3] (intl) dollar at purchasing power parity[4] (ppp) of GDP in 2001 (IEA 2003a). Per capita consumption is still however much lower than that of the United States. Annual per capita consumption in South Africa is 2.4 tons of oil equivalent compared to 8 in the United States (WRI 2005).

Current national energy supply is secure and well-structured. South African energy is dominated by coal, which contributes 70% of primary energy (DME 2005b) and fuels 93% of electricity production (DME 2005b). Currently, 33 % of the coal mined is exported. Of the total national supply, 55 % is transformed into electricity, 21 % into petroleum products, 4 % into gas and the remaining 20 % is used directly (ERC 2003). Energy supply is therefore also carbon dioxide-intensive. Much of the coal mined is of low quality it is often beneficiated (DME 2004a). Solid waste is discarded annually, and about 6.3 million tons was produced in 2003 (DME 2004a). The industrial, commercial, transport and residential sectors all directly consume coal. National coal reserves are plentiful and according to recent analysis, pressure on supplies is only likely to be felt around 2012, with peak production occurring around 2070 (Dutkiewicz 1994).

Petroleum products account for 38 % of total final energy consumption (TFC). Liquid fuels are derived from refined crude and liquefied natural gas, and from coal. The latter is carried out by the Sasol coal-to-oil process. Most of the crude refined in the country is imported and a small amount of natural gas is liquefied in the Mossgas liquefaction plant. Of the TFC of liquid fuels,

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[3] When comparisons are made with purchasing power parity, the dollar value used is the "International dollar" which is a hypothetical currency unit that has the same purchasing power as the U.S. dollar has in the United States at a given point in time. It shows how much a local currency unit is worth within the country's borders. Conversions to international dollars are calculated using purchasing power parities (PPP). It is used for - namely gross domestic product (GDP) - comparisons both between countries and over time.

[4] Purchasing power parities (PPP) is an alternative exchange rate between the currencies of two countries. It takes into account that some goods like real estate, services (e.g. medical services) and heavy items are non-traded, and thus not reflected in the exchange rate.

72 % is derived from crude, 23 % from coal and 5 % from natural gas. In 2001 139 million barrels of crude were imported (DME 2005b). Currently there is an imbalance in the diesel to petrol demand from the transport sector. If this situation persists or is exacerbated, pressure will be placed on refineries and refined petroleum products may have to be imported. Although small oil reserves are located offshore, petroleum supply is associated with a high import dependency. It has been estimated that the synthetic fuel production from coal will be phased out over the next forty years to produce greater quantities of chemicals. Gas field reserves are also limited, and the Mossgas installation is unlikely to continue beyond the decade.

Gas consumption plays a small part in the South African energy mix, accounting for only 2 % of primary energy supply and 1 % of final consumption (DME 2005b). Natural gas supply is almost exclusively used by the Mossgas gas-to-oil plant and most of the gas consumed directly is produced by coal gasification. By international standards gas consumption is low, due to small reserves, and little has been done to establish industrial gas networks. Although total domestic reserves are not significant, the opportunity for using this potentially low CO_2 emission fuel is not being harnessed.

Electricity supplies 28 % of national TFC (DME 2005b). The national supply body, Eskom, supplies 95 % of demand, with the remainder supplied by small inputs from local authorities. Due to inexpensive coal supply, Eskom boasts the lowest electricity cost in the world. Ninety-one percent of electricity is generated from coal, with small amounts coming from hydro and pumped storage (4 %) and nuclear (5 %). Sulfur related emissions from power stations, though significant, at about 1.5 million tons per year (Eskom 2004; NER 2004b), are tapered as the sulfur content of local coal which is low. Particulate emissions control exit on much current electricity generating plant. Much of rural South Africa is without access to grid electricity, and the cost associated with grid extension has resulted in an increased use of small-scale renewable generation sources, such as, photovoltaics and micro-hydro. South Africa has a large off-grid electrification program. Although small in respect to total generation, in terms of meeting ‘basic needs’, such units are of special significance.

Biomass, mostly fuelwood, is an important fuel in the South African context. Commercial and non-commercial biomass supply just under 20 % of the national final energy consumption. The biomass fuel cycle is unregulated and, as a result, shortages exist in various areas. Most biomass is consumed directly by the domestic sector, with small amounts used for charcoal production and industrial consumption in the form of bagasse in the sugar industry and wood wastes in the pulp & paper industry. Most of the fuelwood used is collected from the areas in and around the consuming settlements. This has resulted in the degradation of large areas of otherwise potentially arable land.

Whereas national energy supply is, in general, well-structured and secure, consumption is characterised by cheap costs, inefficient and environmentally damaging use, and uninformed decision-making. Also, important environmental and efficiency implications result from the transformation and extraction of primary energy carriers. The major consuming sectors that will presently be discussed include: industry, commerce, transport and residential. Of special interest is the residential sector where energy supply is both a need and a precursor for human development of the SA population, and the industrial sector in which is potential for improved efficiency.

The cost of commercial energy is kept low as a result of an abundant, inexpensive coal supply and efficient power generation. It is argued by analysts that this offers South Africa an important economic edge, reducing input or capital investment costs or both. However, due to a lack of specific knowledge, market structure and data availability, it has often been incorrectly assumed that medium- to long-term profits are currently being maximised. The result is inefficient energy use, and this in turn leads to accelerated national reserve depletion. Also, the extra energy intensities that result require increased extraction and transformation processing. The cumulative effect results in significant pollution increases. Current low energy costs are also retarding the potential development of new energy sources. Thus increased fuel mix is limited with its associated supply security and possible efficiency improvements.

Large quantities of coal are used for power generation, liquid fuels production and direct consumption. Linked with its extraction are noticeable environmental impacts. Thus increased electricity and petroleum demands result in important ‘upstream’ emissions and environmental impacts. For example, most of the methane released from the South African energy sector is as a result of coal mining. Land scarring occurs with pit digging and discard dumping. Discard dumps are prone to spontaneous combustion, water pollution from run-off, and increased surrounding particulate concentrations. The conversion of coal to petroleum products is about 40 % efficient, for example at Sasol, with significant emissions resulting. National power generation is relatively efficient, operating at about 35 %. These stations produce large amounts of CO_2, SO_2, NO_x and ash. However, current stacks that penetrate the inversion layers, and effective ESP particulate controls, minimise impacts of all but the carbon dioxide emissions. Also, the coal used by Eskom is of such low calorific value that it has no other commercial use. Thus its use does not currently impact on potential foreign exchange earnings.

The industrial sector consumes just over 50 % of final energy, of which 51 % is from coal, 33 % electricity, 12 % petroleum products and 3 % gas (DME 2005b). Energy intensities are high relative to OECD countries. In some instances, specific industries consume up to twice as much energy per ton of output. However, it has been estimated that, by the year 2005, a 9 %-12 % energy saving through improved efficiency standards, with attendant pollution decreases, are possible, with a 1.5-year payback period (Dutkiewitz & De Villiers 1995; Trikam 2002). The low cost of energy has helped provide a competitive advantage, and encouraged the growth of energy-intensive industry, such as aluminium smelting and mining. The use of this low-cost energy is inefficient, though there are significant opportunities to save energy and related environmental impacts cost effectively via energy efficiency measures (ERI 2000; Trikam 2002). Further, these measures will not necessarily change the economy’s energy-intensive structure (Trikam 2002), but rather move it towards better practice and increased profitability (Laitner 2004).

At present, the commercial sector consumes only 6 % of the national TFC. The fuels consumed are electricity 64 %, coal 35 % and gas 1 %. Currently there are no thermal efficiency standards for South African buildings, thus increasing temperature control costs. Also, as developers are not involved in the utilities costs, they are typically borne by tenants. Thus little focus is placed on energy efficiencies. Studies estimate that 20 %-40 % energy savings are attainable in this sector, decreasing emissions, involving a 2-3-year payback period (IEA 1996). Again, these increases in efficiencies offer proportional decreases in the pollution of the fuel carriers concerned.

The transport sector currently consumes 27 % of final energy consumption, of which 3 % is electricity, 0.2 % coal and 98 % petroleum products (DME 2005b). Energy intensities in this sector are high due to various inherited problems and poor fiscal control. The national transport fleet is old and characterised by poor maintenance and low occupancy. Commuting patterns, shaped by apartheid settlement structures, increase fuel consumption and thus emissions. Loading and maintenance regulations are not enforced and potentially more efficient public transport systems are poorly planned. The result has been substantial smog increases and increased road damage.

The residential sector is characterised by extremes in living conditions and multiple fuel use. Fuels used range from electricity, and in more rural areas, to complete dependence on biomass. In this sector little attention has been paid to energy efficiency. Reasons include the relatively low cost of energy for the rich, poor information relating to potential savings or the irrelevance of accounting for energy costs during dwelling construction in poor socio-economic conditions. Three of the major challenges faced by this sector include: the provision of energy needs and environment reclamation, where over-gathering has depleted traditional biomass supplies and damaged large areas of land; secondly, the provision of lighting facilities as a precursor for the economic empowerment and education of rural populations; and, thirdly, the accelerated adoption of ‘clean energy’ that will reduce the current concentrations of indoor pollutants. Also, in terms of consumption, energy costs for the poor are high; thus improved efficiencies are of special importance. Under the current low-cost housing development programme, 50 %-90 % efficiency savings are attainable with only a 1 %-5 % increase in costs (IEA 1996). There exists a significant window of opportunity to improve the energy efficiencies and emissions associated with residential dwellings. In terms of integrating the energy system with other development goals, there exists potential to promote energy-efficient practices via the education systems and community building forums. South Africa's Reconstruction and Development Programme (RDP) (ANC 1994), instituted after the abandonment of apartheid, is driving the construction of over a million low-cost dwellings. By 2015, an estimated seven million new houses will be constructed in the country. The residential sector consumes 16% of final energy, of which biomass contributes 14%, electricity 62%, coal 8%, paraffin 12%, and LPG and candles 2% each.

The sector is also associated with drastic health impacts that result from poor coal and biomass combustion conditions. High particulate emissions result and are exacerbated by poor ventilation in an attempt to increase thermal insulation. These conditions have led to respiratory disease, being the second highest national cause of infant mortality. As fuelwood is depleted, the ecosystem is damaged and increased time is spent in the collection process; with associated opportunity cost losses. The adoption of clean energy in this context implies energy use that reduces particulate and noxious gaseous emissions.

The short- to medium-term potential options for the residential sector include grid electrification, non-grid electrification, transition to low-smoke fuels, clean-burn stoves, solar hot water heaters and general housing efficiency improvements. The primary hurdles for implementation are the establishment of fuel distribution networks, and the manufacture and integration with cultural norms. The aspects of energy systems that must be integrated into cultural norms include: potential new technologies, such as clean-burn stoves, photovoltaics; new fuel management systems, such as community woodlots; and the utilisation of new commercial fuels. The needs are threefold: basic energy, where traditional forms are depleted; lighting for education; and indoor pollution reduction. Current trends show a general movement from traditional fuels, such as biomass and dung, to the commercial fuels - coal, paraffin and gas and finally to electricity. However, rates of penetration of commercial fuels are limited due to cultural norms, disposable income, supply reliability and availability. Electrification is currently taking place rapidly, with recent estimates suggesting that by 2025, 92 % of households will be electrified, with 87 % using electricity only, and 5 % using electricity together with other fuels. The remaining households, mainly in remote rural areas, are predicted to remain dependant on biomass. In terms of costs, current electrification is both via grid and off-grid supply. Off-grid supply is currently delivered to community centres, such as schools and clinics, and for households. The most common technologies presently employed include photovoltaics, diesel generators and micro-hydro schemes. There are several energy service companies which obtained concessions from DME to both install SHS and maintain them.

The challenge faced by the energy sector as a whole is thus twofold. Firstly, to address the unacceptable lot of the poor and, secondly, to employ energy technologies and energy practices that provide inexpensive energy for a competitive economy without straining recourses and the national, regional and global environment. Clearly there are many possible future energy scenarios. The following describes a vision of the future South African energy system and although many of the technologies described are not new, they are presented in the time frame that probably best fits sustainable solutions. Within the context of responsible research, information dissemination, fiscal influences and market forces, there lie opportunities for an optimised energy system, that is, optimised economically, socially and environmentally giving the lowest cost of energy to society as a whole for the short, medium and long term.

In the short term, changes in electricity supply will be seen with the creation of the Southern Africa Power Pool (SAPP) and new local power stations. The power supplied to this pool outside of South Africa will be generated by mostly hydro and some gas. The largest hydro reserves in this area are in the Democratic Republic of Congo where a technical potential 100 000 MW exists, of which 40 000 MW of run-of-river may be harnessed. Currently, South Africa has a generation capacity of 48 000 MW, while the rest of the region has a maximum capacity of 6 000 MW. Hydro power imports hold the potential of significantly reducing the CO_2 emissions that would characterise extra coal utility. However, at current demand growth, it is estimated that the present surplus of electricity will remain until about 2007. Significant energy imports may ensue, which, however, will be limited by political and supply security considerations. Conventional wisdom suggests a limit in the short term of about 9 %. In terms of non-grid electrification there will probably be site-specific renewable implementation.

The international community has ratified the Kyoto Protocol to help reduce global greenhouse gas emissions. The Clean Development Mechanism (CDM) allows developed countries to invest in greenhouse gas mitigating projects that would not have otherwise gone ahead. The projects should be "additional". The emissions that are saved are credited to the investors and the project should further the host countries sustainable development goals. Approximately twenty one million tons of Carbon Dioxide equivalent[5] are currently expected to be saved over a seven year period in South Africa from the CDM (DME 2005b). Other opportunities exist and are being pursued which have a positive environmental effect. We mention a limited number of these. The national electricity regulator assumes that coal fired plant will comply with World Bank emissions standards (NER 2004a). New coal fired (Fluidized Bed) plant is being considered which can burn otherwise discarded coal waste. While increasing emissions from power stations, cleaner energy carries such as electricity will reduce far more severe indoor air pollution (DME 2003a). The poverty tariff, providing 50 kWh per household per month of free basic electricity (UCT 2002), is designed to promote the uptake of electricity and make its use more affordable for newly connected households. Researchers have proposed a system of self-selection by households, by providing "weak access" Other initiatives include the promotion of Basa Njengo Magogo a scheme to reduce the emissions from coal and wood burning in residential areas using common informal stoves (DME 2005b) and the deployment of "Energy Centers" dispensing clean fuels in low income areas.

In the medium-term, initial fossil fuel demand is likely to be supplied by the increased use of coal as primary source and some gas. International pressures placed on fossil fuels may result in increased imports from the SAPP, depending on energy supply constraints, political and security considerations. It is possible that increased gas supply could result from piped methane from the Waterberg and also from pre-mining extraction. Other sources may include: coal gasification and biogas from landfills, sewerage works, liquefied natural gas imports (LNG) and possible gas imports from Mozambique. Another supply option is increased domestic nuclear capacity, probably characterised by high safety 'passive' design. Of particular interest in the South African context is the current interest in the development of the pebble bed nuclear reactor. The reactor is small, has a low energy density, is inexpensive, intrinsically safe, of modular design and gas-cooled. At present, plans are underway for pilot plant feasibility studies, as the system holds potential for distributed generation. During this period there will probably be the emergence of economic fuel cells, both for large-scale power generation and for remote or mobile applications. This will have significant impact in the remote rural areas. In terms of the expanse of energy supply, improved efficient storage will allow for energy supply integration. Intermittent renewable generation will then have scope for commercial generation. In the medium term, new energy carriers and mixes are likely to become important. It is envisaged that in this period energy and pollutant efficiencies will have improved dramatically due to market forces.

The shape of the longer-term energy scene is difficult to meaningfully conceive. But no doubt the impact of low-temperature superconductors is likely to be revolutionary in terms of energy storage and generation. Fast breeder nuclear reactors are likely to be in use, extending nuclear fuel reserves significantly. It has been suggested that nuclear fusion will be viable in this period and supply limitless quantities of hydrogen fuel. This hydrogen would most likely be stored in the form of methanol for easy handling. Other technologies that may characterise this period include advanced solar technologies, including molten salt 'power towers' and the artificial photosynthesis of sunlight into energy carriers. Costs will include externalities and be optimised by market forces.

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[5] Gasses other than carbon dioxide contribute to global warming. For simplicity sake they are reported in terms of the greenhouse effect of tons of carbon dioxide. As such they are reported (together with carbon dioxide in terms of their carbon dioxide "equivalent".

The South African energy system options briefly described are promising, pragmatic and sustainable. The following sections go on to describe the development of policies and technical options that will help realise a sustainable energy future.

2. Identifying and modeling policy options

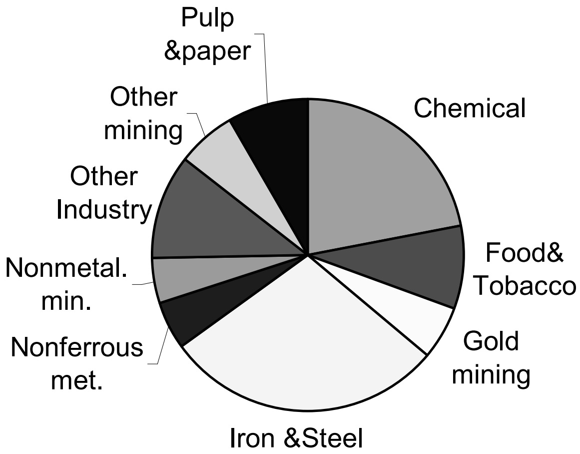
Policies for both demand- and supply-side interventions are considered in this study. Most of these policies are related to a particular sector, but some cross-cutting policies are investigated as well.

2.1 Industry

In the industrial sector we include manufacturing and mining. Under Standard Industrial Classification (SIC) these include activities 30-39 and 21-24 respectively. We describe eight broad industrial divisions 3-10 and consider its output relative to GDP. We also consider changes in energy intensity of each sector in more detail. Combining the two we develop a simple forecasting model and determine estimates useful energy requirements. Throughout the discussion we refer to the year 2000, which is the historical "start year" of our modelling.

Industry, using 42%, is the biggest consumer of final energy. The industrial sector may be divided into eight divisions, mining, iron and steel, chemicals, non-ferrous metals, non-metallic minerals, pulp and paper, food and tobacco, and other.

Figure 1: Energy in industrial divisions, 2000



Total: 1335 PJ

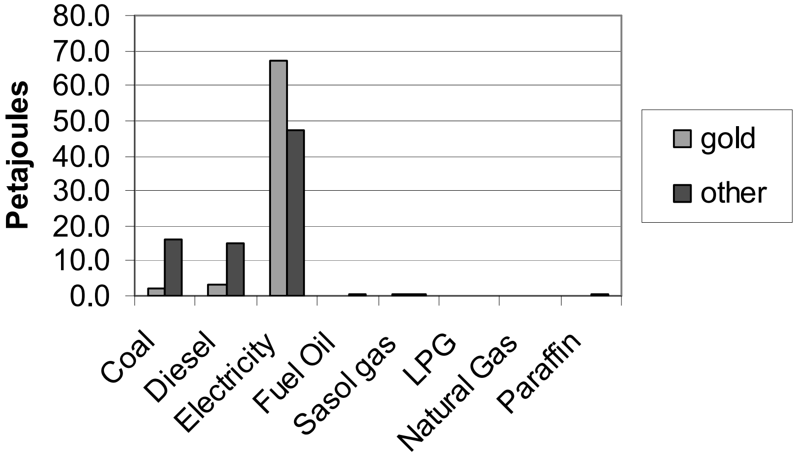
2.1.1 Mining

South Africa has the world's biggest reserves of chrome, gold, manganese, platinum groups metals and vanadium, and huge reserves of other minerals. The industrialisation of South Africa began with the discovery of diamonds and gold in the 1870s.

Mining in South Africa may be logically divided into gold and other. Gold production has declined from 1000 tons in 1970 to 395 tons in 2001. This is because of declining ore grades. However, the energy required per unit of gold has increased fourfold in this period. This is because the mines are going deeper and have to process more ore for each ton of gold. Electricity makes up over 90% of energy use on the gold mines, which are the single greatest users of electricity in South Africa.

Energy use for all other mining together is slightly more than that for gold mining alone. However, while gold mining is in decline the other are increasing and have good prospects. They get about 75% of their energy from electricity.

Figure 2: Energy in gold mining and other mining, 2000

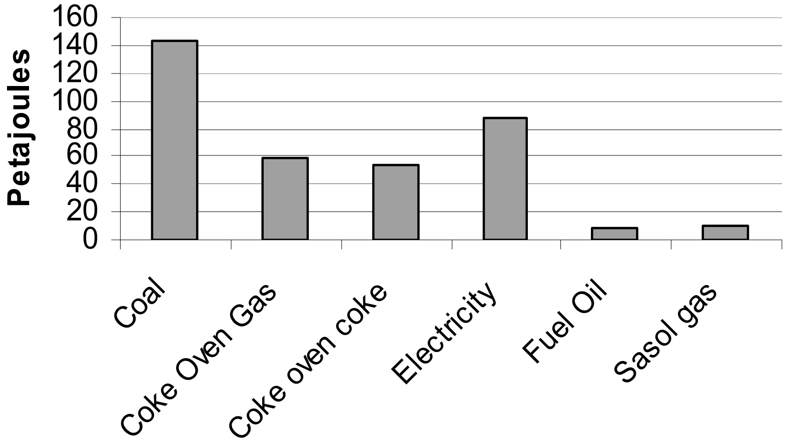


Total: 153 PJ

2.1.2 Iron and steel

South Africa has all the resources required for steel making except coking coal. In 1996 steel production was 6.5 million tons. Since then the industry has modernised towards specialist mills and mills using new technologies that do not require coke. An example is Saldanha Steel which uses the new Corex and Midrex processes to make hot-rolled steel. There has also been considerable investment in stainless steel capacity. The main energy source for iron and steel is coal, followed by electricity. Gas is likely to become a more important source in future.

Figure 3: Energy in iron and steel, 2000

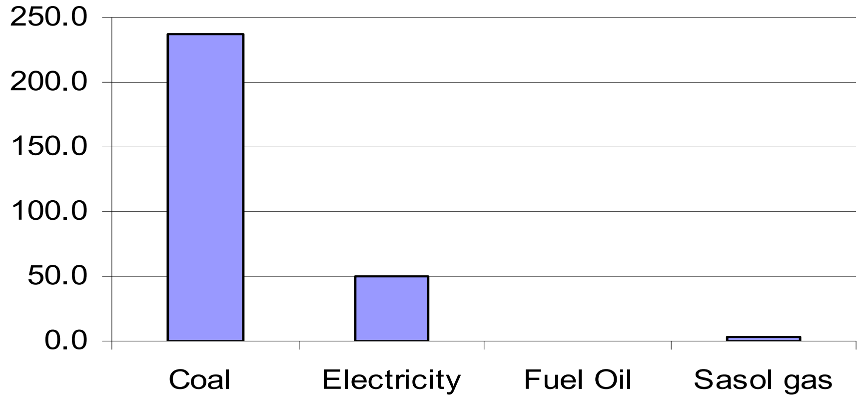


Total: 361 PJ

2.1.3 Chemicals

South Africa's chemical and petrochemical industry is well developed and produces plastics, fertilizers, explosives, agrochemicals and pharmaceuticals. South Africa's special expertise and experience in making chemicals from coal gives it a unique advantage in this field. Coal has been the main feedstock in the past but natural gas will replace some of this in future.

Figure 4: Energy in chemicals, 2000

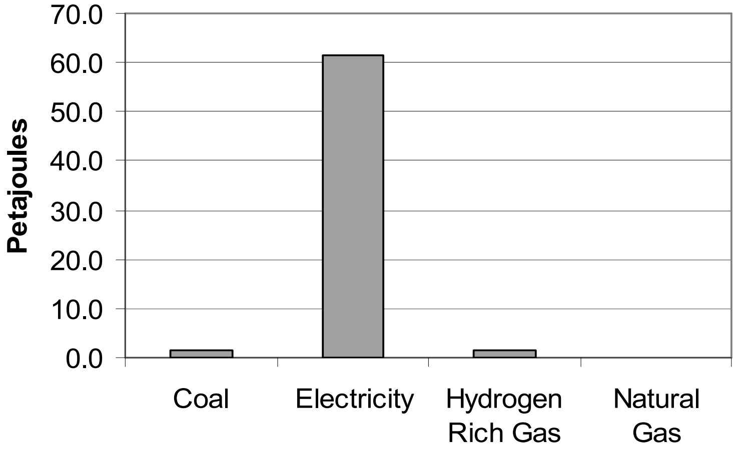


Total: 291 PJ; this includes non-energy use

2.1.4 Non-ferrous metals

The big energy users in the division are aluminium and titanium smelting. South Africa is the world's second largest producer of titanium minerals and made over 662 thousand tons of aluminium in 2001. Expansion of aluminium smelting capacity is expected. Over 95% of the energy used in this division is electricity.

Figure 5: Energy in non-ferrous metals, 2000

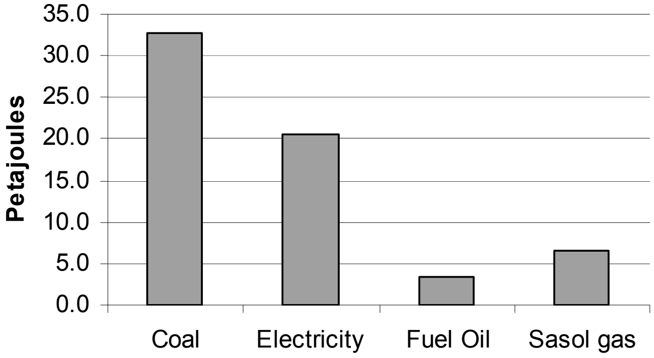


Total: 64 PJ

2.1.5 Non-metallic minerals

This division makes cement, bricks and glass. South Africa cement is made by the efficient dry kilns but some brick-making still uses inefficient "clamp" kilns. South Africa is self-sufficient in all of these products.

Figure 6: Energy in non-metallic minerals, 2000

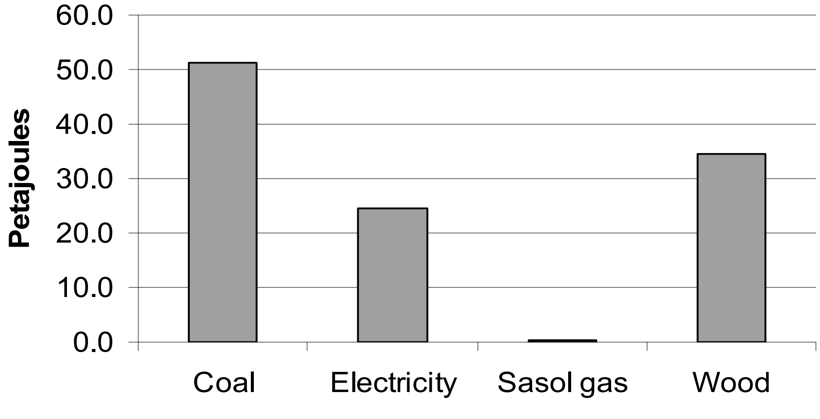


Total: 63 PJ

2.1.6 Pulp and Paper

Only slightly more than 1% of South Africa's area is forested but this provides good conditions for commercial softwood and hardwood species. South Africa has a highly developed pulp and paper industry producing over 4.5 million tons a year and markets its products internationally. South Africa produces the cheapest pulp in the world. Modern pulp mills use black liquor to produce most of their energy requirements, the remainder coming from coal, gas, HFO and imported electricity, which are also used by straight paper mills that do not make their own pulp.

Figure 7: Energy in pulp and paper, 2000

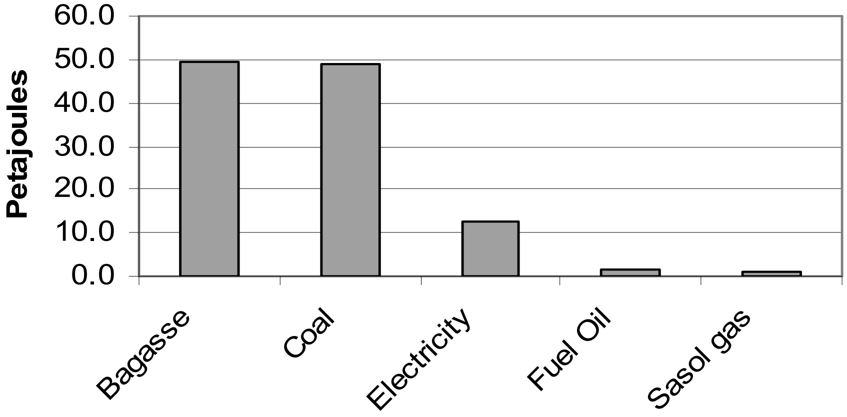


Total: 110 PJ

2.1.7 Food, tobacco and beverages

The single biggest energy user in this division is the sugar refining industry, which gets much of its requirements from bagasse.

Figure 8: Energy in food, tobacco and beverages, 2000

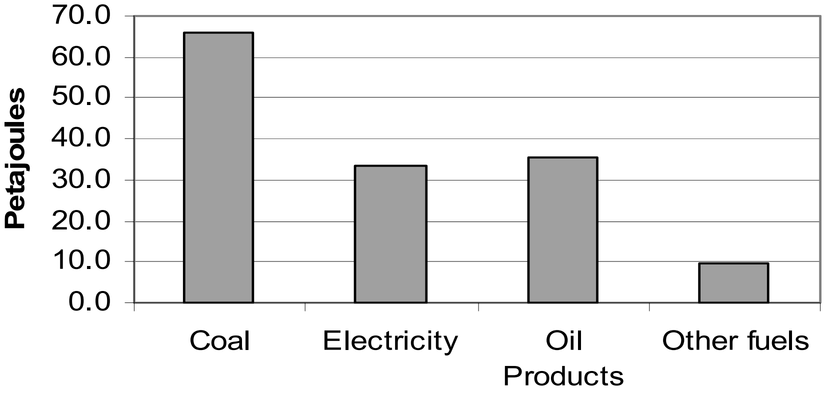


Total: 113 PJ

2.1.8 Other

This division includes manufacturing, construction, textiles, wood products and various other activities in industrial processing and fabrication. It includes large and small industries. This division contains high value economic activity and it is expected that it will grow more quickly than most other divisions.

Figure 9: Energy in "other" for industry, 2000



Total: 145 PJ

2.1.9 Energy Intensity Changes

Next we consider the change in energy intensity over recent history. To do this we consider energy consumption per unit output from major sectors. We chose a relevant indicator of output, and this is generally either physical or in terms of value added. The choice depends primarily on the consistency and convenience of the indicator chosen. Generally, where value added is more a function of market volatility than local production quantities physical output is a preferred indicator, whereas where there is little consistency in physical output (consider the wide array of food stuffs produced) value added may be preferred. (For an in depth discussion of local indicator options, please see Hughes et. al. 2002.)

Unfortunately, reported historical disaggregated energy consumption for South Africa is sketchy with the exception of electricity. It has been shown that fuel substitution over this period has been limited (Dutkiewicz and Stoffberg 1991). In the absence of physical limitations or extreme price hikes and with little policy intervention, little fuel switching is expected (DME 2003).

Table 1 below summarises our findings. In general electricity intensity (relative to 2000) goes down over time with process and efficiency improvements. Exceptions occur when process changes or increased beneficiation happens within industry. For example in gold mining, ore quality is decreasing and it needs to mined from greater depths. The result is that more energy is used per physical unit of gold produced. In the Iron and Steel industry, local beneficiation is expected to increase, resulting in more processing per ton of iron and steel produced. While this results in a drop of energy intensity per unit of value added, there is an increase in intensity per ton produced.

Table 1: Energy intensity data and projections

Source: (Howells 2004)

Sector/Sub-sector	*Year*	*1990*	*1995*	*2000*	*2005*	*2010*	*2015*	*2020*
	Activity measure	*Intensity data with 2000=100*						
Mining								
Gold	Energy / Physical output	75	88	100	112	125	137	150
Platinum	Physical output	107	102	100	99	98	97	96
Coal	Physical output	105	102	100	99	98	98	97
Iron ore	Physical output	104	102	100	99	99	98	98
Copper	Physical output	87	95	100	103	105	106	107
Diamond	Physical output	169	126	100	86	76	69	63
Chrome	Physical output	126	110	100	95	91	88	86
Asbestos	Physical output	58	84	100	109	114	119	123
Manganese	Physical output	102	101	100	100	99	99	99
Rest of mining	Value Added	103	101	100	99	98	98	97
Industry								
Food Bev & Tobacco	Value Added	79	92	100	104	107	110	111
Textile, cloth & leather	Value Added	10	67	100	118	131	140	148
Pulp and paper	Physical output	92	96	100	102	103	104	105
Chemicals	Energy / Value Added	109	103	100	98	97	96	95
N M M	Physical output	82	92	100	104	107	109	111
Iron & steel	Physical output	81	91	100	105	108	110	112
Precious & non-fer	Physical output	94	97	100	101	102	103	104
Rest of basic metals	Physical output	54	78	100	111	118	123	128
Rest of manufacture	Value Added	97	99	100	101	101	101	102

2.1.10 Structural change in Industry

Next we consider structural economic change within the economy. Typically as economies develop they move from heavy industry to service based. That is not to say that industry necessarily declines, but its relative contribution does. Historically, this is the case in South Africa. Table 2 below shows an index of sector output divided by economic growth, normalised so that 2000 has a value of one, for illustrative purposes. This trend is projected in the last four columns.

Table 2: Index of output to GDP for various manufacturing and mining sectors

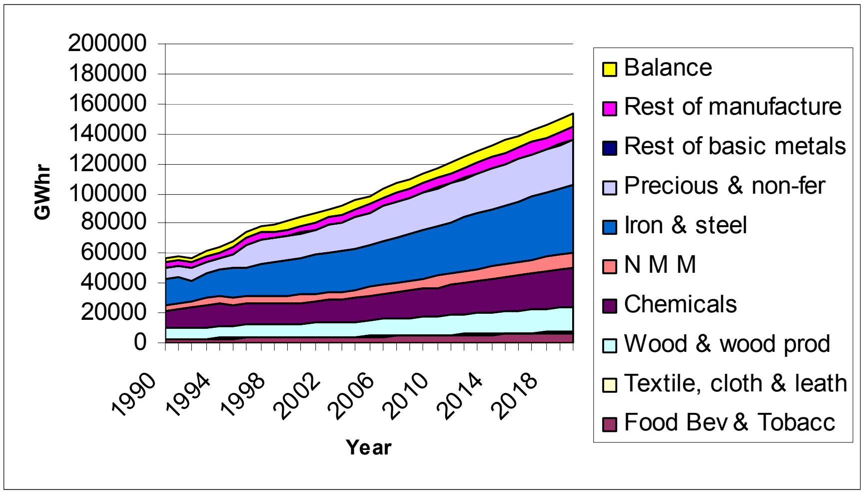
Mining sector	*Year*	*1990*	*1995*	*2000*	*2005*	*2010*	*2015*	*2020*
Gold		203%	155%	100%	76%	57%	43%	33%
Platinum		74%	90%	100%	104%	103%	100%	96%

Coal		94%	102%	100%	99%	92%	85%	79%
Iron ore		106%	109%	100%	99%	94%	89%	84%
Copper		170%	127%	100%	87%	73%	61%	52%
Diamond		90%	87%	100%	104%	103%	100%	96%
Chrome		82%	80%	100%	104%	102%	97%	93%
Asbestos		1461%	478%	100%	82%	67%	56%	47%
Manganese		114%	98%	100%	96%	90%	83%	77%
Rest of mining		99%	102%	100%	106%	96%	87%	79%
Manufacturing sector	*Year*	*1990*	*1995*	*2000*	*2005*	*2010*	*2015*	*2020*
Food Bev & Tobacc		109%	110%	100%	97%	94%	90%	87%
Textile, cloth & leath		477%	90%	100%	85%	74%	66%	60%
Pulp and paper		97%	108%	100%	99%	97%	94%	91%
Chemicals		90%	113%	100%	103%	104%	102%	101%
N M M		117%	116%	100%	97%	94%	90%	87%
Iron & steel		104%	100%	100%	95%	93%	89%	86%
Precious & non-fer		57%	66%	100%	113%	106%	95%	87%
Rest of basic metals		129%	82%	100%	95%	88%	83%	79%
Rest of manufacture		89%	102%	100%	101%	100%	97%	94%

2.1.11 Demand projections

Together with the projection of energy intensity change (see section 2.1.9) and the structural change projections above, an electricity forecast is derived. UNDP's econometric approach is followed (1997). The forecast assumes that shares of fossil fuels remains constant in the reference case, consistent with the IEP (DME 2003a)and past trends (Dutkiewicz and Stoffberg 1991)). The resulting projected of industrial electricity demand are shown in Figure 10 below. These assume a GDP growth rate of 2.8% - the rate chosen for the most recent electricity planning exercises (NER 2004a).

Figure 10: Electricity forecast for the industrial sector



2.1.12 Implementing policy options

On the demand side, **industry** is a major user of energy. The policy objective examined in this sector is to meet the target stated in the energy efficiency strategy (DME 2004a)of 12% reduction in final energy consumption in 2014, relative to business-as-usual projections for energy consumption. The model is constrained to meet this overall target, giving insight into which energy-efficient interventions are chosen to implement the policy. The penetration rates of individual technologies or behavioural changes are examined, taking into account that there may be regulatory, technical and other barriers to actually achieving such rates.

> “The Strategy sets a national target for energy savings, of at least 12%, to be achieved by 2014. This target is expressed in relation to the forecast national energy demand at that time, based on the ‘business as usual’ baseline scenario for South Africa modelled as part of the National Integrated Energy Plan (2003), which uses energy consumption data for the year 2000. The target also assumes that the Energy Efficiency interventions outlined in this Strategy are undertaken; these measures being primarily focussed on low cost interventions that can be achieved with minimal investments. Energy efficiency improvements will be achieved through enabling instruments and interventions including economic and legislative means, information activities, energy labels, energy performance standards, energy audits, energy management and the promotion of efficient technologies” (DME 2004a).

The strategy set a goal for an improvement in energy efficiency of 12% by 2014 relative to projected consumption (DME 2004a). While the DME document covers all energy, the National Electricity Regulator (NER) has approved policy for efficiency in the electricity sector in particular, with an ‘energy efficiency and demand side management policy’ (NER 2003b).

The rationale for adopting the energy efficiency strategy is to meet a series of development goals. The goals South Africa hopes to meet by the adoption of energy efficiency measure can be grouped according to the following themes: Social, environmental and economic sustainability.

Table 3: Goals to be met by energy efficiency

Source: DME (2004a)

Goals
Social sustainability **Goal 1: Improve the health of the nation** Energy efficiency reduces the atmospheric emission of harmful substances such as oxides of sulphur, oxides of nitrogen, and smoke. Such substances are known to have an adverse effect on health and are frequently a primary cause of common respiratory ailments. **Goal 2: Job creation**. Spin-off effects of energy efficiency implementation. Improvements in commercial economic performance, and uplifting the energy efficiency sector itself, will contribute to nationwide employment opportunities. Energy is a necessary, but not sufficient condition for job creation. **Goal 3: Alleviate energy poverty** Energy efficient homes not only improve occupant health and wellbeing, but also enable the adequate provision of energy services to the community at an affordable cost.
Environmental sustainability **Goal 4: Reduce environmental pollution** Energy efficiency will reduce the local environmental impacts of its production and use **Goal 5: Reduce CO_2 emissions** Energy efficiency is one of the most cost-effective methods of reducing GHG emissions, and thereby combating climate change. Addressing climate change opens the door to utilising novel financing mechanisms, such as the CDM, to reduce CO_2 emissions.
Economic sustainability **Goal 6: Improve industrial competitiveness** **Goal 7: Enhance energy security** Energy conservation will reduce the necessary volume of imported primary energy sources, crude oil in particular. This will enhance the robustness of South Africa’s energy security and will increase the country’s resilience against external

energy supply disruptions and price fluctuations.

Goal 8: Defer the necessity for additional power generation capacity It is estimated that the country's existing power generation capacity will be insufficient to meet the rising national maximum demand by 2007-2012. Energy efficiency is integral to Eskom's Demand Side Management programme insofar as it contributes 34% towards the 2015 demand reduction target of 7.3 GW .

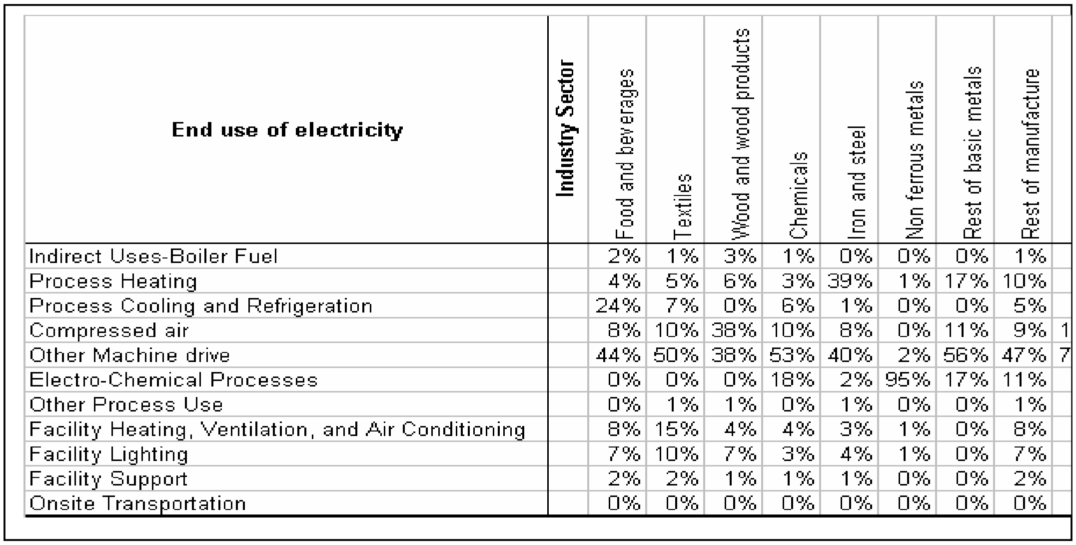
The specific programs that constitute the policy which are being considered to meet this target include the following policies, which assume a high level of awareness.

1. Energy efficiency standards
2. Appliance labelling
3. Education, information and awareness
4. Research and technology development
5. Support of energy audits
6. Monitoring and targeting
7. Green accounting

In order to determine the potential savings that may accrue to any energy efficiency policy it is necessary first to determine the demand for energy end-use. Typically coal is used either for thermal purposes (boilers and furnaces), and oil for a mix of thermal and motive (ERI 2001). The apportionment of electricity is more complex, and we estimate an end-use demand for electricity by industry (Howells 2004a) and this is reported in Table 4.

Table 4: Percentage of end-use of electricity by the industrial sector

Source: Howells (2004a



End use of electricity	Industry Sector	Food and beverages	Textiles	Wood and wood products	Chemicals	Iron and steel	Non ferrous metals	Rest of basic metals	Rest of manufacture	
Indirect Uses-Boiler Fuel		2%	1%	3%	1%	0%	0%	0%	1%	
Process Heating		4%	5%	6%	3%	39%	1%	17%	10%	
Process Cooling and Refrigeration		24%	7%	0%	6%	1%	0%	0%	5%	
Compressed air		8%	10%	38%	10%	8%	0%	11%	9%	1
Other Machine drive		44%	50%	38%	53%	40%	2%	56%	47%	7
Electro-Chemical Processes		0%	0%	0%	18%	2%	95%	17%	11%	
Other Process Use		0%	1%	1%	0%	1%	0%	0%	1%	
Facility Heating, Ventilation, and Air Conditioning		8%	15%	4%	4%	3%	1%	0%	8%	
Facility Lighting		7%	10%	7%	3%	4%	1%	0%	7%	
Facility Support		2%	2%	1%	1%	1%	0%	0%	2%	
Onsite Transportation		0%	0%	0%	0%	0%	0%	0%	0%	

We combine these end-use splits with a detailed industry-by-industry sector energy forecast (NER 2004; Howells 2004b) in order to determine a forecast for the end-use of energy for the industrial sector as a whole. With assumptions about the savings potential of each energy efficiency measure by end-use, it is possible to estimate the total potential savings. Depending on the policies implemented it is assumed that an increased proportion of the technical potential would be realised. Hughes et. al (2003) estimate this as a function of specific program. We adopt a conservative estimate that represents an upper limit to the savings that could be realised. The specific measures we consider are described by Howells and Laitner (2003) and Trikam (2002). For the measures we consider, their payback and proportion of fuel saved below:

1. Variable speed drives: These drives reduce unnecessary power consumption in electrical motors with varying loads (ERI 2000b). Typical paybacks are 3.6 years, conservatively 2.2% of industrial electricity can be saved.

2. Efficient motors (ERI 2000b): These motors are available at higher cost. Efficient motors can reduce power consumption, but may require modifications because running speeds are generally higher than for inefficient motors. Typical paybacks are 7 years, conservatively 2.3 % of industrial electricity can be saved.

3. Compressed air management (ERI 2000c): This measure is easily achieved and often results in significant savings at low cost. Typical paybacks are 0.9 years, conservatively 3.2 % of industrial electricity can be saved.

4. Efficient lighting (ERI 2000b): These measures take advantage of natural lighting, more efficient light bulbs, sky-lighting and appropriate task lighting. Typical paybacks are 3.6 years, conservatively 1.9% of industrial electricity can be saved.

5. Heating, ventilation and cooling (ERI 2000d): These measures are for maintaining good air quality and temperature and can commonly be improved through better maintenance and the installation of appropriate equipment. Typical paybacks are 2.2 years, conservatively 0.6 % of industrial electricity can be saved.

6. Thermal saving (ERI 2000e): Thermal saving refers to more efficient use and production of heat. For steam systems in particular we consider condensate recovery and improved maintenance. Typical paybacks are 0.8 years, conservatively 1.4 % of industrial electricity, 10% oil and 15% coal can be saved.

Confidence that potential energy efficiency savings can be realised in practice can be improved by measurement and verification. Much of this depends on the institutional capacity in the country. In the case of South Africa, institutional infrastructure already exists to measure and verify the implementation of energy efficiency interventions in industry.

Figure 11: Institutions involved in measuring and verifying energy efficiency savings in South Africa

Source: (Grobler & den Heijer 2004).

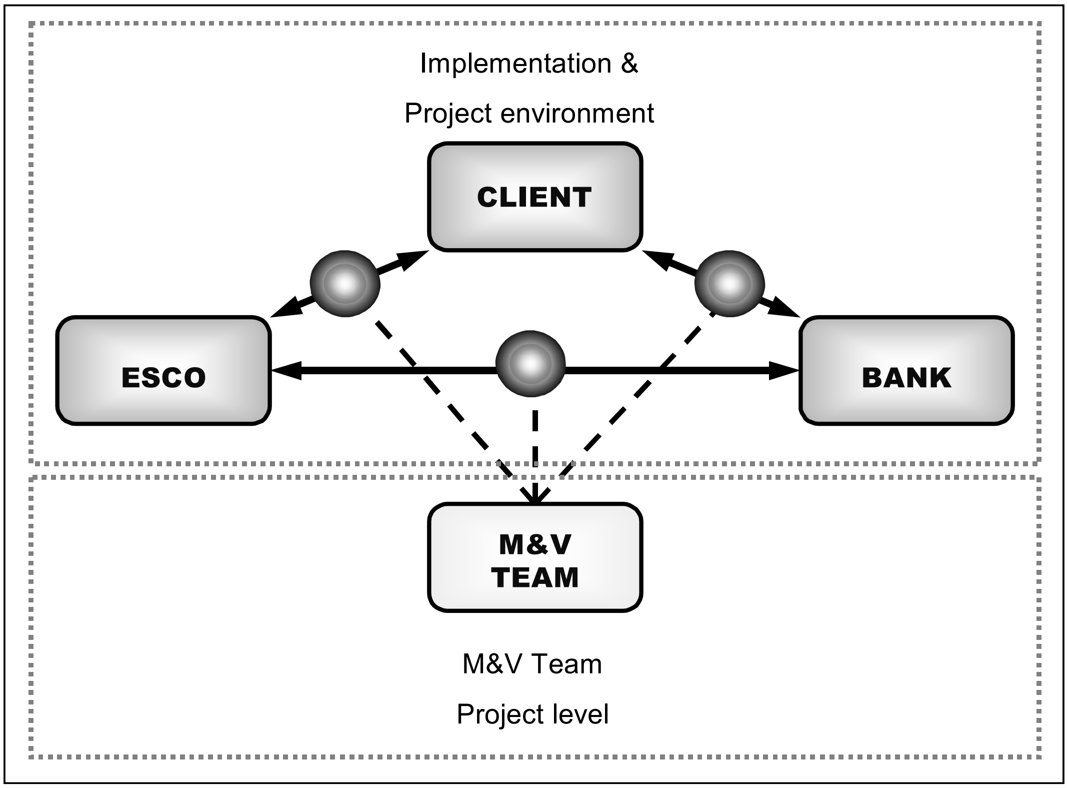


Figure 11 shows that several institutions are involved in measuring and verifying energy savings. Eskom, the electric utility, has a demand-side management programme. The implementation of the programme is outsourced to energy service companies (ESCOs), who assist clients in industry, commerce and residential sectors. The ESCOs carry out specific interventions for companies in industry (the clients in Figure 11). Four universities in South Africa are involved in measurement and verification (M&V) teams. These teams are employed by the utility to measure the savings, against an energy baseline established prior to the intervention. After the intervention, the teams measure energy consumption by once-off use of instrumentation, or long-term data recording. A conservative approach to energy savings is taken by the M&V teams, who only report energy savings that can be verified. Reports on the verified savings are submitted to the National Electricity Regulator (not shown in the figure) as well as the client.

Estimates of electricity savings potential by end use (rather than total reported above) is given in Table 5 below:

Table 5: DSM interventions and their potential (stand alone) savings by end use

Source: Howells 2004a

Use of electricity / measure considered	*Steam system*	*Other thermal measures*	*Efficient motors*	*VSDs*	*Efficient lighting*	*Compressed air saving*	*HVAC*	*Refrigeration*	*Load shifting*

Indirect Uses-Boiler Fuel	15%	5%							
Process Heating		5%							
Process Cooling and Refrigeration				10%					20%
Machine Drive (inc compressed air)			5%	5%		15%		15%	
Electro-Chemical Processes									
Other Process Use									
Facility Heating, Ventilation, and Air Conditioning			5%	10%			30%		20%
Facility Lighting					40%				
Facility Support									
Onsite Transportation									

2.2 Commercial

2.2.1 Definition of commercial sector and commercial sector activity

The commercial sector is an aggregation of the economic sectors defined under Standard Industrial Classification (SIC) codes 6, 8, and 9. Table 6 shows the breakdown of commercial sub-sectors. All public sector activities are included under SIC 9.

Table 6: Commercial sub-sectors by SIC code

SIC	Description
6	*Trade, catering and accommodation*
61	Wholesale trade
62	Retail trade
631	Accommodation
632	Catering
8	*Finance, property and business services*
81	Financial institutions
82	Insurance institutions
83	Auxiliary activities
84	Real estate
85	Renting of equipment
86	Computer activities
87	Research and development
88	Other business activities
9	*Community, social and personal services*
91	Public administration
92	Education
93	Medical and health services
94-99	Other services

The activities of the sector are mainly confined to buildings such as offices, warehouses, shops, accommodation, restaurants, educational facilities and healthcare facilities. Energy-use in the commercial sector therefore largely constitutes building energy-use. For this reason, the driver of energy demand is taken as the total floor area of commercial buildings and demand is thus specified as a minimum required energy service per square meter of floor space.

2.2.2 Energy use patterns in the commercial sector

Table 7 shows fuel use in the commercial sector as estimated by several organisations. About 75 percent of the fuel used is in the form of electricity, while the remainder is mainly coal with small amounts of methane rich gas, LPG and paraffin also being consumed.

Table 7: Energy use in the commercial sector (PJ)

Source	*Year*	*Electricity*	*Coal*	*Methane rich Gas*	*Paraffin*	*HFO*	*LPG*
This study	2001	64	20	1.1	0.15	3.5	12
DME	2001	66	36	0.24	0.15	3.5	12
IEA	2000	62	17	1.2	0.13	-	-
Beyond2020	1999	64	21	1.0	0.17	-	-
NER	2001	29	-	-	-	-	-

This study has identified six energy service demands for the commercial sector:

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

The distribution and market shares of fuels for the different end uses were taken from (De Villiers 2000).

Total floor space in 2001 has been estimated at 77 million square meters (De Villiers 2000).Given the consumption details above the energy service demands per square meter can be derived and are shown in Table 8. All energy intensities are assumed to remain constant throughout the time period except the intensity of the services grouped as "other" which is expected to increase by 0.5% per year.

Table 8: Useful energy intensity of commercial end-use demands

Demand	Useful energy intensity [MJ/m^2/annum]
Cooling	911
Lighting[6]	800
Refrigeration	48

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[6] Lighting service demand is measured in an artificial lighting unit based on efficiencies (lumens/watt) relative to that of incandescent lamps

Space heating	163
Water heating	116
Other	145

2.2.3 Characteristics of energy demand technologies

The energy demand technologies considered in this study are listed in Table 9 which also details their basic characteristics. Actual technology and appliance stocks are a lot more diverse than what is reflected here, but the list is believed to be a reasonable aggregation.

Table 9: Basic technical and economic assumptions for commercial sector demand technologies

Fuel consumed	*Device*	*Year 2000 Efficiency or COP*[7]	*Year 2025 Efficiency or COP*	*Lifetime*	*Residual capacity*	*Investment cost*	*O&M cost*
				Year	PJ/a	R/GJ/a	R/GJ
Cooling							
Electricity	Air-cooled chillers	2	3.1	15	3.51	200	
	Central air conditioners	3	4.1	15	42.07	123	
	Heat pumps (air)	2.2	3.1	15	14.02	322	
	Room air conditioners	2	3.2	15	10.52	168	
Lighting							
Electricity	CFLs	4	4	5	3.69	37.7	14.7
	Fluorescents	4.5	4.5	5	43.08	74.8	8.4
	Halogen	2	2	2	1.23	13.6	10.4
	Incandescents	1	1	1	4.30	45.2	11.2
	HIDs[8]	7	7	6	9.23	5.5	15.4
Refrigeration							
Electricity	Refrigerators	1	1	15	-	-	-
Space heating							
Electricity	Heaters	100 %	100 %	15	5.10	230	-
Coal	Heaters	80%	80%	15	7.17	383	-
Methane rich gas	Heaters	92%	92%	15	0.306	383	-
Water heating							
Electricity	Heaters	100%	100%	15	2.04	31	-
Coal	Heaters	80%	80%	15	6.02	46	-
Methane rich gas	Heaters	92%	92%	15	0.76	46	-
Paraffin	Heaters	91%	91%	15	0.14	46	-
LPG	Heaters	91%	91%	15	0.01	46	-
Other							
Electricity	Appliances	100%	100%	5	8525	-	-
Coal	Appliances	75%	75%	5	2640	-	-

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[7] COP: Coefficient of performance - ratio of output heat to supplied work.

[8] High intensity discharge lamps (includes mercury vapour and metal halides)

LPG	Appliances	90%	90%	5	3	-	-

2.2.4 Demand projections

Service demand is linked to floor space and useful energy intensity. Two set of assumptions are thus needed to project future service demand: time series data for total floor space (in square meters) and future changes in useful energy use per square meter. Energy intensity has been discussed in Section 2.2.2 above. Floor space is assumed to depend on total sales in the commercial sector. This study has used the Industrial Development Corporation's projections of future sales in the sector up until the year 2015 (IDC 1999). For the remainder of the period the average growth rate from 1990 to 2015 have been used to extend the time series. It is assumed that growth in floor space will be proportional to sales growth at a ratio of 0.7. This indicates that for every percent in sales growth total floor area will grow by 0.7%, which again reflects an assumption of more efficient use of floor space (not more people per area). The resulting projection is shown in Table 10 below.

Table 10: Projection of total commercial floor area. 2000 to 2025

	2000	*2005*	*2010*	*2015*	*2020*	*2025*
Floorspace [Million m^2]	75.2	86.4	102	120.5	142.7	169.3

2.2.5 New building thermal design

HVAC systems are the biggest consumers of energy in the commercial sector. The most important influence on energy use is the design of the building and a new building envelope design can significantly reduce consumption. The following measures are considered under this category:

- Optimization of thermal mass for local climate
- Optimal insulation
- Glazing
- Correct orientation; and
- Building shape.

It is assumed that 40% reduction in final energy demand for HVAC per square meter can be achieved through these measures compared to the base line (De Villiers 2000).with a five-year payback period. This aggregated value is highly uncertain and a distribution where it is assumed that 30% reduction is achievable for one sixth of floor space and 50% reduction is achievable for one sixth of floor space at the same cost was assumed. Similar distributions were also assumed for all subsequent measures.

Barriers to improved thermal design are increased initial cost, split incentives (the developer often does not pay the energy bill), and lack of training of architects and consulting engineers in efficient building practices.

2.2.6 HVAC retrofit

Options for HVAC retrofit include:

- Switching off air-conditioning when there are no occupants
- Eliminating re-heat, in which pre-conditioned air is reheated in a heating coil in the duct system
- Prevent mixing of hot and cold air

- New air-conditioning set-points
- Ventilation with outside air and night cooling
- Use of evaporative cooling
- Use of computerized energy management systems

It is assumed that 35% of energy consumption is achievable for 50% of existing buildings through a combination of these measures (De Villiers 2000). Overall payback period is estimated at three years.

Barriers include lack of awareness by building owners and a general perception that energy services are not an integrated part of the commercial activity and therefore not given attention in cost analysis.

2.2.7 Efficient HVAC systems for new buildings

The same principles described in section 2.2.6 above apply to new buildings. It is assumed that a further 25% reduction can be achieved with an average payback period of 5 years (De Villiers 2000).

2.2.8 Variable speed drives for fans

Roughly half of HVAC energy demand is assumed to be used by fans. Fitting variable speed drives (VSD) on fans can reduce energy consumption by 15% per square meter (De Villiers 2000). Only variable volume air handling units can be operated with VSDs and these units account for 25% of all air handling units. VSDs are assumed to have a technical lifetime of 15 years and a cost of R0.56 per kWh of electricity saved.

2.2.9 Efficient lighting systems for new buildings

It is estimated that 20% of lighting energy requirements can be reduced at a three year payback through efficient design and management of the lighting system by:

- Introducing more switches, photo-electric sensors and occupancy sensors
- Reduce lighting levels in areas where illumination is higher than necessary
- Introducing skylights and other building design features

Barriers to efficient lighting system are increased initial costs, split incentives and lack of training of architects and consulting engineers in efficient building energy practice.

It is further assumed that in both new and existing buildings energy demand can be reduced by replacing lamps incandescent and standard fluorescent lighting with more efficient lamps such as high-pressure sodium and metal halide lamps and more efficient fluorescent lighting. The relative costs, efficiencies and market shares for various lamp technologies are given in Table 9:.

2.2.10 Heat pumps for water heating

The cost of a 50 kW heat pump is roughly R 50,000 and its annual maintenance is R2,500 (Graham 1999). A heat pump will reduce energy consumption by 67% compared to an electrical resistance heater.

Barriers to installation of heat pumps are the high investment costs and the possibility of operational problems.

2.2.11 Solar water heating

It is assumed that in South Africa, on average, 90% of hot water (for a particular system) could be generated by solar energy with the remainder would be heated by a back-up source when solar irradiation is insufficient. Solar water heaters have a lifetime of about 20 years and the installation costs are about R 35,000 for a 1000 litre system which translates into roughly R 475 per GJ.

Barriers to installation of solar water heaters are the high investment costs and the possibility of operational problems.

2.2.12 Fuel switching

In addition to the specific measures mentioned above general fuel switching through substitution between the technologies listed in Table 9: is allowed to ensure a more cost effective provision of energy services.

2.3 Residential

2.3.1 Defining the sector - six household types

The key unit in the residential sector is the household. Energy is mostly related to households, rather than individuals – for example, electricity grid connections are made to households, and monthly expenditure is better known per household than per person.

Six household types are defined here, differentiated along urban / rural, high / low-income and electrified / non-electrified dimensions. The energy use patterns of rich and poor households differ quite markedly from one another, as do those of rural and urban households. Given the policy drive to universal electrification since the 1990s, the distinction between electrified and non-electrified households has become significant, with lack of electricity being seen as similar to energy poverty.

For this sector, activity levels are defined by the number of households, which were 11,205,705 according to the 2001 Census (SSA 2003a). Definitions of urban and rural are technically difficult in SA, exemplified by the existence of 'dense rural settlements' like Bushbuckridge or Winterveld, and the Census no longer reports this distinction. Other statistical publications continue to report different patterns of urban and 'non-urban' (e.g. SSA 2000, 2002). For the purposes of evaluating electrification, the National Electricity Regulator distinguishes between urban and rural connections (NER 2001, 2002a), so that for the purposes of this study, we can assume a 60:40 split of urban to rural households.[9]

There is no single source breaking down these household types by income group. However, the income and expenditure statistics are reported for urban and non-urban households (SSA 2002: Fig 4.9), dividing each group into quintiles.

Table 11: Income and expenditure in urban and non-urban areas by 1995 quintile (in 2000 market values), only 2000

Source: SSA (2002)

	Income	
	Urban	*Non-Urban*
Quintile 1 (top)	18%	4%
Quintile 2	20%	9%
Quintile 3	23%	18%
Quintile 4	20%	29%
Quintile 5 (bottom)	19%	40%

It seems reasonable to define energy poverty for the purposes of this analysis by treating the bottom two quintiles as 'poor', i.e. the poor are those with an *annual* per capita income less than R4033, and expenditure less than R3703.[10] Consequently, 61% of urban households could be

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[9] The percentages used in the modeling are 59.61% urban households, 40.39% rural, but reporting them with two decimals would give a false sense of accuracy.

[10] At exchange rates of R6/$1 and given SA household size, this works out to less than $2 per person per day.

considered not poor or ‘rich’ (medium to high income), while in rural areas only 31% would fall into this category. In other words, almost seven out of rural households are poor by these assumptions.

The proportion of poor and rich households varies across urban and rural areas, with the former having a much higher share of medium and high-income households. Similarly, the share of electrified households is lower in rural areas, as shown in Table 12.

Table 12: Numbers and shares of rural and urban households, electrified and not

Source: Own calculations, based on NER (2002a)and (2002)

	Electrified	*Unelectrified*	*Rich*	*Poor*
Urban - households	5,330,166	1,349,240	4,074,438	2,604,968
Share	79.8%	20.2%	61%	39%
Rural - households	2,276,729	2,249,571	31%	69%
Share	50.3%	49.7%	1,403,153	3,123,146

Taking three categories – rich / poor, urban / rural, electrified / not would yield eight household types. However, rich urban households are all electrified, and most rural rich households are as well. Again there is no comprehensive statistical survey available, and it is furthermore clear that access to electricity still differs by population group. Almost all African (99%) and coloured (>99%) households in the highest expenditure category in urban areas had access to electricity for lighting, as against proportionately fewer households in this expenditure category in non-urban areas (79% of African and 93%of coloured households) (SSA 2000: 70). These percentages only refer to the highest income group, and weighted by population groups would give some 84% of rich rural households electrified. With this information, it is possible to derive the number of households in each of six household types shown in Table 13. Further calculations reveal that 33% of the rural poor are electrified, while not quite half (48%) of the urban low-income households have access to electricity.

Table 13: Six household types, with total numbers in 2000, shares and assumptions

Source: Own calculations, based on assumptions and data in text

Household	*No. of households*	*Share of all households (HH)*	*Notes*
Urban rich electrified (UHE)	4,074,438	36.4%	Virtually 100% of rich urban HH are electrified
Urban poor electrified (ULE)	1,255,728	11.2%	remainder of urban electrified must be poor
Urban poor unelectrified (ULN)	1,349,240	12.0%	rest of urban HH must be non-electrified
Rural rich electrified (RHE)	1,181,279	10.5%	assume 84% of rich rural HH are electrified
Rural poor unelectrified (RLE)	1,095,449	9.8%	remainder of rural electrified must be poor
Rural poor unelectrified (RLN)	2,249,571	20.1%	rest of rural HH must be non-electrified; number of HH includes the few rich rural not electrified

Of course, reducing all households in the country to six types still abstracts enormously from the rich diversity of different energy patterns. However, for purposes of national level scenarios provides some distinction of the major residential energy use patterns. Perhaps the biggest omission is the lack of geographical disaggregation – poor urban unelectrified households in Cape Town, for example, would use paraffin extensively for cooking, heating and lighting;

while households in the same category in Gauteng are more likely to use locally available coal. Apart from responding to different fuel availability, there are also climatic differences.

Beyond physical access to electricity, the issue of affordability of *using* electricity is emerging as a central policy challenge. The issue is not simply about getting the supply out to households. Policy measures are also needed in order to facilitate that the use of energy is affordable to households given their specific living conditions and income. South Africa has experimented with the ‘poverty tariff’ (see section 1.3), but this does not address all energy needs. Further work is needed in understanding these issues, and particularly the how the ‘energy burden’ can be relieved, i.e. how energy expenditure can be reduced as a share of total household income. Creative approaches to modelling may need to be found, since current approaches do not include households as real entities, including characteristics such as average income levels.

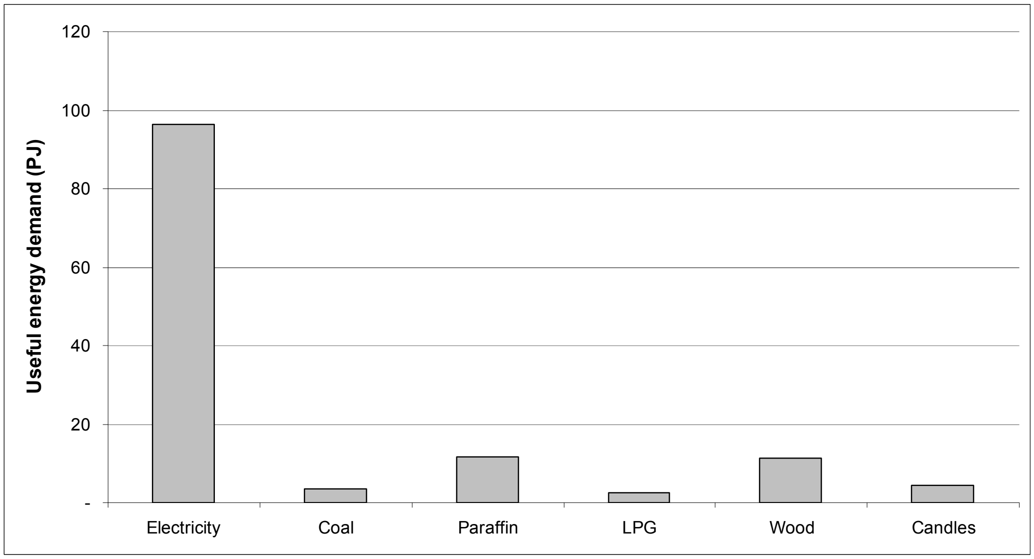
Since each additional household type requires additional data in the modeling, the number of household types needs to be limited. Further disaggregation could be achieved in future work, but is constrained by our limited knowledge of distinctive energy use patterns. For example, there is relatively little research on rich rural unelectrified households, compared to their urban counter-parts.

2.3.2 Energy use patterns in the sector

Energy use patterns in the residential sector show the continued use of multiple fuels. Five major end uses are considered – cooking, space heating, water heating, lighting and electrical appliances for other uses.

Multiple fuels are used in the residential sector, with electricity clearly dominating useful energy demand (see Figure 12). This reflects both in the increased use of energy, but also the relatively high efficiencies of electrical appliances. Patterns of household energy demand differ significantly in rich and poor, urban and rural households (Mehlwana 1999; Mehlwana & Qase 1998; Simmonds & Mammon 1996).Electricity contributes a larger share of household energy use in urban areas than in rural, while the inverse is true for fuelwood. About 5% of the total electricity is sold to the domestic sector, so that the bar for electricity represents 34.6 TWh of final energy (NER 2001).

Figure 12: Demand for useful energy in the residential sector by energy carrier (2001 total: 130 PJ)



Consumption of other fuels is very difficult to attribute to individual end uses. Survey results (where they ask about energy consumption by household type at all) typically report monthly consumption of fuel. For example, household members may be able to give an indication of the litres of paraffin used per month, but not know how much is used for to heat the house, boil water, cook or produce light.[11]

Household energy use pattern vary across the six household types. Table 14 shows the consumption for each end use for the base year 2001 (see Table 62 for projections into the future). The energy services related to each end use are delivered by multiple technologies for most end uses, as can be seen from Table 15.

Table 14: Useful energy demand by household type for each end use (2001)

PJ	*Urban high-med income electrified*	*Urban low income electrified*	*Urban low income non-electrified*	*Rural high-med income electrified*	*Rural low income electrified*	*Rural low income non-electrified*
	UHE	*ULE*	*ULN*	*RHE*	*RLE*	*RLN*
Cooking	15.8	1.4	1.8	1.8	0.6	3.1
Water heating	23.2	4.3	1.2	2.8	0.7	5.3
Space Heating	16.3	2.4	2.0	1.7	0.5	6.1
Lighting (in PJ)	7.4	2.7	2.3	4.1	2.0	4.2
Other electricity	12.6	0.1	-	3.3	0.1	-

The fuel use patterns in this study are being determined endogenously in the model, given appropriate technology-specific discount rates. A future study may wish to compare the optimized results with a simulated future, based on expected fuel use patterns.

2.3.3 Characteristics of energy technologies

The key characteristics of technologies included for the residential sector are shown in Table 15. Of course there are many more technologies that are used in reality, but some of the major energy-consuming ones have been included here. The information is organised by the services that households required – the end uses of cooking, space heating, water heating, lighting and electrical appliances.

The nominal appliance costs were collected for this study in early 2005; they were deflated from end of 2004 to provide costs in year 2000 Rands. Residual capacity refers to the capacity available in the base year, without any further investment.

Table 15: Key characteristics of energy technologies in the residential sector

Fuel consumed	*Device*	*Efficiency*	*Capital cost - nominal*	*Adjusted cost*	*Lifetime*	*Residual capacity*	*Investment cost*
		%	2005 Rand	2000 Rand	years	PJ	R / GJ
Cooking							
electricity	hot plate	65%	R 229	R 178	5	0.6559	230.1160
	oven	65%	R 2,349	R 1,823	9	16.2011	435.8943

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[11] Note that in Table 14, lighting is also reported in energy units (PJ) to facilitate comparison to other end uses, rather than lighting units. In other analysis, we adjust for the relative efficiencies of different lighting technologies, so that the same level of lighting service is delivered. For example, a CFL produces four times as much lighting as an incandescent light for the same amount of energy input. The energy is converted to light, not thermal heat – at least the useful part. The units are take incandescents as norm, so that for them 1 LU = 1 PJ, but for CFLs, 1PJ = 4 LU. The relative efficiencies of non-electric lighting technologies, including paraffin wick lights, gas pressure lamps and candles, are low.

	micro-wave	60%	R 874	R 678	5	0.1004	2,556.3243
paraffin	wick	40%	R 107	R 83	3	0.1657	77.6743
	primus	42%	R 37	R 29	6	2.4558	29.8504
gas	ring	53%	R 249	R 193	5	0.7088	45.6038
	stove	57%	R 4,995	R 3,877	9	1.1136	293.2659
Wood	stove	25%	R 848	R 687	9	2.7729	366.1427
coal	stove	13%	R 5,231	R 4,060	11	-	
	brazier	8%	R 0	R 0	1	-	-
Water heating							
electricity	geyser	70%	R 2,172	R 1,686	22	29.7663	255.5052
paraffin	wick/kero/pot	35%	R 37	R 29	3	1.8019	34.8500
gas	geyser	84%	R 4,298	R 3,479	22	0.2936	2,813.7125
solar	SWH (integral)	100%	R 7,150	R 5,549	17	0.1922	588.1703
Coal/wood/ wastes	stove(jacket/pot)	40%	R 0	R 0	1	5.4846	-
Space Heating							
electricity	Radiant heater	100%	R 100	R 78	6	11.8984	18.2595
	Rib/fin/radiator	100%	R 968	R 751	9	7.3770	176.4690
paraffin	heater	73%	R 59	R 46	9	3.4390	26.3508
gas	heater	75%	R 993	R 771	5	0.3012	166.3370
wood	open fire/stove	40%	R 0	R 0	-	-	-
coal	stove	59%	R 5,231	R 4,060	11	-	
	brazier	8%	R 0	R 0	1	-	-
Lighting							
electricity	incandescent	100.00%	R 3	R 2	1	14.2820	7.9843
	fluorescent	290.29%	R 13	R 10	4	-	
	CFLs	400.00%	R 17	R 14	10	0.0989	245.0688
paraffin	wick	1.71%	R 5	R 4	4	3.8536	4.3635
	pressure	7.43%	R 192	R 155	4	-	
gas	Pressure	5.71%	R 250	R 194	4	-	
candles		0.05%	R 1	R 1	0.01	-	40.6078
Other electrical appliances							
Electricity	Appliances	80%			5	16.0407	

Lifetimes and efficiencies are taken from previous studies (De Villiers & Matibe 2000; DME 2003a), updated in some cases by expert input. (Cowan 2005; Lloyd 2005)For all end uses other than lighting, the efficiencies relate to the amount of useful energy delivered by the appliance for each unit of final energy delivered to the household. For lighting, however, relative efficiencies reflect the amount of lighting service produced, not thermal outputs.

2.3.4 Projections of future residential energy demand

Projected future energy demand in the residential sector, in the first instance, would depend on the changing number of households in each group, as well as the changes in the amount of energy services consumed by each household. Future household numbers in turn will likely depend on population growth rates, the impact of HIV / AIDS, and migration patterns. Changes in useful energy intensity would depend on changing fuel use (notably electrification) and income levels. We assume that this pattern of household / population growth will continue, but that population growth rates will be lower due to the impact of AIDS. Since this important assumption is a driver of future energy patterns beyond just the residential sector, it is discussed together with other key assumption about the future in section 3.2.2.

2.3.4.1 Urban - rural shares in future

Given the definition of household types in this study, the distinction between urban and rural households is important. Rates of electrification are much higher in urban areas, and other fuel use patterns differ too. Urban population growth rates for earlier periods were substantially higher, e.g. population growth from 1946- 1970 was 3.45% per year, 3.09 % for 1970-1996 (SACN 2004).Overall, this gives a picture of a growing population, but growth slowing down to lower rates. Will SA's population continue to urbanise? There have been some suggestions that rural populations have peaked and will stabilise or even decline (Calitz 1996). We assume that virtually all the household growth – moderate as it is projected to be - will occur in this broadly defined urban category and that rural household numbers remain stable. Under these assumptions, 64% of the population will be urbanised by 2030.

2.3.4.2 Households and household size

Energy use in many respects relates more directly to households, rather than to individuals. Electricity connections, for example, are made to each household. A notable trend across South African cities is that households have been growing faster than population. Given that urban areas are where most of the population growth is expected to occur in future. Across South Africa's nine largest cities, population grew between 1996 and 2001 by 2.8% per year, but households increased at 4.9% per year (SACN 2004:179)]. Possible reasons include people moving out of backyard shacks and establishing new households, particularly where incomes increase; migration from rural areas to the cities and associated cultural changes; and increased household formation. Such trends are consistent with demographic experience elsewhere in the world, where increasing income levels are negatively correlated with fertility and population growth rates (REF). The average number people per *urban* household has dropped from 3.98 in 1996 to 3.58 in 2001;(SACN 2004).in the national picture, it has dropped from 4.48 to 4.0% over the same time (SSA 1996, 2003b), although these trends are probably partly the result of reconsideration of earlier Census data. Given demographic trends elsewhere in the world, it seems plausible to assume that household size will continue to decline a little further, reaching 3.8% by 2030.

2.3.4.3 Trends in energy consumption

One of the key changes since 1990 has been the electrification programme, which has gradually moved energy use patterns to a greater reliance on electricity – although affordability of using electricity remains an issue in low-income households. Universal access to affordable electricity will remain a corner-stone of policy for the sector and treated as a 'given' in considering policy choices. Government's commitment to achieving universal access has been reiterated in many policy speeches (Mbeki 2004; Mlambo-Ngcuka 2002b, 2003, 2004). For the purposes of this study, we assume that by the end of the period, 99% of urban and 90% of rural households will be electrified. Together with other projections, this implies that 17% of *poor* rural households will still be non-electrified by the end of the period, as will 3% of urban low-income households.

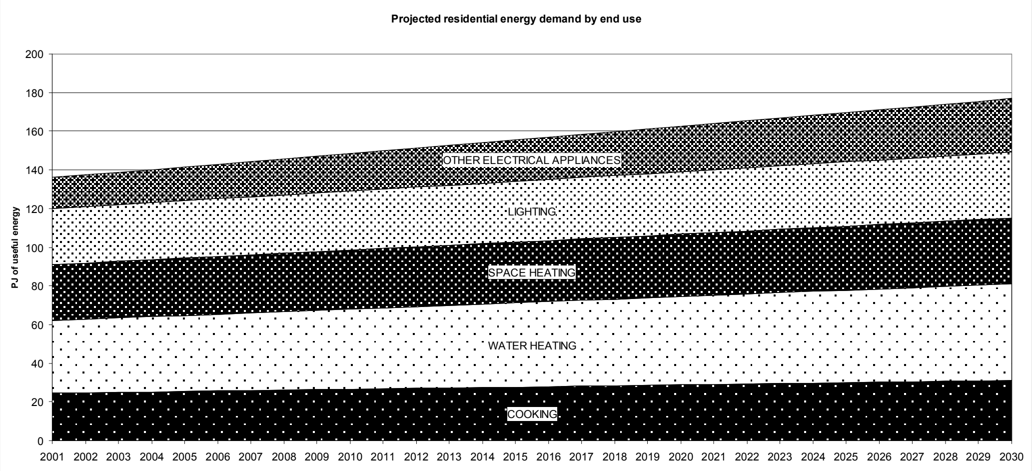
As highlighted in the discussion of affordability, access will need to be complemented with policies to promote affordable use – or put another way, to promote use of energy not only for lighting or entertainment, but also for cooking and productive uses. A supplementary study on the poverty tariff found that a 'weak access' approach was feasible – a self-targeted tariff with a current limit (UCT 2003). The proposal in the original report (UCT 2002)was that customers who wished to received the free electricity would agree to limit supply to 8A (compared to 20A or 60A household connections). However, the supplementary work found that that many households already owned appliances with ratings above 1.8 kW, meaning they could not be used with an 8A supply, or there use would be very limited. A 10 A supply was found to improve social acceptability, with an estimated further R150 million needed for network reinforcement over several years.

2.3.4.4 Changing patterns of energy consumption

Electrification is one major factor driving energy transitions in rural areas. The concept of an energy transition has been described by some as a “universal trend” whereby households move from traditional fuel, consisting of wood, dung and bagasse, through transitional energy sources (coal, paraffin and LPG) to ‘modern energy services’ – electricity (ERI 2001).While some shifts in fuels occur, questions have been asked whether this process is happening in a linear fashion, and whether it takes adequate account of persistent use of non-commercial fuels (Yamba et al. 2002).These fuel use patterns continue for several years after households receive electricity services;(Mehlwana 1998).indeed, wealthier consumers also shift back to consumption of firewood. Proposals have been made to more effectively represent multiple fuel use and the use of a single appliance for multiple end uses in modeling, (Howells et al. 2005)focusing more on the energy services than on fuel used.

Overall, energy demands are increasing over the period. Most of the increase derives from increasing incomes – more households move from the poor to rich classification, where more energy is used per household. For electrical appliances, the intensity of energy use (electricity for other appliances per household) is increasing.

Figure 13: Projected energy demand by end use



2.3.4.5 Poverty

All projections of the future require assumptions. Perhaps one of the most difficult required here is about poverty in the future. We choose a middle path between assuming that poverty is reduced dramatically, and a future world in which the share of poor households is unchanged. At least in absolute terms, we assume that overall income levels increase so that 70% of urban households are non-poor, compared to 61% in 2001. Shares of low-income households decline to 60% in the reference scenario by 2030, down from 69% in 2001. This overall affect does not claim to address issues of relative poverty, where households may still consider themselves poor, as high-income households have grown wealthier.

2.3.4.6 Future activity levels

Given the data for the starting year of 2001 and the assumed changes as described above, the changes in the numbers and shares of the six different household types in this study are shown in Table 16.

Table 16: Number and share of households, estimated for 2001 and projected for 2030

Source: See text for underlying data and assumptions

	2001		*2030*	
	No. of households	*Share of households*	*No. of households*	*Share of households*
UHE	4,074,438	36.4%	6,050,063	45.9%
ULE	1,255,728	11.2%	2,506,455	19.0%
ULN	1,349,240	12.0%	86,429	0.7%
RHE	1,181,279	10.5%	1,810,520	13.7%
RLE	1,095,449	9.8%	2,263,150	17.2%
RLN	2,249,571	20.1%	452,630	3.4%
Total	11,205,705		13,169,247	

More detail is provided in the Appendices, with

Table 61 showing the energy demands by end use and household type, and providing household number as projected for selected intermediate years. provides the total demands for each end use, as well as the grand total of residential energy demand for various years from 2001 to 2025.

2.3.5 Solar water heaters and geyser blankets

Energy policies for the residential heater could start with water heating, one of the major end uses in the sector. However, given the high capital costs of SWHs, this is likely to focus on middle- and upper-income households, and is also more likely to take place in urban areas. Estimates of penetration rates vary quite widely, from 20% over 15 years (De Villiers & Matibe 2000)to 60% of electricity for water heating avoided, amounting to 2 PJ per year (DME 2003b). A simpler intervention with lower initial costs is the installation of geyser blankets, still providing a substantial energy saving. Voluntary guidelines already exist in the form of the South African Energy and Demand Efficiency Standards. A process is underway to turn these into mandatory building codes, but the technical specifications are not available yet.

For solar water heaters, it would make sense to out new and existing buildings, requiring all new urban middle- and upper-income households to install hybrid solar-electric water heaters instead of electric storage geysers. “Virtually no SWH are encountered in low-cost housing areas”(DME 2004b). SWH would save 60% of electricity use (Karekezi & Ranja 1997; Spalding-Fecher et al. 2002b). Existing homes would be encouraged to insulate existing electric storage geysers (saves 12%)(EDRC 2003; Mathews et al. 1998), and required to do so if replacing existing electric geysers. Currently 1-3% of households have geyser blankets (Borchers 2005), and we assume 2% for this study.

Typical costs of an electric geyser were R1500 in 2005 (cost survey for this study). Solar water heaters currently are more expensive, around R8 000 to R12 000 installed; however with new vacuum tube technology costs are likely to decline to R4000 to R6000 (Borchers 2005). A reasonable figure for a hybrid solar and electric system would be R6500 installed (EDRC 2003); R 6 000 given for ‘machinery’ plus R 1 500 ‘other’ costs by study for Cabeere (DME 2004b: 93). Vacuum tube technology is already available (http://www.solardome.co.za/) in SA, so it can be expected that the prices would decline from R6 000 in 2005 to R4 000 by 2010, in real terms. Since the vacuum tubes themselves are imported, economies of scale in importing will be important in reducing the price, which would imply a step change in relation to the introduction of a new technology. Future research is needed to quantify the point at which this step change is likely to occur in terms of levels of output, imports or cumulative production. Enquiries with local distributors indicate an expectation that by 2010, all SWHs sold will use vacuum tube technology.

2.3.6 Simulating building codes for energy-efficient housing

The Department of Housing commissioned a study early in 2003 to set up a framework for regulation of environmentally sound building. The policy here would be to revise the SAEDES guidelines to specify which measures should be included in the energy-efficient housing package and any technical details required for these interventions, and to make these standards mandatory for all new subsidy-supported housing.

Since most of the thermal energy in a house escapes through the roof (Holm 2000), the single most effective intervention in the building shell is the installation of a ceiling (possibly with additional insulation on top of the ceiling) (Spalding-Fecher et al. 2002a). In addition, a layer of low-cost insulation above the ceiling and on the walls can improve the thermal performance of the building shell (Holm 2000; Winkler et al. 2002). The low cost housing codes should be implemented from 2003/4, with all new homes being built to this code and upgrades in existing Reconstruction & Development Programme (RDP) housing phased in over 10 years. This study examines the implications.

RDP housing typically does not include ceilings, so the costs of these are included at R1,278 for a 30 m^2 RDP house in 2001 (Holm 2000; Thorne 2005). Middle- and upper-income houses already have ceilings, so only insulation is installed, at a cost of R2,031 for a 90 m^2 three-bed-roomed house in 2001. These interventions can be combined with passive solar techniques (correct orientation, north-facing windows and optimized roof overhang) to make for a more efficient building shell.

Although it is technically possible to eliminate the need for space heating through proper insulation, orientation and ceilings, i.e. achieve 100% savings (Holm 2000), many households will choose to use some of those potential savings on more space heating. This ‘take-back’ effect will reduce the actual savings achieved, although it still provides development benefits because it means that people who previously had homes that were too cold in winter and too hot in summer can have more comfortable homes (see Schipper & Grubb 2000; Scott 1980; see Spalding-Fecher et al. 2002a). Improved quality of life, e.g. having a house at a more comfortable temperature of 21 deg C, would be achieved by taking part of the energy savings back.

The savings achievable through the ceilings and insulation alone are estimated in the range from 34% to 50%; together with zero-cost passive solar design, we assume that the average of this range, i.e. 42% can be achieved by the package of interventions – ceilings and insulation. This is a conservative estimate compared to previous studies assumed higher savings for passive solar design of houses along with ceilings and insulation (especially in low-cost housing), up to 60-70% of space-heating energy from a variety of sources (EDRC 2003; Holm 2000). This should improve confidence that the savings reported in this study are achievable. Currently, at most 0.5% of households are efficient in their thermal design. The reference case assumes that this share grows at 5% per year in future, i.e. over the period, the number of efficient households doubles twice. The model results will show how much these penetration rates are increased by policy interventions, such as subsidies.

2.3.7 Subsidies for energy efficiency in low-cost housing

It is one thing to demonstrate the technical potential of energy efficiency, but quite another to examine whether such interventions are *affordable*, particularly in low-income households. Most poor communities rely heavily on the national housing subsidy to build decent housing. As discussed earlier, however, this subsidy is not linked in any way to the energy efficiency characteristics of the house. This would be analogous to the incremental subsidy provided for homes in the Southern Cape for mitigating condensation and dampness. The incremental housing subsidy would be set equal to the initial incremental cost of the intervention for the same end-uses covered under ‘building codes’ and ‘appliance standards.’ It is envisaged that this measure could be implemented through existing housing legislation and programmes.

A result of particular interest is the subsidy required to make the interventions with upfront costs affordable, given the relatively high discount rates of poor households. We examine the marginal level of investment needed to make energy-efficient interventions, as described above, economic to poor households. We assume that the discount rate of poor households is higher at 30% than in general (10%). Currently, there is a subsidy for coastal areas (R1003), to which the results from the modeling can be compared. The *required* subsidy is reported in the results.

2.3.8 Efficient lighting

Compact fluorescent light-bulbs (CFLs) use significantly less power than conventional bulbs. Many low-income households use less than 75 kWh of electricity per month, and hot water geysers and electric cooking appliances are uncommon in such households. This implies that much of the electricity use is for lighting and that energy efficient bulbs can markedly reduce electricity bills. From the utility’s perspective, lighting demand has a high degree of co-incidence with peak demand, especially in the winter when daylight fades early and the peak occurs in the evening. CFLs can therefore reduce expensive peak demand. Efficient lighting practices include switching off lights when a room is unoccupied, fitting lower power light bulbs where possible and controlling security lighting with light or movement sensors.

The relative efficiency of CFLs compared to incandescents is about 1:4, and they about ten times longer (10 000 hours versus 1 000 hour life). The efficient lighting initiative has significantly reduced the price of CFLs from 2001 to 2003, and increased the market share of CFLs (ELI 2005). Current market shares vary between zero for poor rural households and 8% for medium/high-income urban households. For the future, this study assumes that penetration rates increase more rapidly in the first half of the period, and then grow more slowly towards some upper limit. Studies in the Netherlands, Germany, and Denmark have gathered detailed data on the uptake of CFLs. In these countries, about half the households have CFLs installed (NL 56%, DE 50%, and DK 46%)(Kofod 1996). These high penetration rates are probably not matched anywhere else in the world and are the upper bound for our reference case.

Table 17: Penetration rates for 2001 and assumptions of upper and lower bounds for the reference case

Household type		*Bound for future*		
	2001		2013	2030
UHE	*8%*	*UP*	35%	50%
		LO	15%	17%
ULE	*1%*	*UP*	20%	40%
		LO	9%	17%
RHE	*6%*	*UP*	30%	50%
		LO	11%	17%
RLE	*0%*	*UP*	20%	40%
		LO	9%	17%

2.4 Agriculture

2.4.1 Agricultural sector activity

The agricultural sector includes all users classified as agriculture, forestry and hunting as well as ocean, coastal and inland fishing under SIC codes 11, 12 and 13. A detailed breakdown of activities included in this sector is given in Table 18.

Table 18: Agricultural sub-sectors by SIC code

SIC	*Description*
11	*Agriculture, hunting and related services*
111	Growing of crops; market gardening; services
112	Farming of animals
113	Growing of crops combined with farming of animals (mixed farming)
114	Agricultural and animal husbandry services, except veterinary activities
115	Hunting; trapping and game propagation, including related services
116	Production of organic fertilizer
12	*Forestry, logging and related services*
121	Forestry and related services
122	Logging and related services
13	*Fishing, operation of fish hatcheries and fish farms*
131	Ocean, inland and coastal fishing
132	Fish hatcheries and fish farms

Of South Africa's total land area of 122.3 million hectares, 13.7% (16.7 million ha) is potentially arable, 68.6% (83.9 million ha) is grazing land, 9.6% (11.8 million ha) protected by nature conservation, 1.2% (1.4 million ha) under forestry, and 6.9% used for other purposes. Of the arable portion, 2.5 million hectares is in the former homelands and 14.2 million is farmed by commercial agriculture. 9.5 million hectares are used for field crops (NDA 2000: 5-6).). About three thousand large commercial farmers produce 40% of the agricultural output, ten thousand farmers are surviving economically producing a further 40% of the agricultural output, and forty to sixty thousand full-time struggling farmers produce the remaining 20% of agricultural output(1). The agricultural sector employed about 10% of the workforce in 2001: 960 489 employed people aged 15-65 in agriculture, hunting, forestry and fishing, out of a total of 9 583 762 (SSA 2004).

Since all agricultural sub-sectors have been aggregated into one group the only common measure of activity is value added and this has therefore been used. Other alternatives for activity variables such as hectares or livestock population are only appropriate when working with a greater sub-division of sectors. Due to the poor data availability a further disaggregation is not deemed feasible for this study.

2.4.2 Energy use in the agricultural sector

Table 19 shows energy consumption in the agricultural sector. An estimated 73 PJ of energy was consumed in the sector in 2001. Approximately 58 percent of this was diesel, 10 percent was other liquid fuels, 30 percent was in the form of electricity and the remaining 2 percent was coal.

Table 19: Energy use in the agricultural sector (PJ)

Source	*Year*	*Electricity*	*Coal*	*Petrol*	*Paraffin*	*LPG*	*Diesel*	*HFO*	*Total*
This study	2001	22	1.5	2.8	2.4	0.13	43	1.6	73
DME	2001	15	2.7	3.8	3.0	0.13	43	1.6	69
IEA	2000	14	1.6	2.6	2.3	0.14	40	-	61
Beyond2020 REF	1999	-	2.7	-	-	-	-	-	-
Eskom	2001	22	-	-	-	-	-	-	-

Energy use is primarily for the purposes of:

- preparing the land
- irrigating the land
- applying nutrients, pesticides and herbicides
- harvesting
- primary processing

Based on this, the following set of end-use demands were considered for this study:

- Traction (tractors, harvesters and on-site transport)
- Irrigation (electricity, diesel and petrol driven pumps)
- Primary processing (electric equipment)
- Heat (hot water for dairies, incubators, drying of crops)
- Other (electricity demands such as lighting and cooling etc.)

The total value added by the agricultural sector in 2001 was ZAR 26,558 million. Based on the fuel use given in Table 19 a set of end-use energy intensities can be derived. These are given in Table 20. The allocation of fuels to various activities is based on the IEP in the case of electricity. For other fuels there are no accurate sources of information. The allocation is therefore a "best guess" although there is a high confidence in attributing the majority of this to traction.

Table 20: Useful energy intensity of agricultural end-use demands

Demand	*2000 Useful energy intensity [GJ/ZAR]*	*2025 Useful energy Intensity [GJ/ZAR]*
Traction	0.564	0.564
Irrigation	0.314	0.401
Processing	0.214	0.344
Heat	0.211	0.211
Other	0.371	0.596

2.4.3 Demand projections

Value added is used as the driver for energy demand in the agricultural sector. The projections are given in Table 21.

Table 21: Forecast of value added in the agricultural sector

	2001	*2005*	*2010*	*2015*	*2020*	*2025*
Agriculture GVA (R millions)	26558	27510	28098	28538	28912	29200

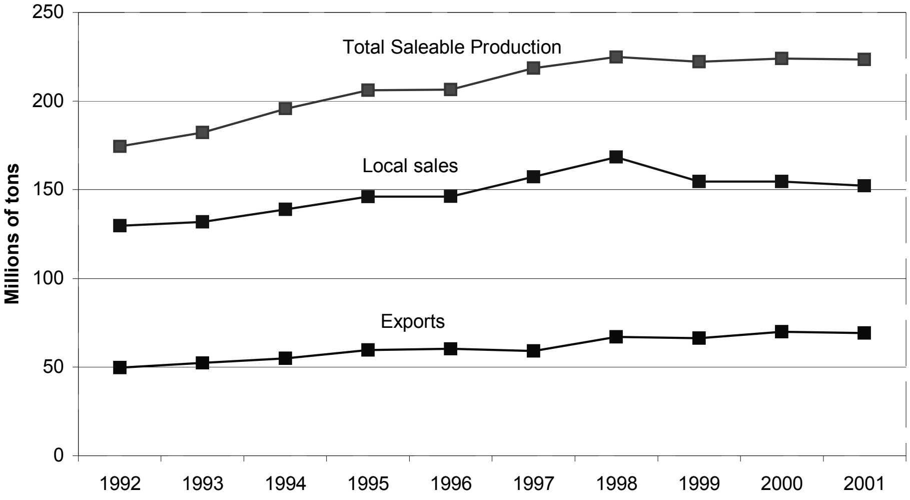
2.5 Coal mining

Coal mining is an important upstream activity, providing fuel for electricity generation, synthetic fuels and industrial processes. No particular policy options in coal mining are investigated here, but some background is relevant.

For a long time the figure given for South Africa's coal reserves has been 55 billion tons, but it is not reliable. The DME is conducting a thorough study to assess the true reserves but an interim estimation of 38 billion tons (Prevost 2003) is the best figure available now. Figure 14 shows coal production from 1992 to 2001.

Figure 14: Total saleable production, local sales and exports of South African coal, 1992 to 2001

Source: DME (2003)

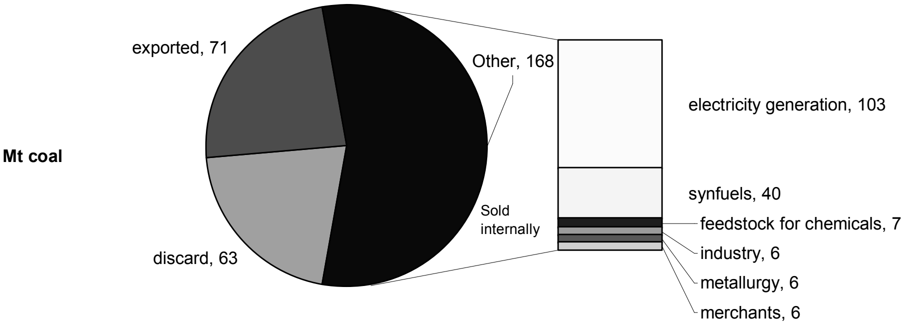


In 2001, South Africa mined 290 million tons of coal, of which 223.5 million tons was saleable. 152.2 millions tons went to the local market and 69.2 million to export. 66.5 million tons were discards, too low in heating value and too high in ash to have commercial value now. However, these discards might be burned in fluidised bed combustion (FBC) boilers in future.

The use of coal for export, various internal uses and discards is shown in Figure 15.

Figure 15: Coal used for export, domestic uses and discards, 2003

Source: (DME 2004c).



The prices of domestic coal were reported by DME as more constant over time than coal for export.

Table 22: Price of coal for local sales, 1994 – 2003

Source: DME (2004c)

Year	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*
Rand / ton	40	43	46	49	53	54	57	63	75	79

South African coal prices were R60.73 / ton of coal for electricity generation in 2001 in 2000 Rands. Calorific values of SA's sub-bituminous coal for electricity generation was 20.1 MJ / kg, lower than average figures due to its relatively high ash content (Pinheiro 1999). For details of assumption about future coal prices, see section 3.2.4. This section puts SA coal prices in the context of other fuel prices.

2.6 Electricity generation

In the **electricity sector**, we examine alternative supply options, from natural gas, renewable energy technologies, PBMR nuclear, imported hydro, and fluidised bed combustion (FBC) coal-fired plants. Some bounds are set on the ranges of supply from each source, within which the model optimizes. The implications for total energy system costs, environmental implications, water use, job-creation potential and other parameters are examined. In other words, we examine the electricity development paths for the major supply-side options in the sector. These are complemented by the various demand-side interventions which have been described in the sections on each economic sector above.

The excess capacity, which that the electricity sector has experienced for the last three decades of the twentieth century, is ending. The decisions about who will supply new power stations, and what energy sources will they use (ERC 2004a)will shape SA's energy development path for the next few decades.

The overarching *policy* goal for electricity supply is that of the 1998 White Paper on Energy Policy, namely to "ensure security of supply through diversity" (DME 1998). The strong commitment to ensuring security of supply and to do so by pursuing all energy sources has been restated by the Energy Minister in her budget vote speech (Mlambo-Ngcuka 2004).[12] Government will examine all available energy technologies, and plan for future capacity needs based on planning to select the least-cost option. In his 2004 State of the Nation speech, the President acknowledged the need for new capacity by announcing that a tender would be awarded in the first half of 2005, to deliver "new generating capacity to provide for the growing energy needs from 2008" (Mbeki 2004). Investors will tender to provide the most cost-effective means to build new capacity of a certain quality (e.g. reliability, availability, emissions).

- The modeling approach for the present study will include all existing power plants and the technology options spelled out below, using renewables, gas, nuclear, coal and imported hydro. Lead times for different technologies will be included, as will the cost of unserved energy.[13]
- The reference case will be very close to the National Integrated Resource Plan currently being developed by the ERC modeling group and others for the NER (NER 2004b).
- Future policy cases will model departures from the reference case, as outlined below.
- Our approach to scenario modeling is first to consider using each of the energy *technologies* separately. The implications of using these technologies in terms of costs (capital and O&M, fixed and variable), wider impact on the economy, environmental impacts (notably local air pollutants and GHGs) and social benefits (e.g. electricity prices, job creation?) will be examined. *Policy* recommendations will be drawn from considering these implications. Given the large scale of the study, reporting will be at the level of policies and scenarios.

Table 23: Characteristics of new power plants

Source: NIRP(NER 2004b)

	Units of capacity	Investment cost, undiscounted	Fixed O&M cost	Variable O&M cost	Lifetime	Lead Time	Efficiency	Availability factor
Type	MW	R/kW	R / kW	c / kWh	Years	Yrs	%	%
Coal								
New pulverized fuel plant	642	9,980	101	1.1	30	4	35%	252%
Fluidised bed combustion (with FGD)	233	9,321	186	2.9	30	4	37%	88%
Imported gas								
Combined cycle gas turbine	387	4,583	142	11.5	25	3	50%	85%
Open cycle gas turbine (diesel)	120	3,206	142	16.2	25	2	32%	85%
Imported hydro								
Imported hydro	9200 GWh / yr			2.1	40	6.5		
Renewable energy								
Parabolic trough	100	18,421	121	0	30	2	100%	24%
Power Tower	100	19,838	356	0	30	2	100%	60%
Wind turbine	1	6,325	289	0	20	2	100%	25, 30, 35%
Small hydro	2	10,938	202	0	25	1	100%	30%
Land fill gas (medium)	3	4,287	156	24.2	25	2	n/a	89%

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

[13] Unserved energy occurs when load is interrupted. Attaching a cost to the lost revenues do to this energy not being provided allows comparison to the cost of increasing capacity (perhaps specific peaking capacity) to meet the demand.

Biomass co-gen (bagasse)	8	6,064	154	9.5	20	2	34%	57%
Nuclear								
PBMR initial modules	165	18,707	317	2.5	40	4	41%	82%
PBMR multi-modules	171	11,709	317	2.5	40	4	41%	82%
Storage								
Pumped storage	333	6,064	154	9.5	40	7	storage	95%

2.6.1 Switch from coal to gas

Natural gas currently only accounts for 1.5% of the country's total primary energy supply (DME 2002c). Total proven gas reserves of South Africa are about 2 tcf,[14] which could rise with further exploration (ERC 2004a). New fields are being explored off the South African West Coast (Ibhubesi), Namibia (Kudu) and Mozambique (Pande and Temane). All of these are relatively small, with larger fields further away in Angola (ERC 2004a). During 2004, gas from Mozambique started being delivered to Gauteng – but for use at SASOL and in industry, rather than in electricity generation. Import of liquefied natural gas (LNG) by tanker is an option being considered (NER 2004b).

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

A policy case for natural **gas** is investigated, building 3 combined cycle gas turbines (**CCGT**) of 1950 MW each, or a total of 5 850 MW by 2020. Gas is being imported by pipeline from Mozambique since 2004, but its preferred use has been for feedstock at SASOL's chemical and synfuel plants (Sasol 2004a). The alternative is shipping of Liquefied Natural Gas, potentially landed at Saldanha in the Western Cape, Coega in the Eastern Cape or Richards Bay in KwaZulu Natal. Gas turbines have relatively short start-up times and play an important role in meeting peak power. Construction of a LNG terminal would add two years to the lead time of a project, due to environmental impact assessments and harbour modifications. This makes the total lead time, even under a fast-track option where LNG terminal construction is done in parallel with building the plant, five years; otherwise it would be eight years (NER 2004a: Appendix 3). Fifteen units of 390 MW each could be constructed with lead times of 5 years spreading them over the period. The policy case is implemented with a higher upper bound than the reference case, which following the NIRP included a maximum of 1 950 MW of CCGT.

2.6.2 Renewable energy for electricity generation

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

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

Renewable resources like wind and solar are intermittent in nature. Intermittency means that these technologies cannot be dispatched on demand (IEA 2003b). Technical solutions and business and regulatory practices can reduce intermittency, e.g. by through variable-speed turbines or complementing wind with an energy technology capable of storage, e.g. fossil fuels, pumped storage or compressed air storage. Storage, however, imposes a cost penalty. Since utilities must supply power in close balance to demand and the amount of capacity of highly intermittent resources that can be incorporated into the energy mix is therefore limited. The level of intermittent renewables that can be absorbed requires further study. In Denmark, Spain and Germany, penetration levels over 15% (and up to 50% for a few minutes) have in some instances caused grid control and power quality problems, but not in other cases (IEA 2003b). With South Africa's penetration of renewables for electricity generation being very low (about 1%, from hydro and bagasse (NER 2003a)), the grid will absorb most fluctuations. SA's renewable energy target of 10 000 GWh per year which is 4% of of estimated generation in 2013, but would require 3 805 MW assuming 30% availability factor.

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

The *theoretical potential* for renewable energy in South Africa's lies overwhelmingly with solar energy, equivalent to about 280 000 GW (Eberhard & Williams 1988: 9). Technological and economic potentials would be lower than the theoretical potentials – by various estimates – shown in Table 23. Other renewable energy sources – wind, bagasse, wood, hydro, and agricultural and wood waste – are much smaller than solar.

Table 24: Theoretical potential of renewable energy sources in South Africa, various studies

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

	DANCED / DME	*Howells*	*RE White Paper*
Resource	PJ / year		
Wind	6	50	21
Bagasse	47	49	18
Wood	44	220	
Hydro	40	20	36
Solar		8 500 000	
Agricultural waste		20	
Wood waste			9

The most recent estimates of the potential of renewable energy are being compiled for the South African Renewable Energy Resource Database (SARERD) (www.csir.co.za/environmentek/sarerd/contact.html). More detailed GIS maps will be sold, with revenues used to update the data (Otto 2003). In estimating *economic* potential, there is even less data. With little commercial use of renewable energy, there is not sufficient experience regarding local costs and markets to provide estimates of much accuracy. What is available, however, is a study on the renewable energy sources that could provide 10 000 GWh of electricity to meet the target (see

Table 25 below).

Government has adopted a White Paper on Renewable Energy (DME 2003b). The Energy Minister's 2003 budget speech indicated that renewable energy policy would be subsidised (Mlambo-Ngcuka 2003)– see subsidy statement below.

The Energy Minister's 2003 budget speech indicated that renewable energy policy would "lead to the subsidisation of Renewable Energy and develop a sustainable market share for clean energy" (Mlambo-Ngcuka 2003). Two major types of subsidies can be considered:

- investment subsidies, as an up-front grant, given per unit of installed capacity; or
- production subsidies, through a rebate per kWh of renewable electricity produced.

Productions subsidies in the form of feed-in tariffs[15] are based on energy production and so provide an incentive to use capital efficiently. The motivation for subsidising renewable electricity is the local and global socio-economic and environmental benefits that are not captured by existing markets. The policy would be to formulate these incentives as production subsidies (as opposed to capital subsidies, which do not guarantee production). For example, the "Green Electricity" tariff negotiated for the World Summit on Sustainable Development, was 50 c/kWh, which was based on current estimates of the cost of grid-connected wind power (Morris 2002). Such a subsidy would have a similar effect to negotiating a higher tariff, as the Darling wind farm has negotiated a preferential tariff of 50 c / kWh with the City of Cape Town (CCT 2004; CCT & SEA 2003).

Production subsidies would be given to renewable electricity generators. However, in implementing this policy in a modeling framework, rather than setting a RE subsidy level (since no c/kWh number was known by May 2005), we analyse the subsidy *required* to deliver 10 000 GWh from each RET.

To put such values in context, one can consider a back-of-the-envelope calculation of carbon revenues that renewable energy projects could earn through the Clean Development Mechanism. The carbon price was rising rapidly, with € 20 being quoted for a ton of CO_2 in the EU Emissions Trading Scheme in June 2005 (www.pointcarbon.com). The price for CERs (with higher risks related to future delivery) were closer to €10 / t CO_2, but were expected to converge as the issuance of the first CERs increased certainty. At R8.50 / € and an grid system-average emission factor of 0.89 kg CO_2 / kWh (Eskom 2003), a 'subsidy' between 7.6 and 15.3 c/kWh could potentially be recovered from CDM revenues for zero-emissions technologies like renewables.

In 2003, government adopted a target of 10 000 GWh renewable energy consumption (DME 2003b). Although this is not limited to electricity but also includes solar water heating and biofuels, the policy document explicitly calculates that this would be 4% of expected *electricity* demand in 2013. A number of technologies could contribute to the goal, including solar thermal electricity (both the parabolic trough and 'power tower' options), wind turbines (at three availability factors, 25, 30 and 35%), small hydro facilities (Eskom and other), biomass co-generation (existing and new) and landfill gas (four sizes). The share of renewable electricity is set at 3.5% (10 TWh out of 283 TWh projected for 2013).

To implement the policy case with various RE technologies in Markal, a user constraint sets the sum of activities of all RETs equal to 36 PJ in 2013, interpolated linearly from existing 8.5 PJ in the base year (hydro and bagasse) and extrapolated beyond the target year.

Estimates of capacity developed for SA are shown in

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[15] See (Winkler 2005)for analysis of the merits of different policy approaches for renewable energy in SA.

Table 25. In Markal, upper bounds are placed on LFG and wind). Solar thermal electric technologies are not limited so much by the available resource, but more by cost.

Table 25: Technically feasible potential for renewable energy by technology

Source: DME (2004b)

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

Note that

Table 25 includes the solar resource (the largest theoretical potential, see Table 24) *only* for water heating, not for electricity generation. In the present study, we include solar thermal technologies for electricity generation to draw on the largest energy flow.

The characteristics of the renewable options are summarised earlier for comparison in Table 23. The data served as input to the modeling and is broadly consistent with the second NIRP. For many renewables, O&M costs are only fixed ones, with no fuel costs. Efficiencies are typically assumed to be 100%, but availability factors are important in reflecting the intermittency of some resources. Note that the molten salt storage for the solar power tower increases its availability relative to the parabolic trough (without any storage).

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

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

Table 26: Declining investment costs for wind and solar thermal electricity technologies

Source: (NER 2004a)

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

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

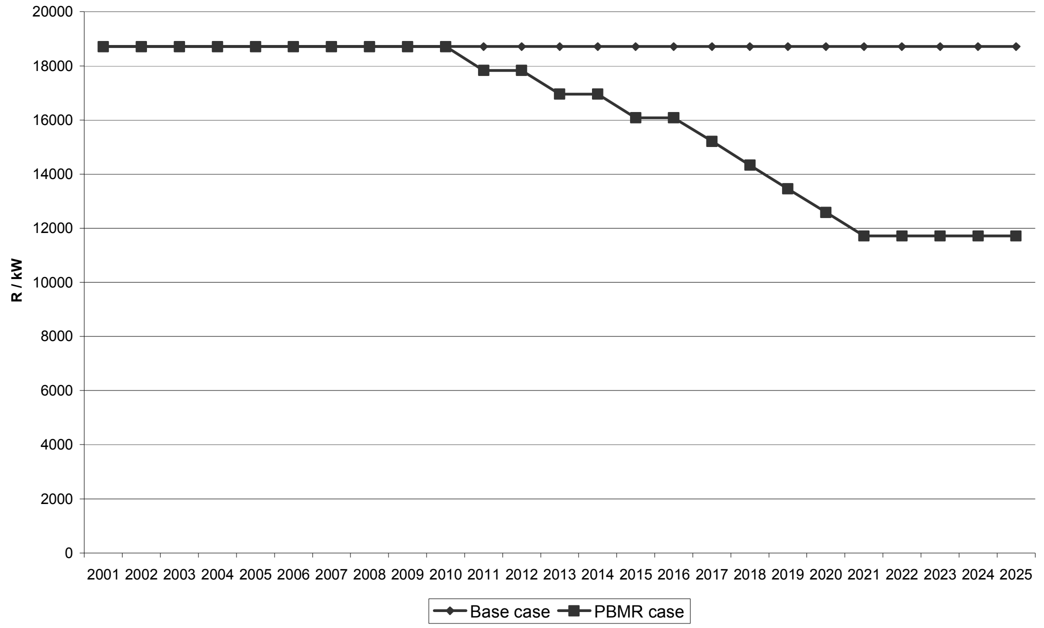
2.6.3 Going the nuclear route – the Pebble Bed Modular Reactor (PBMR)

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

In modeling the PBMR new nuclear technology, we assume that waste management policy is completed and enforced. A major focus has been to develop the PBMR for the export market and prove the technology domestically. The PBMR does not appear in the NIRP and therefore will not be included in the reference case.

A policy case is modelled which assumes that twenty five 165 MW stations are built in SA, and examines the implications for economic, social and environmental parameters. The investment costs for the PBMR are assumed to show learning, but based on total production for domestic use and export. Over the period, over 32 modules are produced. It is assumed that cost reduction through learning will have been realised at this point. Specifically, costs are modelled to decline from R 18707 per installed kW in 2010 to R 11 709 by 2021 (NER 2004a). These cost assumptions are illustrated in Figure 16.

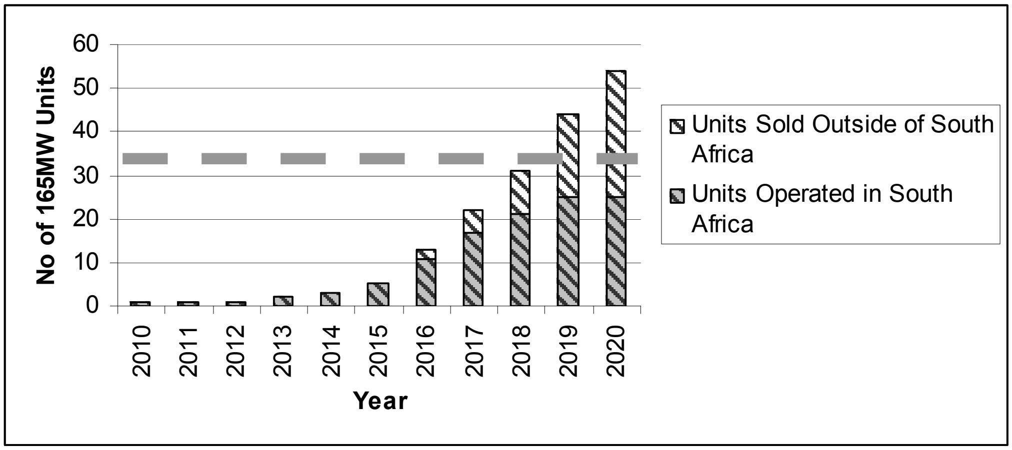
Figure 16: Schematic description of assumed PBMR costs in reference and policy scenarios



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

Figure 17.

Figure 17: PBMR Production for local use and export



2.6.4 Importing hydro-electricity from the region

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

The Mepanda Uncua site in Mozambique has a potential for 1300 MW and an annual mean generation of 11 TWh. It is located on the Zambezi river downstream of Cahora Bassa and could be connected to the SAPP grid through a total of four 400kV AC lines to Cahora Bassa and Maputo. Installed capacity of 1 300 MWe at a plant factor of 64% provides 7 288 GWh / year of firm energy (NER 2004a). The plant is assumed to come on line in 2011, with a lead time of 6.5 years. Upper bounds are placed on the increase of imported hydro up to the generation from Mepanda Uncua and to limit existing hydro imports.

Table 27: Estimated costs during construction at 2001 prices

Source: NIRP (NER 2004a: Appendix 3)

	Euro	***US$***
Construction of dam and power plant	871 million	1 018 million
Construction of transmission lines	953 million	1 114 million
Environmental management	17 million	19.8 million

Note: costs do not include interest

The estimated total financing requirement of the project, including price contingencies and interest during construction is about 2.6 billion Euro, half of which is for the power station and half for the transmission lines (NER 2004a). Assuming an exchange rate of R8 / 1 euro, and deflating to 2000 Rands, this converts to R 11.4 million for the 1300 MW station.

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

A scenario in which imported hydro is increased above the quantity in the reference case is included in the analysis. One of the major options for diversifying the fuel mix for electricity is to meet growing demand by importing hydro-electricity from Southern Africa. SA itself has only small hydro resources (0.8% of generation) (NER 2002a), and already imports electricity from the Cahora Bassa dam in Mozambique (5294 GWh in 2000) (NER 2000). We assume that imports from Cahora Bassa continue and grow due to Mepanda Uncua.

The average cost of existing electricity imports was 2.15c/kWh, well below the cost of South African generation in 2001 (NER 2001). It is not certain that such low prices will continue into the future. The existing import costs are part of a long-term agreement with Mozambique for Cahora Bassa. The future fixed operation costs are assumed to be R 234 million per year, with no variable cost (NER 2004a). Future prices could thus vary between R6 / GJ for existing up to R 99 / GJ for Mepanda Uncua. At the cost of avoided generation from a coal-fired plant, at 22.11 c / kWh (NER 2004a) or R 61.5 / GJ, no hydroelectricity would be used by the model. The approach taken is to assume that the weighted avarege of electricity imports from existing sources and Mepanda Uncua add up to 59 PJ at R 47 / GJ.

2.6.5 Reducing emissions from coal-fired power plants

A first step includes modifications to the existing pulverised fuel (PF) plants. Future plants are likely to be dry cooled (reducing specific water use) and install flue gas desulphurisation (FGD, removing SO_2), even though local coal has a low sulphur content (ca. 1%) (SANEA 2003). Both have cost implications, with dry cooling reducing efficiency by about one percentage point, and desulphurisation adding some 8.5% of the capital cost of stations (NER 2004a).This study assumes that baseline plants include FGD and removal of particulates (to World Bank standards). Existing stations do not have FGD, but do have either electrostatic precipitators or bag filters for removing particulates.

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

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

Emission standards can be set using target or limit values. Target values are long term goals intended to avoid harmful long-term effects on human health. Target values are to be pursued through cost-effective progressive methods. For SO_2 and NO_x, only limit values have been published so far, which are based on avoiding harmful effects based on scientific knowledge (Standards SA 2004).The SO_2 emission standards for power stations will meet World Bank standards.

Fluidised bed combustion has the advantage of making use of discard coal, and reducing the increase of dumps.

2.7 Transport and liquid fuels

2.7.1 Liquid fuel supply

Apart from modest production at the Oribi and Onyx fields of the south coast, all crude oil is imported, mainly from the Arabian Gulf. Total domestic supply in 2001 was 18,185 thousand metric tonnes. The imported crude oil is primarily landed at Durban, Cape Town and Saldanha bay. In Durban the crude oil is stored at the Natcos tank farm owned by Sasol, and then piped to the refinery at Sasolburg. Another pipeline runs from Saldanha Bay to Cape Town. Both Saldanha and Cape Town has got bulk storage facilities.

Refined petroleum products come from two different sources; crude oil refineries and synthetic fuel plants. A unique aspect of the liquid fuels industry in South Africa is the significant contribution to total supply from synthetic fuels. Sasol and Petrosa, the Synthetic fuel producers, rely on the Fischer-Tropsch process to convert a mixture of carbon monoxide and hydrogen into hydrocarbons and water. Sasol produces this syngas from coal at their Secunda plants. The plants are centered at a major coal field and the annual consumption of coal is approximately 30 million tons per annum. PetroSA use natural gas as feedstock in their Gas-to-Liquids (GTL) plant at Mossel Bay. The gas and condensate is piped from the offshore FA and EM fields which are also owned and operated by PetroSA. PetroSA produces 30,000 barrels of product a day from natural gas and a further 15,000 from condensate. There are four conventional refineries in South Africa namely, Calref - the Caltex plant at Milnerton in Cape Town, Enref owned by Engen, the Sell and BP owned Sapref in Durban and Natref at Sasolburg owned by Sasol and Total. Table 28 shows the expansion of capacity of all the South African refineries over the past decade.

Table 28: Capacities of South African refineries (Barrels per day or crude equivalent)

Refineries	*1992*	*1997*	*2001*
Sapref	120,000	165,000	180,000
Enref	70,000	105,000	115,000

Calref	50,000	100,000	100,000
Natref	78,000	86,000	86,000
Sasol	150,000	150,000	150,000
PetroSA	45,000	45,000	45,000
Total	513,000	651,000	676,000

The products leave the refineries for bulk distribution by road, rail and pipeline, which is primarily done by the various refining companies. Another important player in the primary distribution network is the Transnet subsidiary Petronet which owns and operates a high pressure steel, pipeline distribution network in the eastern parts of the country. Petronet transports a wide range of fuels including crude oil, petrol, diesel, jet fuel and methane rich gas. The pipeline network has not got sufficient capacity to handle the increasing demand and the lack of capacity is becoming a major problem. Various expansion options are being considered

The marketers of liquid fuels in South Africa are BP, Caltex, Engen, Sasol, Shell and Total. These all have marketing arms, but in general do not source solely from their own refineries.. Thus, a litre of petrol bought at a service station in Cape Town will most likely come from the Calrex refinery at Milnerton, regardless of retailer. In this way the distribution costs are kept at a minimum.

2.7.2 Transport sector activity

The transport sector covers all tranport activity in mobile engines regardless of the sector to which it is contributing (SIC divisions 71, 72 and 73), and is divided into sub-sectors as given in

Table 29.

Table 29: Transport sub-sectors by SIC code

SIC	*Description*
71	*Land transport; transport via pipelines*
711	Railway transport
712	Other land transport
713	Transport via pipelines
72	*Water transport*
721	Sea and coastal water transport
722	Inland water transport
730	*Air transport*

2.7.3 Transport energy use

Transport energy use in 2001 is shown in Table 30. Total energy consumption in this sector was 613 PJ. 56 percent of this was petrol, 30 percent was diesel, 10 percent was jet fuel, and 3 percent was electricity. The remainder was aviation gasoline, LPG, Fuel oil and coal.

Table 30: Energy use in the transport sector (PJ)

Source	*Year*		*Electricity*	*Petrol*	*Diesel*	*Jet fuel*	*Aviation gasoline*	*Total*
This study	2001		13	349	184	66	0.88	613
DME	2001		20	349	184	66	0.88	620
IEA	2000		19	328	154	64	0.82	566
IEA non-OECD stats?	1999		16	-	-	-	-	-
Eskom	2001		13	-	-	-	-	-
NER	2001		22	-	-	-	-	-

86 percent of the energy was used for road transport, while 11 percent was used for aviation which includes fuelling of international flights. 3 percent was used by railroads while small amounts were used for pipeline transport and internal navigation.

The following end-use services were identified for the transport sector:

- Passenger transport
    - Car travel (vehicle kms)
    - Bus travel (vehicle kms)
    - Taxi travel (vehicle kms)
    - Motorcycle travel (vehicle kms)
    - Rail travel (passenger kms)
- Freight transport
    - Light commercial truck transport (vehicle kms)
    - Medium commercial truck transport (vehicle kms)
    - Heavy commercial truck transport (vehicle kms)
    - Rail transport (tonne kms)
- Aviation
    - Jet air craft travel (PJ)
    - Propeller air craft travel (PJ)
- Pipeline transport
    - Pipeline transport of liquids (tonnes)
    - Pipeline transport of gas (tonnes)

2.7.4 Characteristics of energy demand technologies

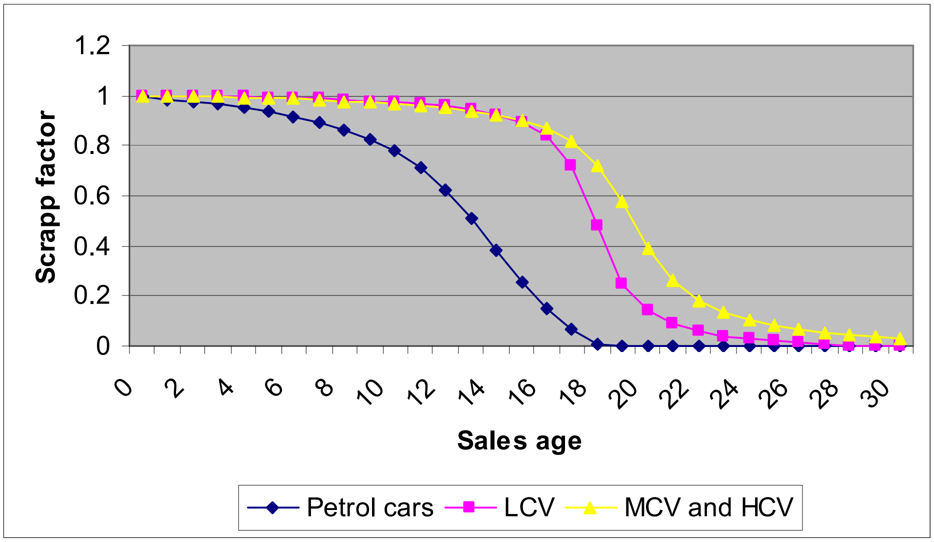
A bottom up analysis based on vehicle population, average annual mileage and fuel efficiency was used to estimate the fuel use of different vehicle categories. The assumptions are summarised in Table 31.

Table 31: Vehicle population and characteristics

Vehicle type	*Vehicle population*	*Average annual mileage (km/vehicle)*	*Total mileage (Billion vehicle kms)*	*Fuel efficiency (l/100km)*	*Total fuel use (PJ)*
Petrol cars	3874335	14575	56.47	8.2	186.34
Diesel cars	39135	15000	0.59	7.8	1.76
Motorcycles	158606	10000	1.59	5.2	3.17
Petrol taxis	248837	30000	7.46511	13.3	37.33
Diesel taxis	0	30000	0	11.9	0.00
Buses	25943	39495	1.0246	18.3	7.16
Light commercial diesel vehicles	377964	30000	11.34	11.3	48.99
Light commercial petrol vehicles	959504	25000	23.99	13.3	122.16
Medium commercial diesel vehicles	170899	39495	6.75	18.3	47.20
Heavy commercial diesel vehicles	71313	79163	5.65	33.1	71.64
Total					525.75

Vehicle survival rates were based on scrapping curves suggested by Verburgh * and Stone * and these are shown in Figure 18.

Figure 18: Vehicle scrapping curves



2.7.5 Demand projections

Population growth was assumed to be the major driver of passenger transport demand. Demand was also adjusted to reflect an increase in private vehicle ownership as GDP per capita grows. Table 32 illustrates the assumed values for transport activity intensities

Table 32: Per capita passenger transport intensities by mode

	2001	*2025*

Buses [Vehicle-kms/capita]	22.9	22.9
Private cars [Vehicle-kms/capita]	1273.0	1476.7
Taxis [Vehicle-kms/capita]	166.6	166.6
Motorcycles [Vehicle-kms/capita]	35.4	35.4
Rail [Pass-kms/capita]	581.4	581.4

Freight transport demand was assumed to grow in relation to value added in the transport sector. Simple linear regression for the years 1993 to 2004 showed a very good correlation ($R^2 = 0.99$) with the overall GDP. The relationship obtained from the regression was therefore used to forecast value added in transport based on the predicted GDP growth rate. The resulting time series data is shown in Table 33.

Table 33: Forecast of value added in the transport sector

	2001	2005	2010	2015	2020	2025
Transport GVA	85646	110123	140419	175201	215133	260977

Past trends in vehicle kilometers traveled per unit of value added were extrapolated to forecast demand intensity for actual physical transport. These forecasts are shown in Table 34 and generally show declining intensities, i.e. fewer vehicle-kilometers per Rand.

Table 34: Freight transport intensities

	2001	*2025*
Light commercial trucks [Vehicle-kms/kR]	412.5	346.5
Medium commercial trucks [Vehicle-kms/kR]	78.8	66.2
Heavy commercial trucks [Vehicle-kms/kR]	65.9	55.4
Rail [tonne-kms/kR]	1.2	1.2

Pipeline transport was assumed to be related to current and expected future pipeline capacity and utilization factor rather than any population or economic driver. Aviation demand was assumed to grow in relation to value added in the transport sector. The assumed intensity changes were based on current trends and are given in Table 35.

Table 35: Aviation transport intensities

	2001	*2025*
Jet aircrafts [GJ/mZAR]	770	524
AvGas aircrafts [GJ/mZAR]	10.3	4.3

2.7.6 Liquid fuel policies

In terms of **liquid fuel** supply, plans for the expansion of an existing refinery are part of the reference case and no further expansion is envisaged. The policy alternative would be the importation of petroleum products.

Initiatives to refine bio-fuels are also examined, although these are expected to make up a relatively small share of the market within the study period. Bio-diesel and eco-diesel pay only 70 % of the General Fuel Levy on mineral fuels . In 2001, the General Fuel Levy amounted to 98 (94.8) cent per litre on petrol (unleaded petrol), 81 cent per litre on diesel and 56,7 cent per litre on biofuels in terms of the Customs and Excise Act, No. 91 of 1964. Hence the exemption amounts to a tax break of 29.4c / litre of leaded petrol.

2.8 Energy-related environmental taxation

The use of economic instruments for environmental fiscal reform is being considered by Treasury {National Treasury, 2006 #2551}. We analyse the option of a fuel input tax on coal used for electricity generation..

Indications are that if full (mid-range) carbon costs were to be internalised, a tax of approximately R60-80 per tonne of coal combusted might be necessary {Blignaut, 2004 #2077}. For a fuel input tax, the *'taxable event'* would be the combustion of fossil fuels used for power generation. The tax would follow the established system of VAT payments and should be collected by SARS. The revenue raised could be used for a variety of different purposes including allocation to municipalities to compensate for lost revenue base from restructuring; as part of a tax-shifting exercise; transitional assistance for affected sectors; projects to improve household energy efficiency; and / or new projects, both smaller and larger-scale, promoting the development of renewable energy technologies. Such a tax should be implemented in a revenue-neutral manner, with proceeds being recycled either into subsidies for renewable energy, or general relief for poor communities, e.g. zero-rating of VAT on additional basic food-stuff items.

While R 70 is close to the price of ~R75 / ton of coal in 2005, the fuel costs overall are a relatively small part of the total cost of energy. We model the implications of a fossil fuel input tax at R40 and R70 per ton of coal, examining the implications of such a major intervention by Treasury, were it to be adopted within the forthcoming framework (National Treasury 2006). Any tax – whether input or output-based - would have to be assessed against this framework.

The policies could potentially be extended to coal for synfuel production and industrial use, or alternatively, the environmental outputs could be taxed directly, e.g. in a pollution tax.

3. Modeling framework and drivers

3.1 Model description

In order to consistently account for the attributes of the energy system and the role that energy interventions play in that system, we use the MARKAL (short for market allocation) energy model.[16] MARKAL (an acronym for MARKal ALlocation) is a mathematical model of the energy system that provides a technology-rich basis for estimating energy dynamics over a multi-period horizon. The objective function of MARKAL is to minimize the cost of the system modelled (Loulou et al. 2004).

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

MARKAL computes energy balances at all levels of an energy system: primary resources, secondary fuels, final energy, and energy services. The model aims to supply energy services at minimum global cost by simultaneously making equipment investment and operating decisions and primary energy supply decisions. For example, in MARKAL, if there is an increase in

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

demand for residential lighting energy service (perhaps due to a decline in the cost of residential lighting), either existing generation equipment must be used more intensively or new equipment must be installed. The choice of generation equipment (type and fuel) incorporates analysis of both the characteristics of alternative generation technologies and the economics of primary energy supply. Supply-side technologies, e.g. power plants, require lead times. MARKAL is thus a vertically integrated model of the entire energy system.

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

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

3.2 Drivers of future trends and general assumptions

3.2.1 Economic growth

In the absence of interventions that de-couple energy demand from economic growth, projections of GDP are an important driver. Economic growth over the next twenty-five years is hard to predict.

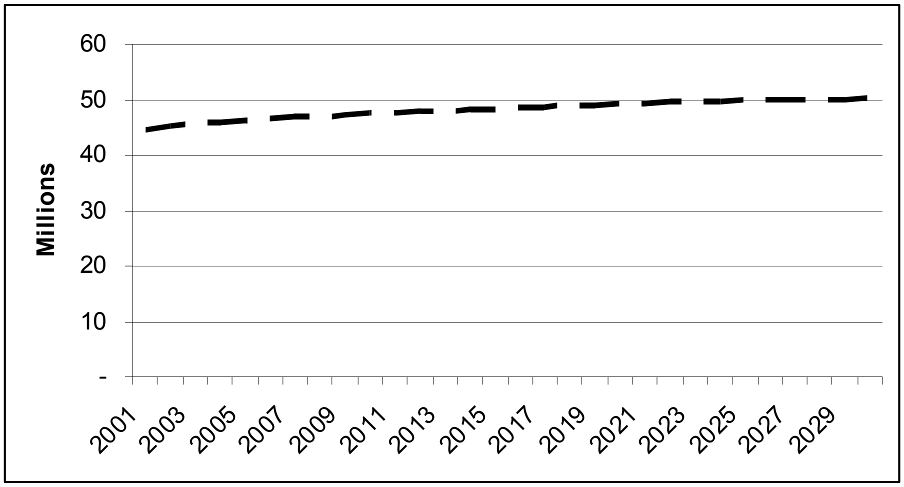
Most government projections therefore assume a smooth growth rate into the future. Annual GDP growth was assumed to be 2.8% per year in the first Integrated Energy Plan (DME 2003a), while the Integrated Resource Plan also considers forecasts of 1.5% and 4% (NER 2001/2). A sensitivity analysis around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

3.2.2 Population projections and impact of AIDS

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

Figure 19: Population projections by ASSA model

Data source: (ASSA 2002).



Other major institutions also project trends in population, some distinguishing between scenarios with more or less impact of AIDS. However, due to the HIV/AIDS in the country, population projection might be higher than actual. The Development Bank of Southern Africa (DBSA) uses population projection, differentiating on low and high impacts of HIV/AIDS (Calitz 2000a, 2000b).The first Integrated Energy Plan also included projections of population growth (ERI 2001), which are shown together with other estimates in Table 36. Not all studies covered all years.

Table 36: Population projections from various sources, millions

	DBSA low AIDS impact	*DBSA high AIDS impact*	*ASSA 2002 (base run)*	*IEP assumptions*	*UN world population projection*	*This study*
2001			45	44	43	44.8 [17]
			46			46.4
2011	56	49	48	50		47.6
2016	61	50	48		45	48.5
2025	70	49	50	57	44	49.7
2030			50			50.0

The ASSA projections seem reasonable, still indicating population growth over the period, but at lower rates, growing 12% over the 30 year study period, with annual growth rates between 0.1 and 1.0%.

An important difference relates to population projections in the reference case. The population projections used in the IEP were for 50 million (here: 47.4 million) and 57 million (49.1 million). While the IEP projections are reduced from previous estimates, they are still higher. Another source of differences relates to confidential data which was used for previous studies was not available for this study.

3.2.3 Technological change

Technology costs change over time. This is particularly true for new technologies, which benefit from learning-by-doing and economies of scale. The first proto-type is typically much more expensive than later models, which are produced in smarter, more cost-effective ways and often in larger production runs. Learning by experience reduces costs (Arrow 1962), and this

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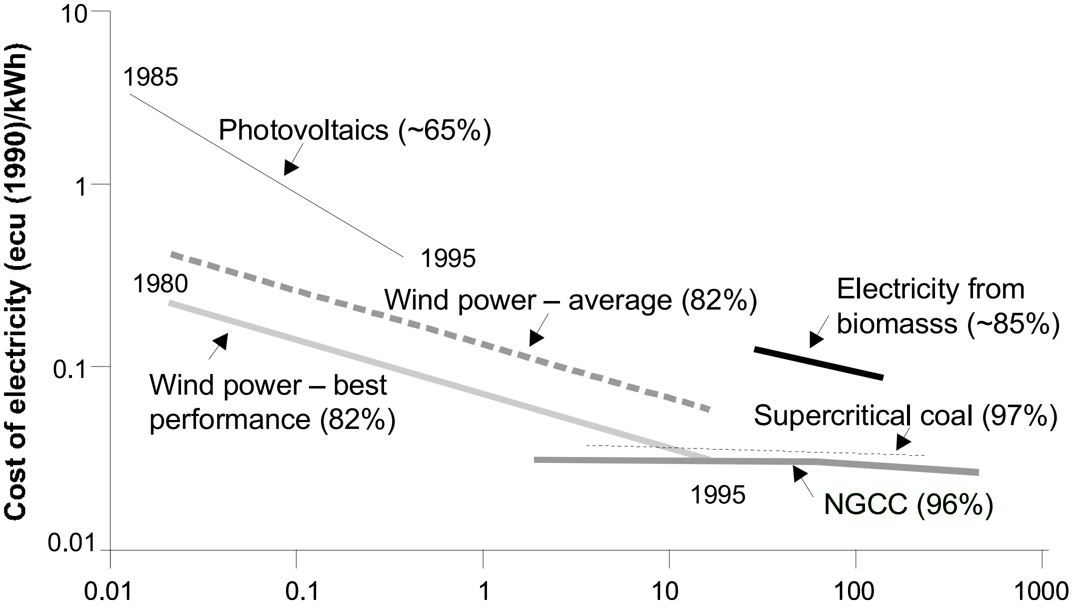
[17] The 2001 Census reported 44,819,778 people in South Africa (SSA 2003a)and we use this number instead of ASSA's projection.

general finding has been found true for energy technologies as well (IEA & OECD 2000).These can be assessed by learning ratios, measuring the reduction of cost per installed capacity for each doubling of cumulative capacity.

The IEA has published estimates of learning or ‘experience curves’, which show the decline in costs (c/kWh) as cumulative electricity production doubles. It is clear that newer technologies, be they renewable or otherwise, have higher progress ratios than mature technologies which have integrated most cost savings decades or centuries earlier. According to the IEA, photovoltaics declined by 35% in price for doublings between 1985 and 1996, wind by 18%, electricity from biomass by 15%; while supercritical coal declined by only 3% and NGCC by 4% (IEA & OECD 2000).

Figure 20: Learning curves for new and mature energy technologies

Source: (IEA & OECD 2000).



We assume that technology costs for new energy technologies change over the period. We only examine technology learning for supply-side technologies in scenarios. Such analysis should be conducted carefully, taking into account several factors:

- The cost reduction is a function of *global* cumulative production, especially where significant components are imported
- A more detailed approach should consider the local content, and component where the learning effect is likely less pronounced
- The applicability of international learning rates to SA remains to be examined.

3.2.4 Future fuel prices

Fuel prices for the study are taken from a variety of domestic and international sources, as shown Table 37. Generally preference is given to national statistics and sources for most fuels, except projections for internationally traded commodities such as oil.

Table 37: Fuel prices by fuel and for selected years

Price for fuel	*Units*	*2001*	*2013*	*2025*	*Source*
Crude oil price	Real crude oil price local production [R/GJ]	24.8	18.0	21.4	(IEA 2004)
	Real crude oil price imports [R/GJ]	27.6	20.0	23.8	“
Petrol price	IBLC [R/GJ].	50.3	51.4	60.9	(DME 2001)
Diesel price	IBLC [R/GJ].	44.9	45.9	54.4	“
Paraffin price	Bulk [R/GJ]	58.0	59.3	70.3	“
	Drum [R/GJ]	80.5	82.3	97.6	“
HFO price	Bulk [R/GJ]	35.7	36.4	43.2	“

LPG price	Bulk [R/GJ].	112.1	114.6	135.8	“
	Drum [R/GJ].	124.4	127.2	150.8	“
Coal price	Electricity generation [ZAR/GJ].	3.02	3.02	3.02	Prevost in (DME 2002b)
	Sasol [ZAR/GJ]	2.54	2.54	2.54	“
	Domestic/commercial [ZAR/GJ]	3.45	3.45	3.45	“
	Industry [ZAR/GJ]	3.18	3.18	3.18	“
Biomass price	Wood [c/l]	30.0	30.0	30.0	See note below in 3.2.4.1
	Bagasse [R/GJ]	0.0	0.0	0.0	
Natural gas price	LNG [R/GJ]	21.5	21.5	21.5	(NER 2004a)
	PetroSA [R/GJ]	20.0	20.0	20.0	(DME 2003a)
	Sasol pipeline [R/GJ]	22.1	22.1	22.1	(Sasol 2004a)
Electricity price	Import [R/GJ]	5.5	Endogenous	Endogenous	(NER 2001)
	Export [R/GJ]	16.3	“	“	“
Electricity price including distribution costs	Agriculture [R/GJ]	41.4	“	“	(NER 2001)
	Commercial [R/GJ]	41.0	“	“	“
	General [R/GJ]	57.4	“	“	“
	Manufacturing [R/GJ]	10.5	“	“	“
	Mining [R/GJ]	9.8	“	“	“
	Residential [R/GJ]	44.6	“	“	“
	Transport [R/GJ]	21.8	“	“	“
Uranium price	Import [R/GJ].	3.2	3.2	3.2	(NER 2004a)

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

3.2.4.1 Note on biomass costs

Biomass / fuelwood prices are in most cases low or even negative. For paper and sugar mills, biomass is a waste product. In the residential sector, most households report zero purchase costs (not couting time budgets and opportunity cost). In the Eastern Cape, low household energy expenditure was attributed to “because their fuel needs are met almost exclusively by collected – not bought – fuelwood” (ERC 2004b).Similar findings were made in Limpopo, another province with a predominantly rural poor population; some 95% of households do not pay for fuelwood (Mapako et al. 2004).This is true for urban areas such as Khayelitsha as well: “In the survey, the reported expenditures on fuelwood/biomass were zero” (Cowan & Mohlakoana 2005). However, in some of the dense rural settlements, biomass becomes a scarce resource and is bought. The only national average estimate available of the cost of biomass is R28.24 / GJ (De Villiers & Matibe 2000).

To derive a value more transparently, we use an estimate of 50c per kg of wood (Cowan 2005), while acknowledging that the cost of biomass varies widely and should be treated in a locally specific way. R0.50 / kg wood, with 1 ton of wood yielding 15 GJ, gives R33.33 / GJ. This figure is of the same order of magnitude as the national average used by De Villers & Matibe (2000), and we use this as an approximation for commercially used biomass. We apply this value for urban households, but a much lower value (one-tenth) for rural households, i.e. R3 / GJ.

3.2.5 Discounting costs

The general discount rate used in the study is 10%.

However, we assume that poor households have a higher discount rate than high-income households but for poor households, we assume their time-preference for money is 30%. In other words, poor households strongly prefer money now to money later. The implication is that they will be less likely than other sectors to invest in technologies that will lead to energy savings in the future, even though it would reduce monthly energy bills.

Costs are reported in 2000 Rands; where there is a need to adjust cost data from other years, a deflator based on Gross Value Added is used.

Table 38: Cost deflators based on Gross Value Added

Source: (SARB 2005; SSA 2004)

1994	62.5
1995	69.0
1996	74.8
1997	80.8
1998	86.4
1999	92.1
2000	100.0
2001	107.7
2002	118.6
2003	123.5
2004	128.8

3.2.6 Emission factors

Emission factors are needed to convert energy consumption (in energy units, e.g. PJ or GJ) to emissions. The IPCC default emission factors (in tC / TJ, or t CO_2 / TJ) are used for emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), oxides of nitrogen (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulphur dioxide (SO_2) (IPCC 1996: Tables 1-2, 1-7, 1-8, 1-9, 1-10, 1-11 and 1-12 respectively). Following IPCC methodology, local emission factors or adjustments to defaults based on local conditions are made.

For CO_2 from other bituminous coal, 26.25 tC / TJ instead of the IPCC default of 25.8 tC / TJ. The adjustment is based on direct measurements at South African coal-fired power station (Lloyd & Trikam 2004). The higher emissions are consistent with the lower calorific value of SA sub-bituminous coal at 19.59MJ/kg, whereas the IPCC default value is 25.09 MJ/kg coal. Further measurements at more stations in future may lead to a submission of a SA-specific emission factor to the IPCC. The above list already includes important local air pollutants (SO2, NOx, NMVOC), but not particulate matter.

4. Results of scenario modeling

4.1 Reference case

The reference case presents a path of SA’s energy development that can also be called ‘current development trends’ or a base case. The reference case for this analysis is similar to that of government plans, the first Integrated Energy Plan (IEP) (DME 2003a).and for electricity, the second National Integrated Resource Plan (NIRP) (NER 2004a). The time-frame for the base and policy cases is from 2001, the base year, until 2025. The modeling approach was to extend the model run to 2030 to avoid sudden changes in the end year. Costs are reported in 2000 Rands. The energy balance for the reference case is shown for 2001 in Table 39, with a projected future energy balance in the appendix (see the second part of Table 39).

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Table 39: Energy balance for the base case, start and end year

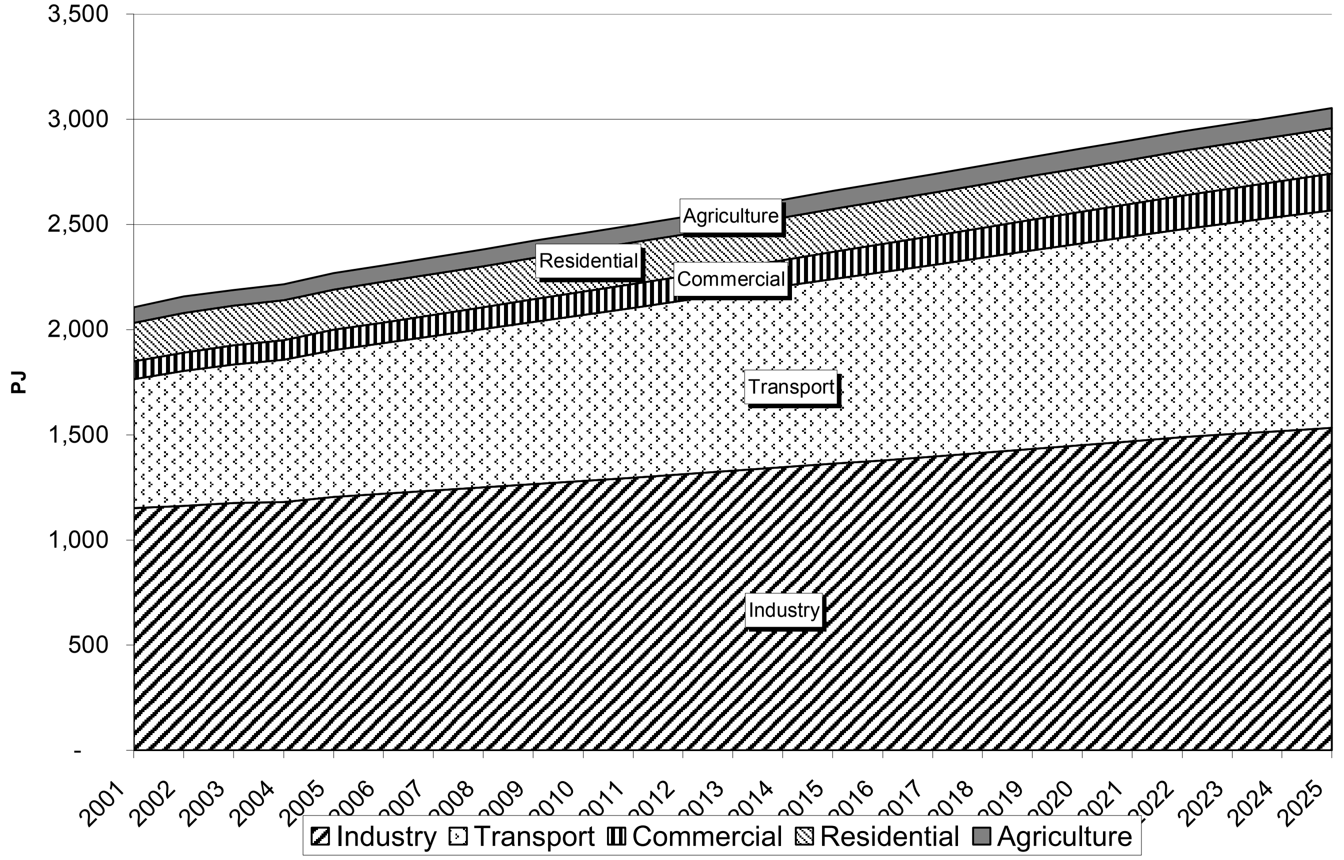
2001															
PJ	*Coal*	*Discard*	*Crude oil*	*AvGas*	*Diesel*	*LPG*	*Petrol*	*Jetfuel*	*Paraffin*	*HFO*	*Gas*	*Biomass*	*Renewables*	*Nuclear*	*Electricity*
Production	4900	692	56	0	0	0	0	0	0	0	98	76	7	0	0
Import	0	0	763	0	0	1	0	0	0	0	0	0	0	138	33
Export	-1716	0	0	-7	-117	0	-60	0	-3	-90	0	0	0	0	-24
Stock changes	0	692	0	0	0	0	0	0	0	0	0	0	0	0	0
TPES	3184	0	819	-7	-117	1	-60	0	-3	-90	98	76	7	138	9
Transformation															
Electricity generation	-1734	0	0	0	0	0	0	0	0	0	0	-3	-7	-138	694
Oil refining	0	0	-1119	8	376	16	413	76	28	108	0	0	0	0	0
Coal liquefecation	-859	0	300	0	0	0	0	0	0	0	0	0	0	0	0
Transmission losses	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-60
Total transfomation	-2592	0	-819	8	376	16	413	76	28	108	0	-3	-7	-138	633
Final energy demand	592	0	0	1	259	17	353	76	24	18	42	101	0	0	633
Statistical differences	0	0	0	0	0	0	0	0	0	0	56	-27	0	0	9

Agriculture	2	0	0	0	43	0	3	0	2	2	0	0	0	0	22
Commerce	20	0	0	0	0	13	0	0	0	0	1	0	0	0	64
Industry	562	0	0	0	32	0	1	0	1	17	41	72	0	0	414
Residential	8	0	0	0	0	4	0	0	21	0	0	29	0	0	121
Transport	0	0	0	1	185	0	349	76	0	0	0	0	0	0	13

2025														
PJ	*Coal*	*Discard*	*Crude oil*	*AvGas*	*Diesel*	*LPG*	*Petrol*	*Jetfuel*	*Paraffin*	*HFO*	*Gas*	*Biomass*	*Renewables*	*Nuclear*
Production	8563	1393	56	0	0	0	0	0	0	0	0	96	7	0
Import	0	0	1283	0	0	19	0	22	0	0	0	0	0	138
Export	-3408	0	0	-11	-59	0	-38	0	-1	-175	0	0	0	0
Stock changes	0	1232	0	0	0	0	0	0	0	0	0	0	0	0
TPES	5155	161	1339	-11	-59	19	-38	22	-1	-175	0	96	7	138
Transformation														
Electricity generation	-3063	-161	0	0	0	0	0	0	0	0	-57	-3	-7	-138
Oil refining	0	0	-1639	12	539	15	536	114	34	193	0	0	0	0
Coal liquefecation	-859	0	300	0	0	0	0	0	0	0	0	0	0	0
Transmission losses	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total transfomation	-3921	-161	-1339	12	539	15	536	114	34	193	-57	-3	-7	-138
Final energy demand	1234	0	0	1	480	33	498	137	33	19	92	141	0	0
Statistical dofferemces	0	0	0	0	0	0	0	0	0	0	-149	-48	0	0
Agriculture	2	0	0	0	47	0	4	0	3	2	0	0	0	0
Commerce	45	0	0	0	0	29	0	0	0	0	3	0	0	0
Industry	1187	0	0	0	43	0	1	0	1	17	89	131	0	0
Residential	1	0	0	0	0	4	0	0	29	0	0	10	0	0
Transport	0	0	0	1	389	0	494	137	0	0	0	0	0	0

Final energy demand is shown in Figure 21, with fuel consumption for industry, transport, commercial, residential, non-energy and agricultural sectors included. Fuel consumption in industry and transport clearly dominates, with other sectors contributing smaller shares. As can be seen from the wedged shape of the transport fuel consumption, demand in this sector is growing most over the period. The data underlying this figure are reported in Table 65.

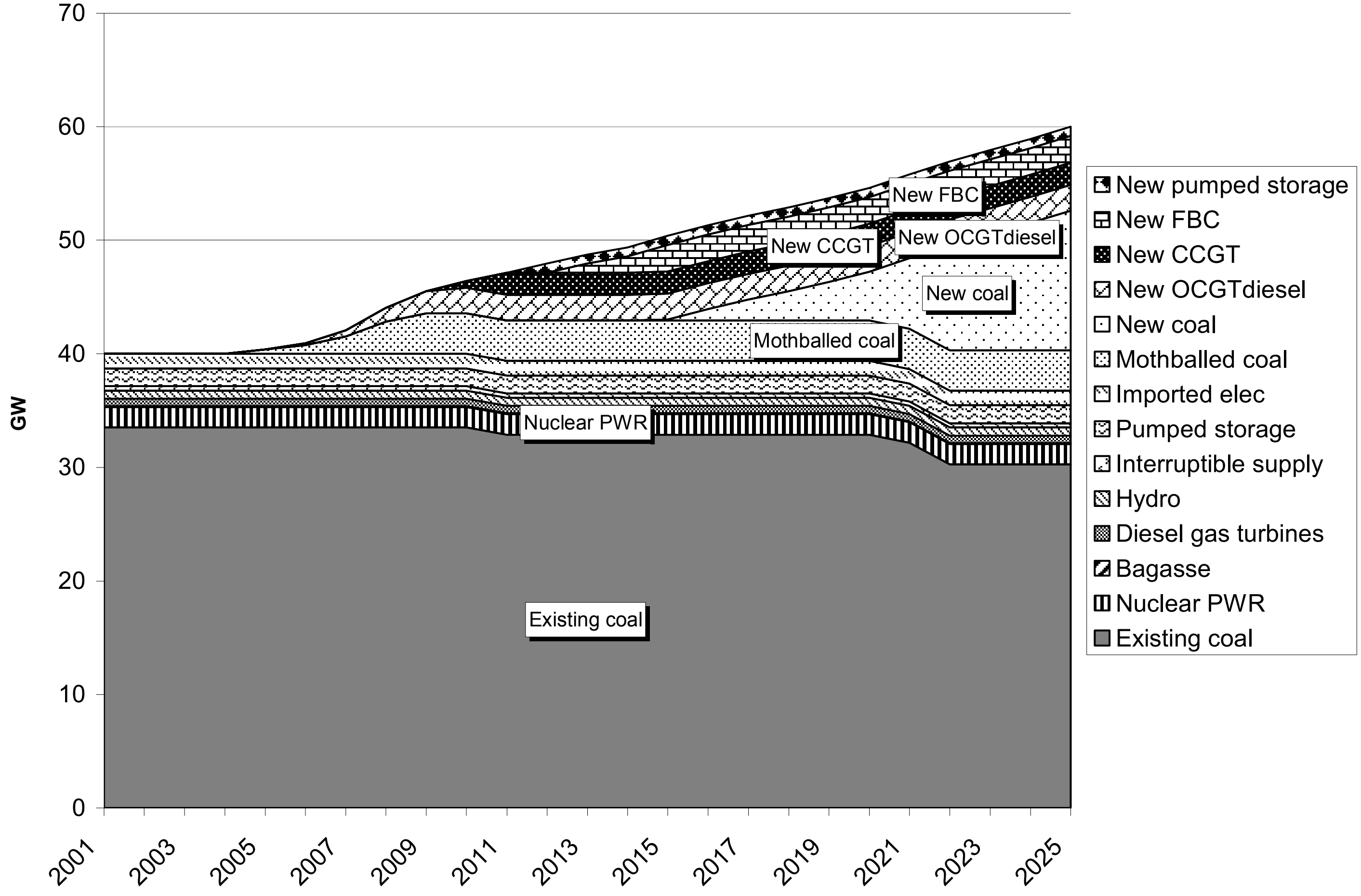
Figure 21: Fuel consumption by major energy demand sector



The expansion of electricity generation capacity is shown in Figure 22, grouped by plant type. The underlying projections are reflected in Table 64 in the appendices. The reference case is broadly consistent with the integrated resource plan, since the reference case for the NIRP was conducted in collobaration Eskom, the NER with the ERC's modeling group (NER 2004b). Small differences between the reference case presented here and the NIRP relate to the treatment of the reserve margin and the exact timing of new investment. Table 23 summarised the key characteristics of the technologies for electricity generation. Demand in our reference case is after demand-side management, and we include interruptible supply.

Existing coal continues to supply most of the capacity in the reference case, mothballed coal stations are brought back into service, and new pulverised fuel stations are built. The major sources of new capacity in the reference case are gas (open cycle and combined cycle) and new fluidised bed combustion, using discard coal. Smaller contributions come from existing hydro and bagasse, electricity imports, existing and new pumped storage and interruptible supply.

Figure 22:Electricity generation capacity by plant type



The reference case shows that existing stations continue to provide a substantial part of capacity up to 2025. Investment in new capacity is directed in re-commissioning ('de-mothballing') three coal-fired power stations, building new pulverised coal stations, open cycle gas turbines (diesel-fueled) as well as combined cycle gas, and some new pumped storage. The total capital investment in each year is shown in Table 40.

Table 40: Capital investment in electricity generation capacity (R millions)

	Mothballed coal	*New coal*	*New OCGT diesel*	*New CCGT*	*New FBC*	*New pumped storage*
2001	-	-	-	-	-	-
2002	-	-	-	-	-	-
2003	-	-	-	-	-	-
2004	-	-	-	-	-	-
2005	308	-	-	-	-	-
2006	308	-	548	-	-	-
2007	784	-	1,162	-	-	-
2008	2,088	-	2,308	-	-	-
2009	2,000	-	2,308	-	-	-
2010	-	-	946	2,669	-	-
2011	-	-	-	6,267	-	-
2012	-	-	-	-	-	4,178
2013	-	-	-	-	7,479	-
2014	-	-	-	-	5,763	-
2015	-	868	-	-	8,910	-
2016	-	9,254	-	-	-	-
2017	-	8,315	-	-	-	-
2018	-	7,293	-	-	-	-
2019	-	8,201	-	-	-	-
2020	-	9,026	-	-	-	-

2021	-	19,502	-	-	-	-
2022	-	30,705	-	-	-	-
2023	-	10,001	-	-	-	-
2024	-	10,110	-	-	-	-
2025	-	10,931	-	-	-	-

Figure 23 shows the capacity of refineries in SA, as well as the imports of finished petroleum products. Most of the capacity is provided by existing refineries, including the Secunda and PetroSA refineries. There is some expansion of refineries (‘new crude oil refineries’). Imports of finished products account for s small part of overall capacity.

Figure 23: Refinery capacity in the base case

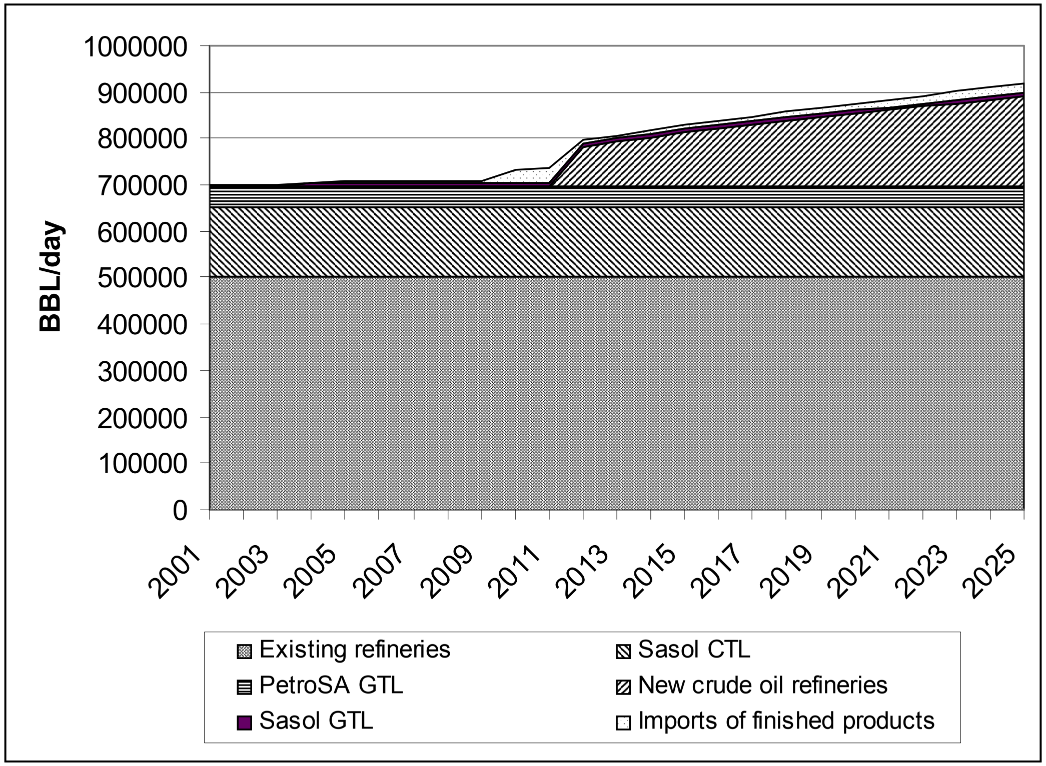


Figure 24 shows the total CO_2 emissions for the reference case, while Figure 25 shows local air pollutants, specifically SO2, NO_x and non-methane volatile organic compounds (NMVOCs). Emissions of both local and global air pollutants increase steadily in the reference case, over the period. Carbon dioxide emissions increase from 337 Mt CO_2 in 2001[18] to 591 Mt CO_2 in 2025 – an increase of 75% over the entire period.

Figure 24: Carbon dioxide emissions in the reference case (MtCO2)

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[18] The base year number is fairly close to the CO_2 emissions reported in the Climate Analysis Indicator Tool (WRI 2005).for 2000 – 344.6 Mt CO_2. It is somewhat higher than the 309 Mt CO_2 from fuel combustion reported in the Key World Energy Statistics for 2001 (IEA 2003a).

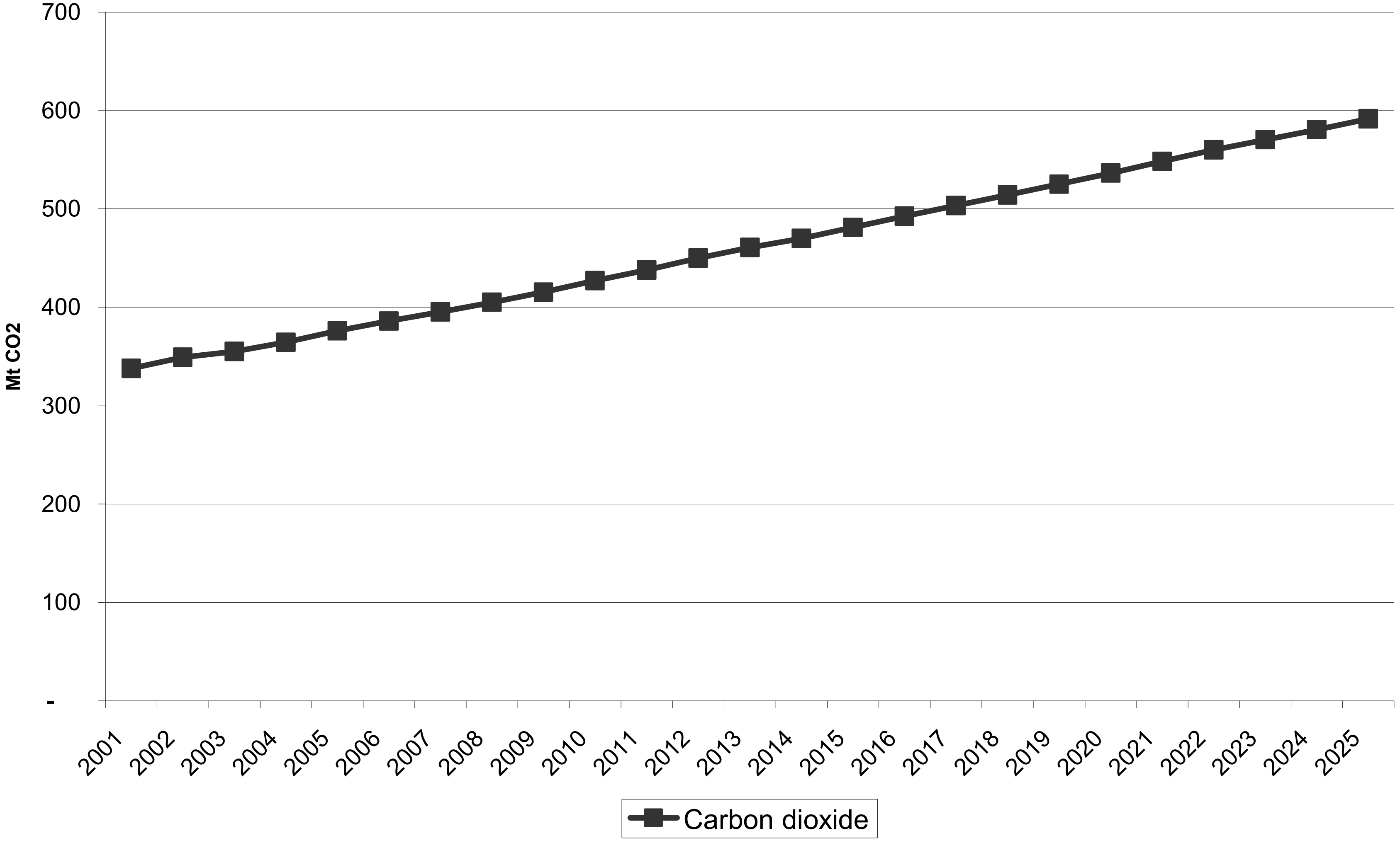

700
600
500
400
300
200
100
-
Mt CO2
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
Carbon dioxide

Figure 25: Local air pollutants in the reference case

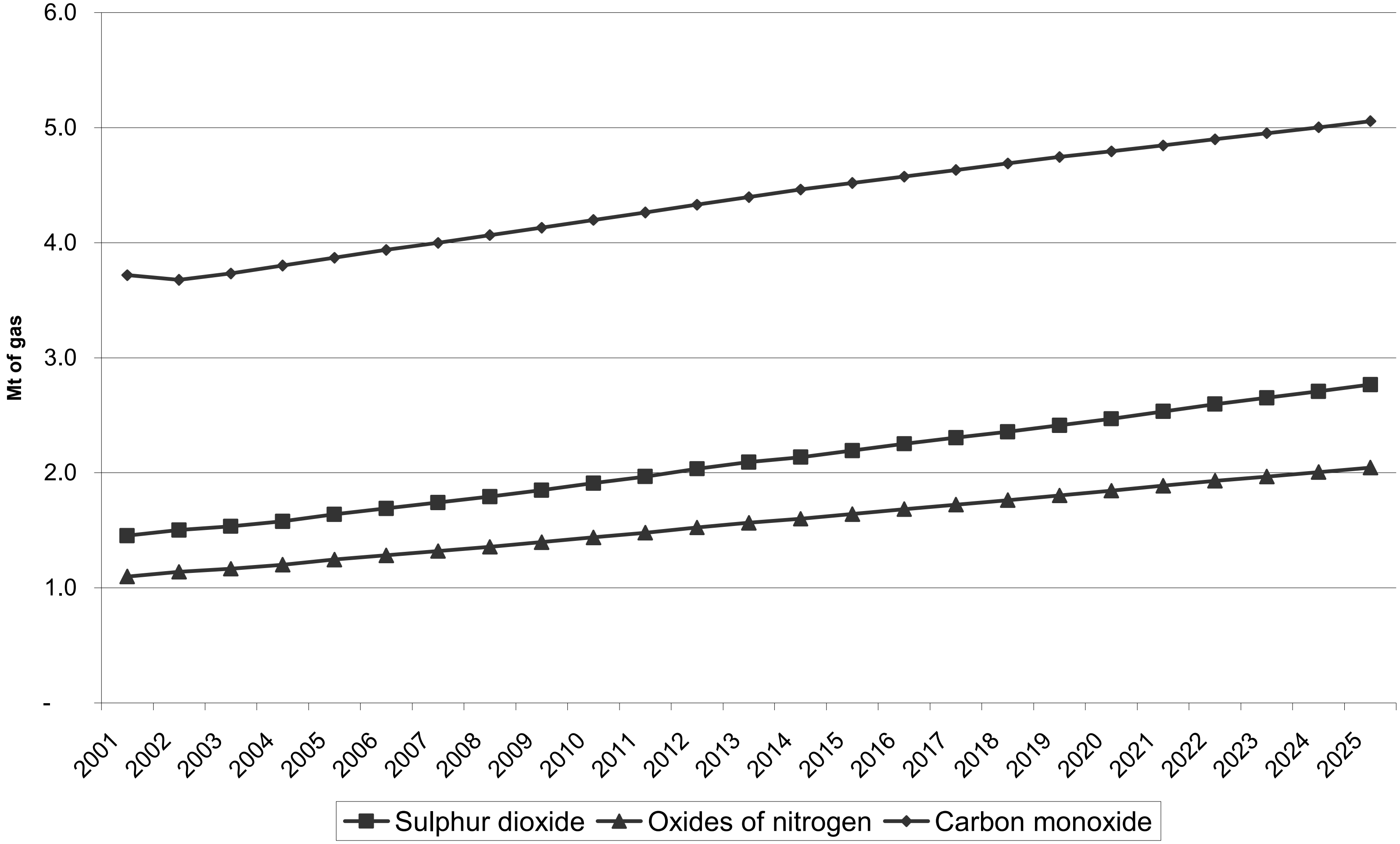


Figure 26: Reference energy system

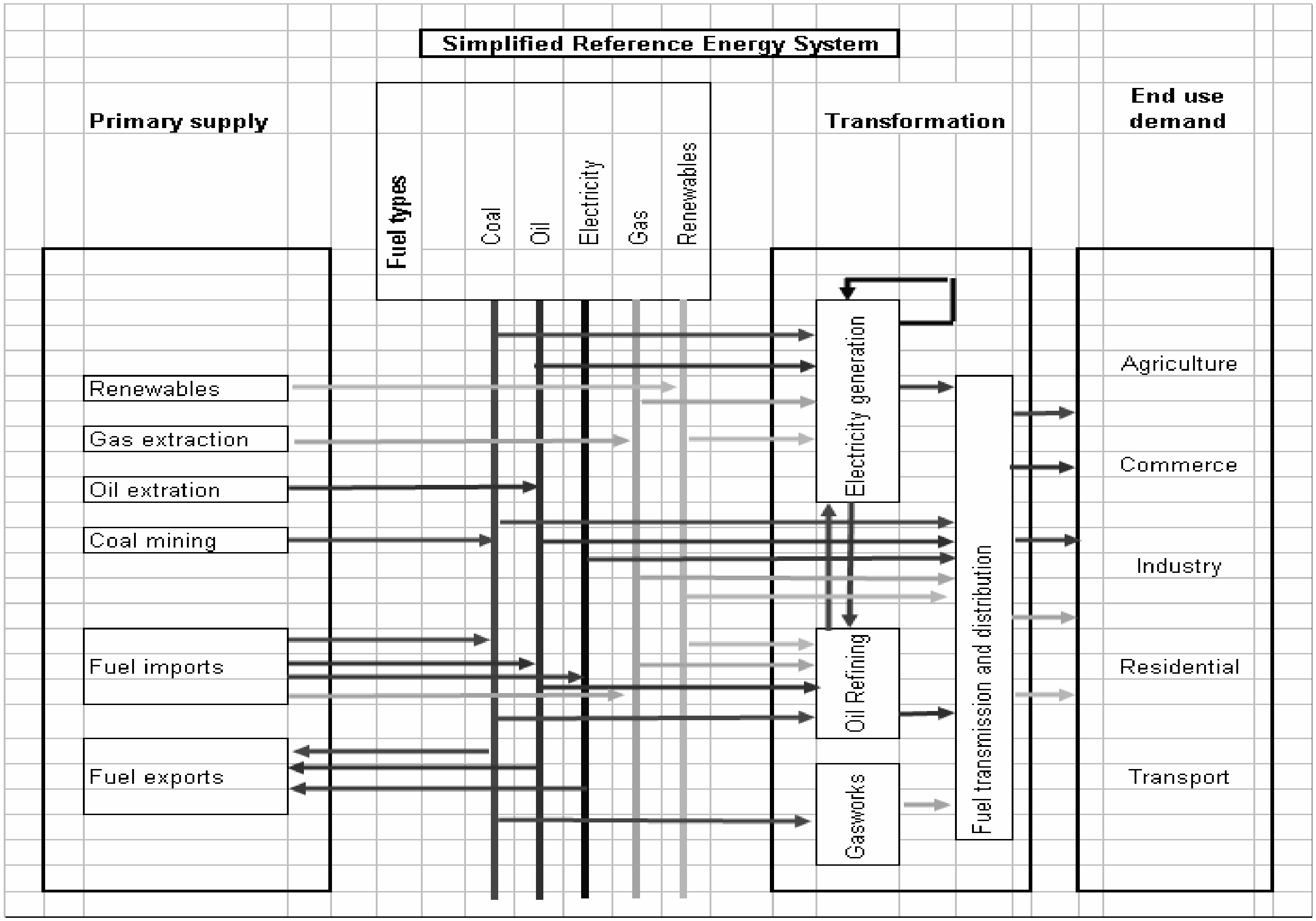


Figure 27: Detailed view of RES for pulp & paper and residential demand sectors

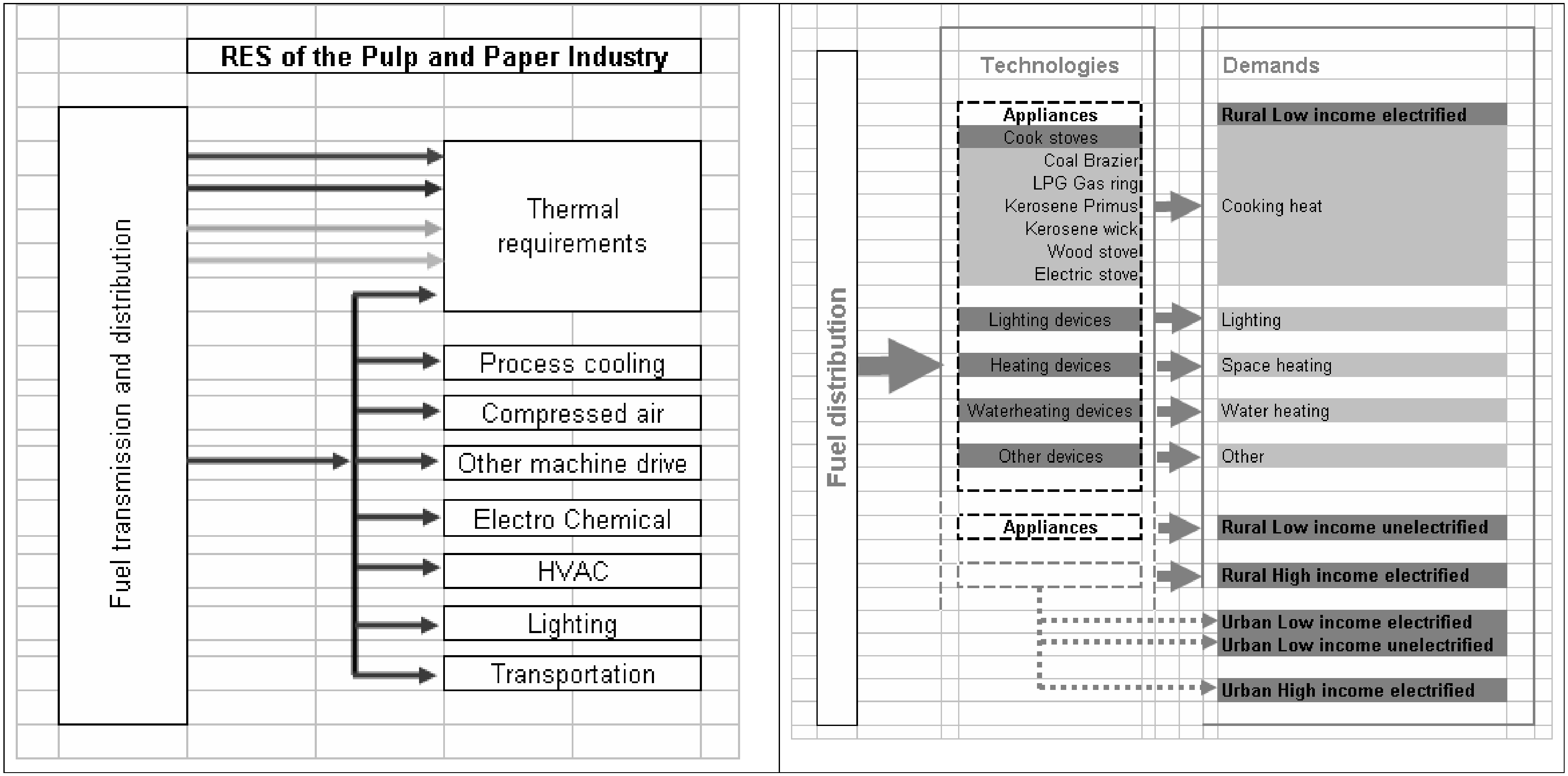


Figure 26 shows a high-level overview of the reference energy system (RES) and the flows from primary energy supply through transformation to energy demand in different sector. The actual database is significantly more disaggregated. To give some impression of further detail, Figure 27 shows a simplified RES for a pulp & paper mill and part of the residential sector.

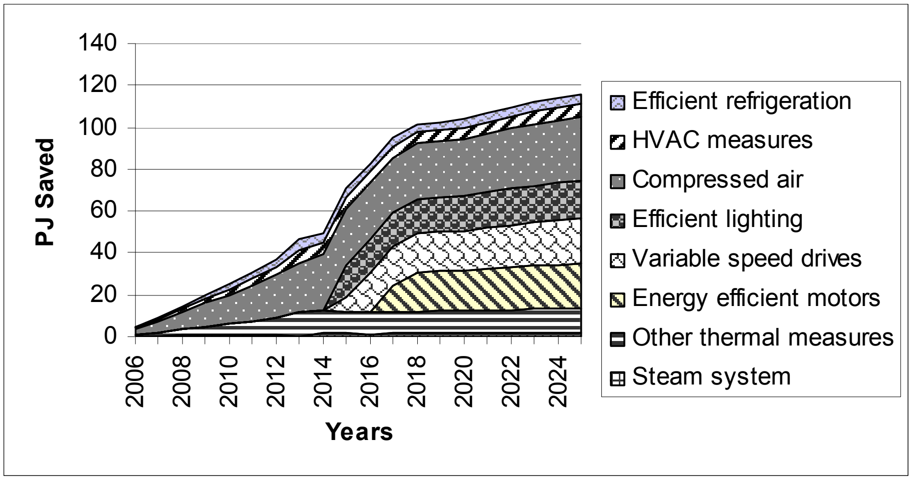
Having outlined the structure of the model and the reference case, we turn next to examining alternative possible futures. None of the policy cases are predictions of the future, nor is any one more likely than another. The rationale for each policy case is described below. Note that policy cases do not have the same level of effort, e.g. electricity supply options are designed according to available resources and technologies, not to all add the same capacity or generate the same amount of electricity. The cases seek to understand the implications – economically, socially and environmentally – of strong promotion of particular options.

4.2 Industrial energy efficiency

The industrial energy efficiency scenario is effective both in lowering the cost of the energy system and reducing emissions from coal fired power stations as well as emissions from industrial facilities. Emissions from power stations are reduced as a result of decreased electricity consumption. In this scenario, the cost of the energy system, relative to the base case is reduced by 18 billion Rand. Over the entire period, carbon dioxide emissions are reduced by 770 Mt CO_2.

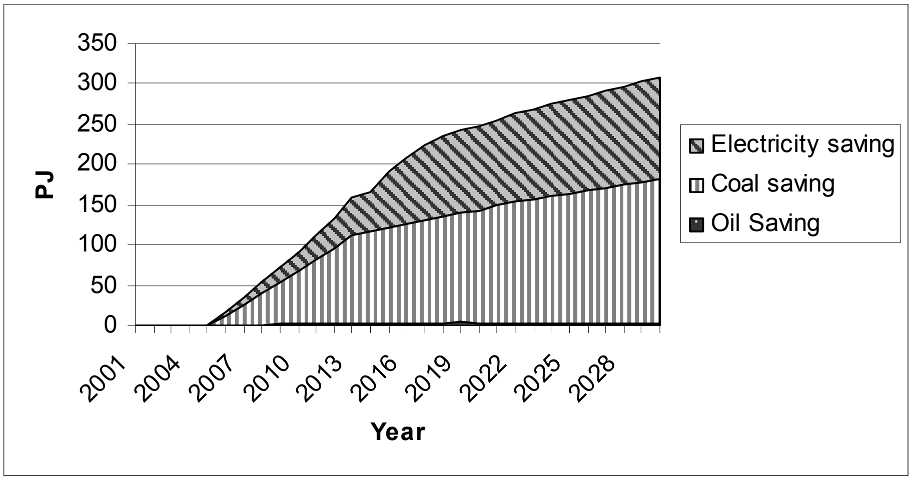
The scenario was modeled by expanding the potential penetration of a range of energy efficiency technologies up to a limit which allowed a target of 12% savings by 2014 over the base case to be achieved. The measures are described earlier and they are not included in the base case. Interestingly, different energy efficiency technology options are taken up by the industrial sector as the marginal cost of generating electricity increases. Thus energy efficiency technologies that are economic midway through our scenario period (when new base-load power stations are required) are not economic at the beginning of the period (characterized by low electricity costs). The trend is summarized in Figure 28 below.

Figure 28: Electrical Energy Saved by Energy Efficiency Technology



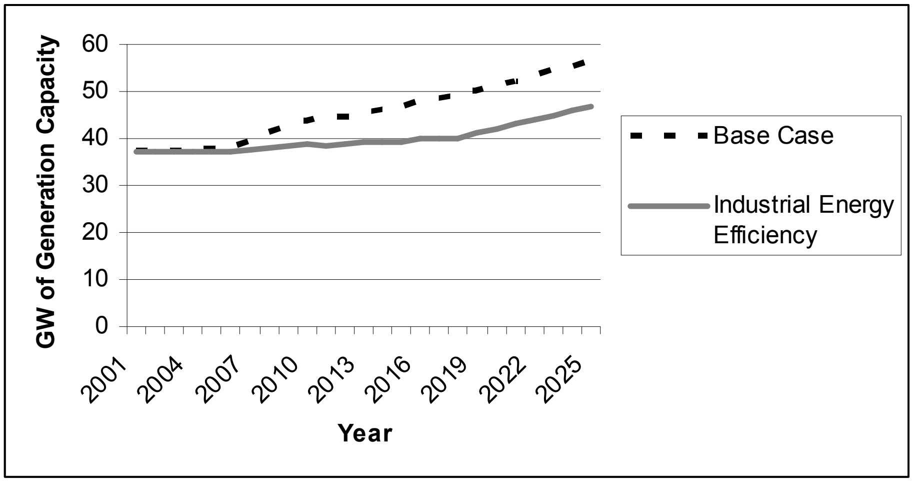
Most of the energy saved is coal and electricity, these both being the most important fuels for industry as shown in Figure 29. The savings were limited to 12%, and potentially more saving is possible in an economic or cost-effective manner.

Figure 29: Energy Saved by Carrier in the Industrial Sector



If the target could be achieved through aggressive policy, the result has important implications for power generation. It would postpone the need for new base load power stations by 4 years, and peaking power plant by 3 years. Given potential lead-time constrains with building new power plant (including Environmental Impact Assessments etc.) and possible short term peak supply shortages, energy efficiency could play an important role to manage electricity supply needs. The overall changes in generation requirement are significant and shown in Figure 30 below.

Figure 30: Changes in capacity requirements



It should be noted however, that although economically efficient, the uptake of energy efficiency to these levels will not be achieved without significant policy intervention. Electricity in South Africa is not priced at its marginal cost of production. Rather it is charged at its average cost of production. This is significantly less than the marginal cost of production when new power plants need to be constructed. Therefore in reality someone saving a unit of energy would not be rewarded to the same level as someone producing a unit of electricity[19]. Were electricity price to equal the marginal cost of production, the uptake of energy efficient practice would be encouraged. As consumers are not rewarded for saving energy, in the same way as producers are rewarded for producing electricity, appropriate "economic signals" should be used to encourage the uptake of energy efficiency options. Simply pricing electricity at its

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[19] If producers were to build a new power station, they would be guaranteed a return n his investment, they would be paid their (long run) marginal cost of production and the ***average*** tariff would be increased to accommodate this. If consumers were to save a unit of energy, they would only be rewarded in terms of a reduced bill based on this average tariff

marginal cost of production is an efficient policy instrument, but it may result in unwarranted effects. Much of South Africa's industry (upon which the economy rests) relies on low cost electricity and therefore it may not be desirable to increase electricity prices.

A further conclusion to be drawn from the model results is that ideally there should be a significant uptake of energy efficiency options during the medium term. This could allow time for appropriate policy implementation. However, depending on the vociferousness of the measures chosen, energy efficient practices may penetrate the market at a less than optimal level. Further modelling should attempt to accurately the penetration rates appropriate with the policy action taken. Such modelling might also investigate a different industrial policy which emphasises higher energy-efficiency (and lower energy- and emissions-intensity) as a competitive advantage (compared to the present focus on low electricity prices).

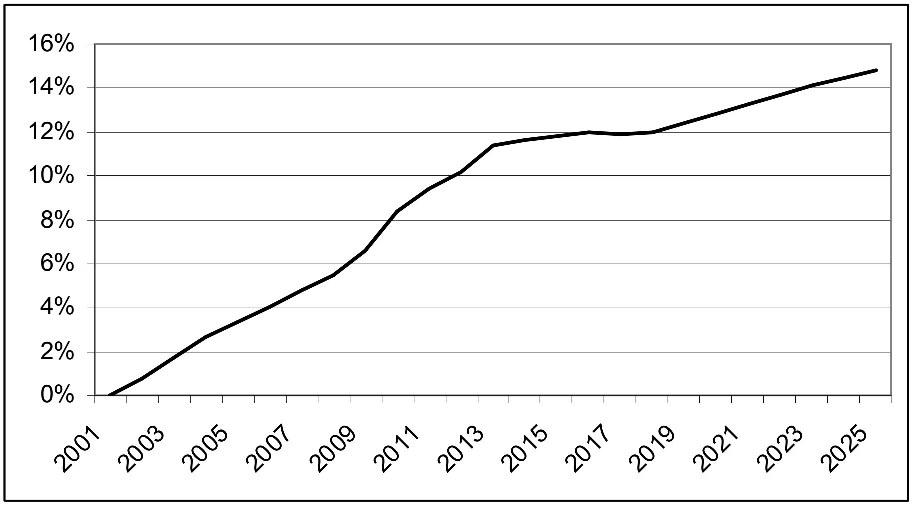
Finally, even though saving energy is "under-encouraged" by average, rather than marginal pricing, there are energy efficiency measures which have a low payback period. These should be encouraged and are reported earlier, including improved compressed air management and thermal measures including boiler optimisation and steam saving.

4.3 Commercial efficiency and fuel switching

The measures described in section 2.2 are combined in this scenario. A target of a 12% reduction in final energy demand by 2014 for the sector was imposed in accordance with the DME's energy efficiency targets (DME 2005a). The modeling results indicate that the target is achievable and would also lead to a substantial saving of approximately 13 billion rand over the entire time horizon. It is important to note that the costs are based on engineering estimates of the various measures and that other costs such as information campaigns, costs related to the formulation, implementation and enforcement of building codes, costs of lost business hours due to HVAC or similar retrofits and other down times and inconveniences are not included in the analysis. Actual costs are thus most certainly higher than what is reported here, but not high enough to obviate the additional gains. International experience suggests that such costs might be in the order of 5% (in the order of 5% of the investment costs (Spalding-Fecher et al. 2003)).

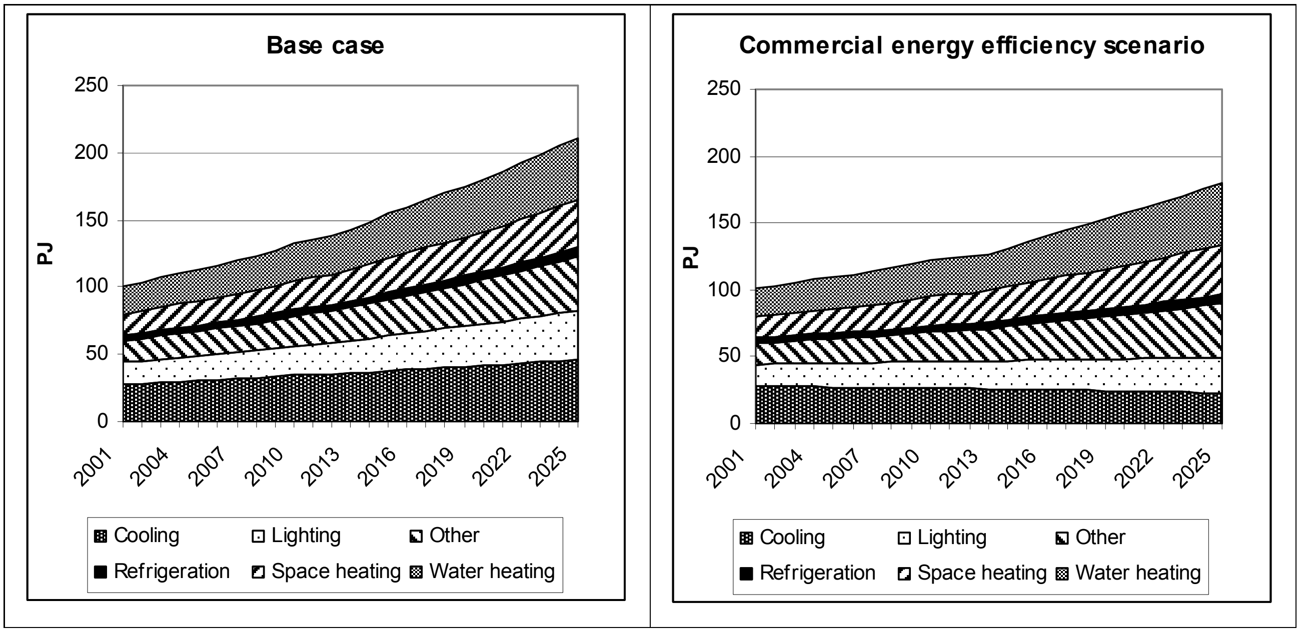
The reduction in energy use compared to the base case is given in Figure 31. Improvements rates are highest in the period leading up to the target year in 2014. After that progress predictably slows down in absence of more stringent targets. The rate of improvement picks up again towards the end of the time horizon. This can be explained by the fact that the cost optimal energy efficiency improvements are 2-3% lower than the 12% target. To reach the target one thus has to invest in more energy efficiency equipment and measures than what is economically efficient.

Figure 31: Reduction in final energy demand for the commercial sector



The main savings accrue due to improvements in HVAC systems and the thermal design of buildings. Implementation of building codes and retrofits occur at the maximum rate allowed by the deterministically specified rates. Cooling demand is effectively halved by 2025 compared to the base case. Efficient lighting practices and more efficient lamps also account for some of the savings and relative savings are approximately 30% for this end use. As in the case of HVAC systems efficient design of lighting systems are implemented at a rapid rate. We also see a switch to more efficient fluorescent and high intensity discharge lamps. The change in final energy use by end-use is given in Figure 32.

Figure 32: Commercial energy demand by end-use

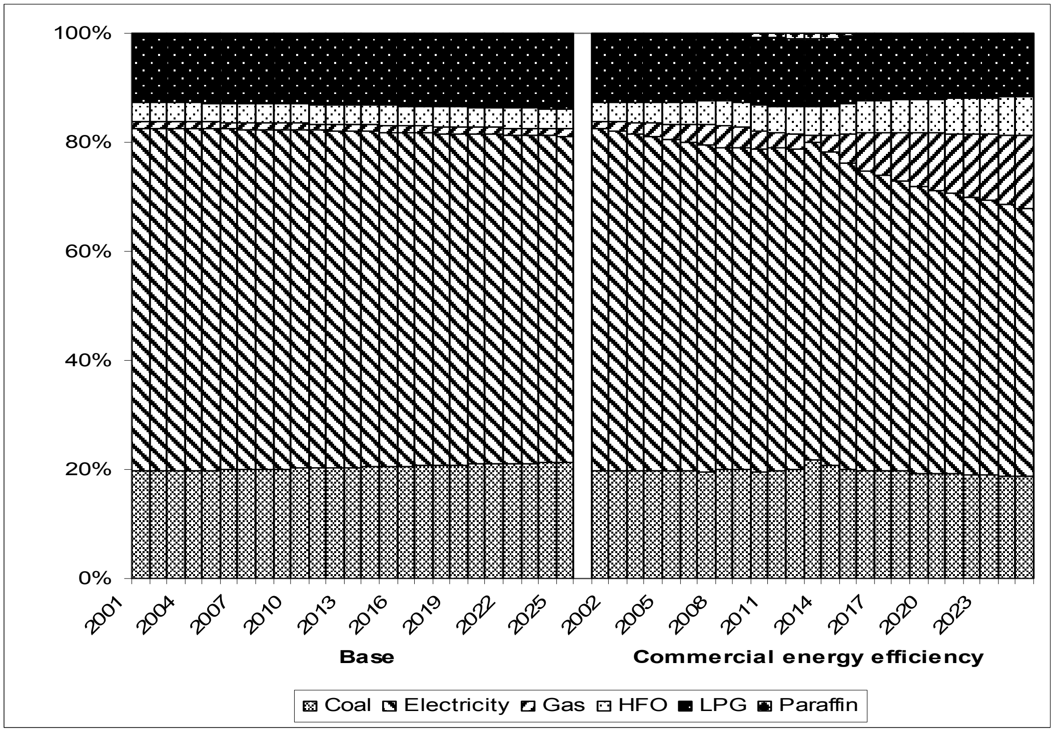


Base case

Commercial energy efficiency scenario

There is also significant fuel switching to natural gas for heating purposes. Fuel shares for final energy demand in the commercial sector are given in Figure 33. The relative reduction in electricity demand is largely due to efficiency improvements in the use of electric demand devices rather than fuel switching away from electricity. We also see a significant switch to natural gas, mainly at the expense of liquid fuels used for heating.

Figure 33: Fuel shares for the commercial sector



4.4 Cleaner and more efficient residential energy

The residential policy case implements the policies described in section 2.3 – solar water heaters and geyser blankets (SWH / GB), LPG for cooking, efficient housing shell, and compact fluorescent lights (CFLs) for lighting. The bounds on these technologies are freed up to the levels shown in Table 41, allowing the model to choose the most cost-effective options in a wider range.

Table 41: Upper and lower bounds for CFLs, SWH / GB and LPG in the policy case

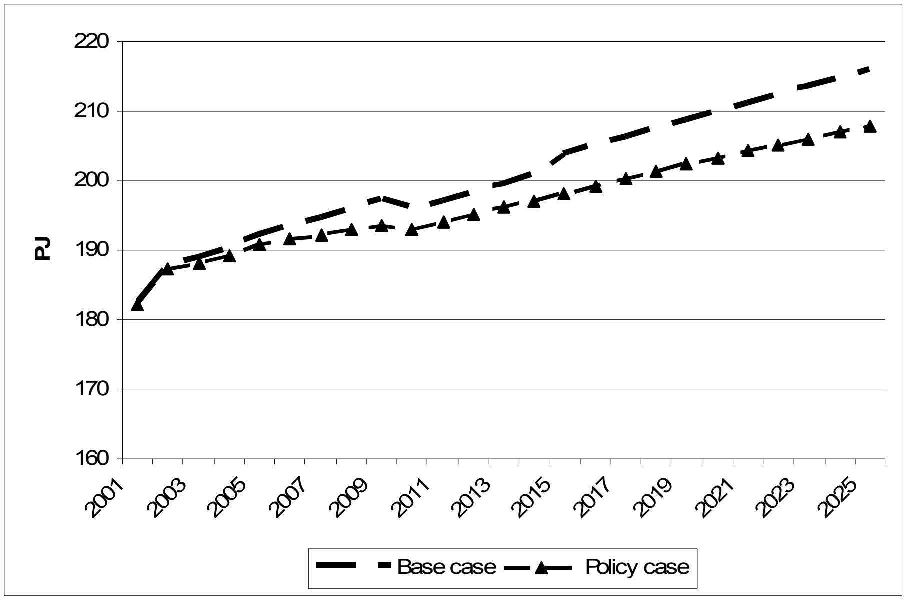
		UHE	ULE	ULN	RHE	RLE	RLN
CFLs	Up	50%	40%		50%	40%	
	Lo	10%	10%		10%	10%	
SWH	Up	50%	30%		30%	20%	
	Lo	20%	20%		20%	20%	
Geyser	Up	20%	30%	20%	30%		
Blanket	Lo	10%	10%	10%	10%		
LPG	Up	50%	60%	40%	50%	40.0%	30%
	Lo	20%	20%	21%	33%	20.0%	6%

Note: Estimate of bounds are based on the following sources: for water heating by SWH are based on (De Villiers & Matibe 2000; DME 2003b, 2004b); for cooking and space heating on (Cowan & Mohlakoana 2005; Davis & Ward 1995; Howells et al. 2005); and for lighting by CFLs on data from the Efficient Lighting Initiative (Bredenkamp 2005; ELI 2005).

For efficient housing, a bound is placed on the number of houses that would be efficient, no more than half of all houses by the end of the period, but allowed to increase from the current 0.5%. The costs of SWH are assumed to decrease, based on the data reviewed in section 2.3.5, from R 6 500 in the base year to R 5 000 by 2010. These cost assumptions are converted to R / GJ in Markal and interpolated linearly.

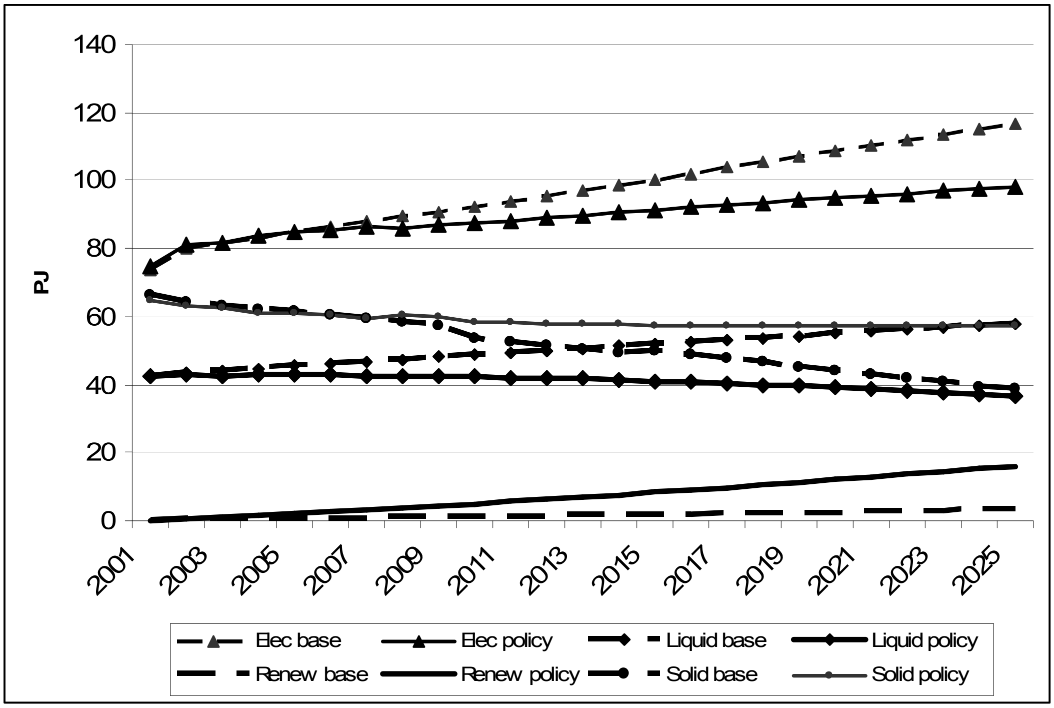
The results of the policy case show a reduction in total fuel consumption. Figure 34 shows the lower fuel consumption compared to the base case, due to efficiency improvements requiring less energy to deliver the same service. Note that the y-axis of Figure 21 is not at zero. The difference by 2025 amounts to 8.13 PJ.

Figure 34: Total residential fuel consumption, comparing policy and base cases



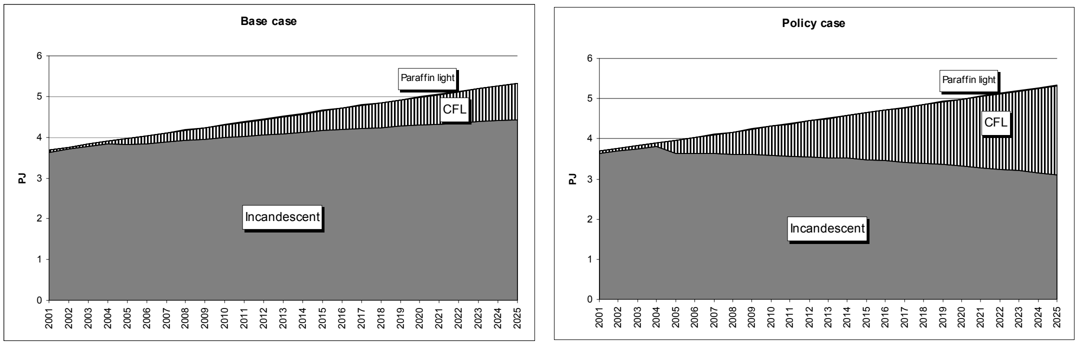
The reduction in Figure 34 is due to efficiency, but also some increase in the use of solar energy for water heating. The increase can be seen in the lowest to lines of Figure 35, indicating more solar energy used in the policy case. Electricity as well as solid and liquid fuels, by contrast, are all lower in the policy than the base case.

Figure 35: Changes in use of electricity, solid fuel, liquid fuel and renewable energy



Some of the shifts caused by the policies for cleaner and more efficient residential energy use are shown in the following figures. Figure 36 shows that CFLs increase their share for richer rural electrified households significantly beyond the base case. CFLs displace mainly incandescents (with paraffin lighting a very small share). CFLs are also taken up by other electrified household types (not shown here).

Figure 36: Shifts in lighting for RHE households from policy to base case



Energy savings through more efficient design of houses are only taken up by urban higher-income electrified households. However, the energy savings for this grouping are substantially higher than in the base case, as illustrated in Figure 37.

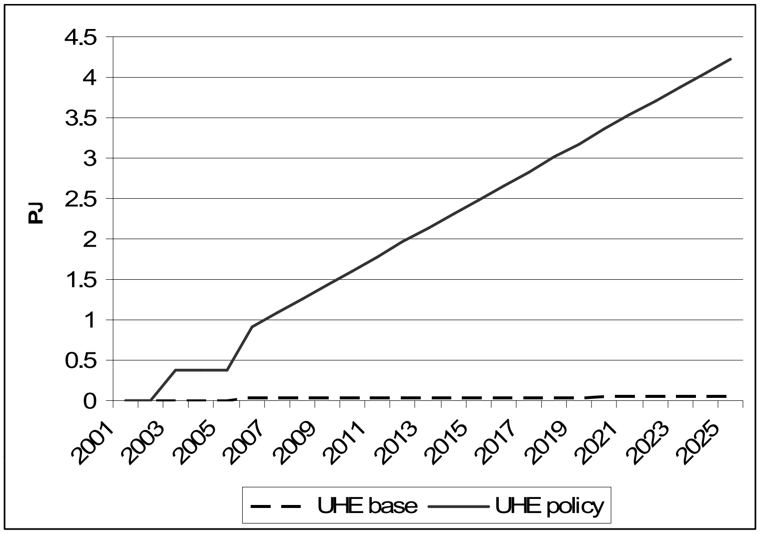
Two policy interventions in water heating, solar water heaters and geyser blankets, offer an interesting comparison. Table 42 shows a much lower total investment for geyser blankets, but also less energy saved in aggregate across all household types.

Table 42: Cost of saved energy for water heating

	Saved energy	*Total investment*	*Cost of saved energy*	
	PJ	*R million*	*R / GJ*	*c / kWh*
Geyser blanket	2.9	5.57	1.9	0.7
Solar water heater	13.0	317	24.5	8.8

However, the energy savings are large in relative terms, and the cost per unit of energy saved is significantly lower for geyser blankets. The lower cost – both upfront and per unit of energy saved – suggests that geyser blankets are appropriate policy interventions in poor electrified households.

Figure 37: Energy savings through efficient houses for UHE households



While energy efficiency makes sense from a societal perspective for low-cost housing, poor households cannot afford the upfront costs of better thermal design or more efficient lighting and water heating (Winkler et al. 2002). .To simulate the impact of a subsidy that would make efficient houses more affordable, the higher discount rate of poorer households was reduced from 30% (no subsidy) to 10% ('subsidised'), the general discount rate for the model. The change was made only for efficient building shells for poorer households.

Household energy consumption patterns in the residential policy case are shown in Table 43. A mid-year between 2001 and 2025 is chosen, and the consumption by household type and end use represented. The table shows not only that poorer households (in both rural and urban areas) use very little electricity for 'other' end uses – probably this represents a small share of households using some other appliances, and a large share using none at all for uses like refrigeration or washing machines. Among non-electrified households, average lighting consumption is low, suggesting that there is little or no access to other commercial fuels (such as kerosene or LPG) for this end use. A limitation in the analysis is that households do not appear in the model directly, only through their energy demand or as units.

Table 43: Household fuel consumption by end use in 2013

*MJ / (HH * mth)*	*Cooking*	*Lighting*	*Other electrical*	*Space heating*	*Water heating*
RHE	126	261	246	118	201
RLE	45	100	6	40	51
RLN	162	2	-	178	102
UHE	324	156	273	334	475
ULE	95	136	8	160	289
ULN	117	1	-	113	53

Which fuels deliver these energy services? As expected, the *share* of electricity used declines in the residential policy case, compared to the base case, as electricity is used more efficiently. A less obvious results in Table 44 is that the shares of LPG and paraffin – two other commercial fuels – increase. Coal remains constant.

Table 44: Shares of commercial fuels of total residential energy fuel use

		2001	*2013*	*2025*
Coal	Base	4%	1%	0%
	Res pol	4%	1%	0%
Electricity	Base	66%	73%	75%
	Res pol	66%	70%	68%
LPG	Base	2%	2%	2%
	Res pol	2%	5%	8%
Paraffin	Base	11%	14%	17%
	Res pol	10%	14%	18%

Further research would be useful on translating this analysis into an energy burden per household household (energy expenditure as a share of total household income). However, this requires further assumptions about average incomes for poorer and richer households, and goes beyond the scope of this report.

Table 45: Shadow price of residential electricity in the base and policy case

c/ kWh	*2001*	*2013*	*2025*
Base	21.4	23.0	38.4
Residential policy	21.4	57.0	31.1

What can be reported are the shadow prices of electricity used in the residential sector, as shown in Table 45. Shadow prices do not represent tariffs, but the difference between the technologies used in this policy case and the least-cost alternative. This information could be used in further work on the energy burden.

The level of subsidy required to make efficiency economic to poorer households can be approximated in a separate Markal scenario. The level of the subsidy can be approximated by comparing the marginal investment with the higher and lower discount rates – with and without the 'subsidy'.

Table 46: Subsidy required for making efficient housing as affordable for poorer as for richer households

Unit: Rand / household	*2001*	*2014*	*2025*
RLE	-138	-195	-166
RLN	-726	-761	-871
ULE	-524	-738	-682
ULN	-112	-100	-117

Note: The values show the reduction in marginal investment as a result of lowering the discount rate for poor households from 30% to 10%. Negative values indicate payments required.

The reduction in investment needed is larger for the RLN and ULE. The order of magnitude of the subsidy required to make efficient housing as affordable for poorer households as for richer ones is in the hundreds of Rands, but less than a thousand Rand. A relatively small additional investment in housing for poor communities creates more comfort, reduces household energy costs, as well as cutting emissions from the residential sector. Energy efficiency in social housing is an area where a policy of direct state financial support to promote energy efficiency seems warranted. In practice, municipal government would need to play an important role in administering a subsidy scheme and providing bridging finance.

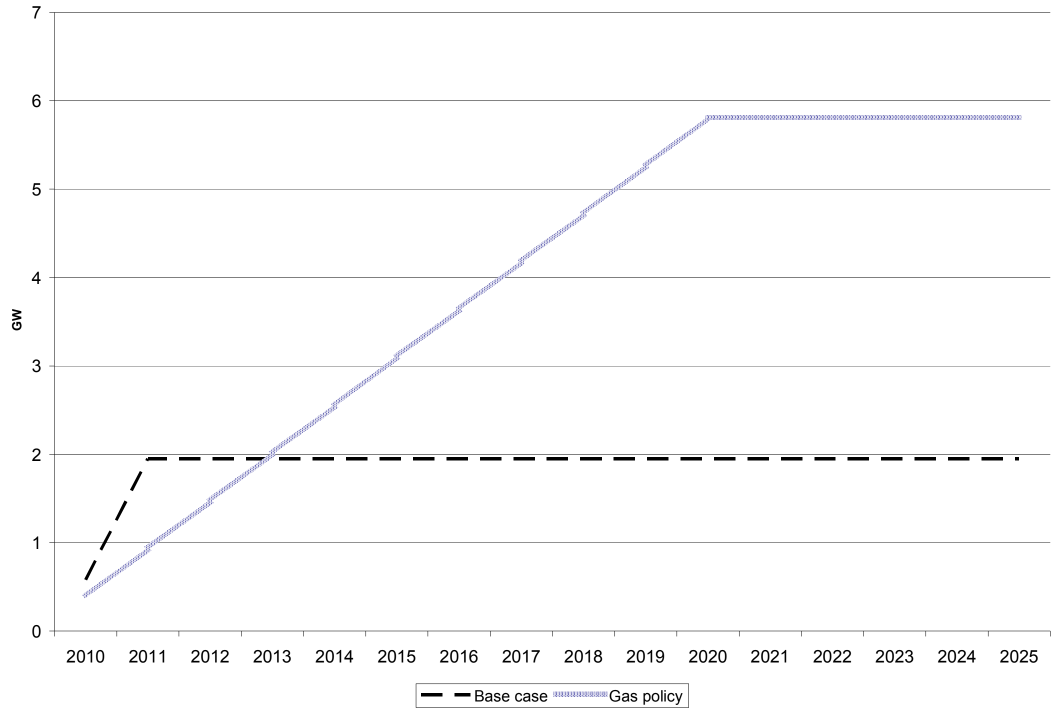
Throughout the policy scenarios, we assume that electrification rates will increase substantially, as outlined in section 2.3. From current 70% to near-universal access to electricity is also part of the residential energy policy scenario.

4.5 Electricity supply options

4.5.1 Imported gas

The imported gas policy case increases the overall system cost by R 0.98 billion over the 25 year time horizon, compared to the base case. The additional costs implies a much longer and more sustained investment in combined cycle gas turbines, as shown in Figure 38.

Figure 38: Capacity of CCGT in gas policy and base cases



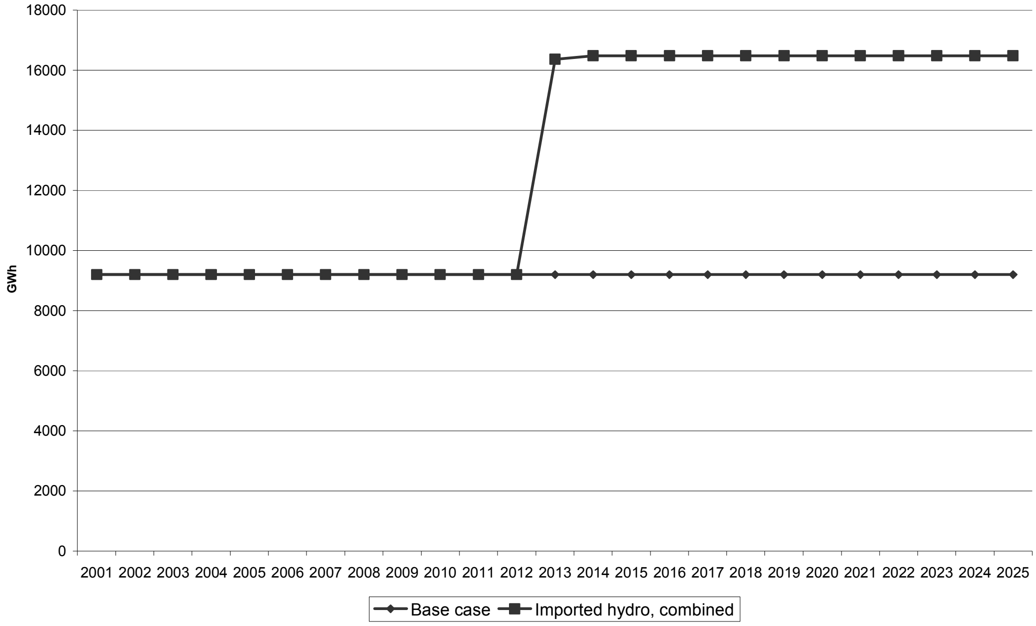
The base case reflects the level of investment in one CCGT in Alternative 1 to the reference plan in the National Integrated Resource Plan (NIRP); the preferred plan itself only had open-cycle gas turbines (NER 2004a). In both cases, investment starts from 2010, but levels off much earlier in the base case and increases up to 2020 in the policy case.

Despite the small changes, gas is a cleaner-burning fuel than coal, and some reductions in local and global air pollutants are observed. Over the 25-year period, 199 Mt of CO_2 emissions can be avoided. Relative to the base case, the reduction for sulphur dioxide, oxides of nitrogen and greenhouse gases are 2.1% lower for the policy case.

4.5.2 Imported hydro

The policy case of importing hydro-electricity increases the amount of hydro-electricity from the base year's 9.2 TWh to 17 TWh. The sharp rise shown in Figure 39 occurs as the combined price (between the fixed contract cost of existing imports and likely higher future costs) becomes competitive.

Figure 39: Imports of hydro-electricity



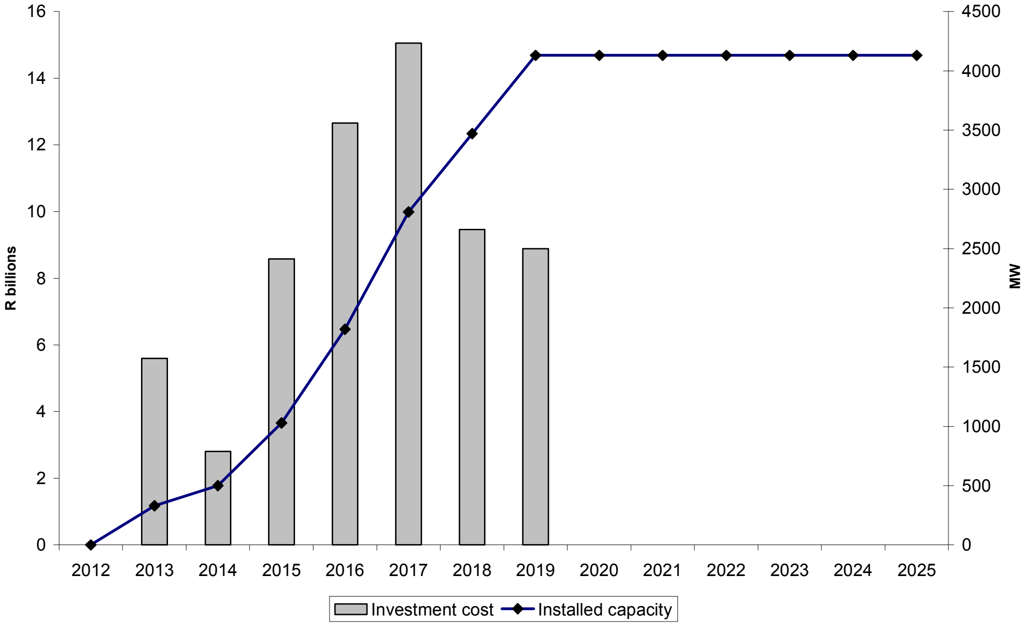
More money is spent on hydro-electric imports in the policy case, an undiscounted R 38 billion compared to R4.6 billion in the base case over the period. Analysis of the direct costs, however, only tells part of the story, with the reduction in investment in other supply side options being the other side. The discounted total system costs are *reduced* by R 3.6 billion over the period of 25 years. Some 167 Mt CO_2 can be avoided compared to business-as-usual, and there is a 1.9% decrease in sulphur dioxide emissions.

However, it should be noted that part of this is a reduction in methane emissions. The emissions of methane from large dams are subject to on-going research (IPCC 2001), and the assumption that hydro-electricity is zero-emissions may change as more information becomes available.

4.5.3 PBMR nuclear

Figure 40 shows the increase in local capacity, starting from 2012, prior to which there is no investment. A steady increase in the installed capacity up to the total of 4480 MW can be seen, as well as the investment requirements in billions of Rands.

Figure 40: Installed capacity and undiscounted investment costs in the PBMR policy case

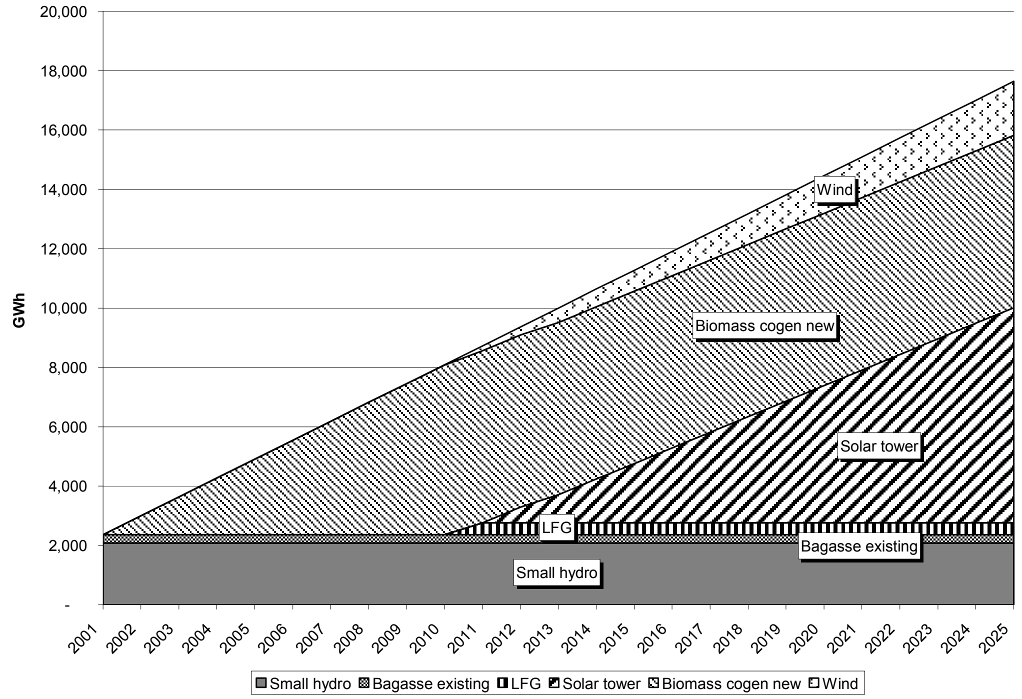


Substantial investments are required, adding up to R63 billion of undiscounted investments over the period. With these investments, 246 Mt CO_2 could be avoided compared to the coal-dominated reference case. However, the impact should also be considered in the overall energy system, with discounted total energy system costs increase by R 4.6 billion for the PBMR case compared to the base case. SO_2 emissions are 3% lower than in the base case.

4.5.4 Electricity supply: renewable energy

The renewable energy policy case was designed to meet the target of 10 000 GWh by 2013, with a portfolio of renewable energy technologies. Costs of renewables were assumed to decrease as global markets grow.

Figure 41: Renewable energy technologies for electricity generation in the policy case



Existing renewables, mostly small hydro and some bagasse, are complemented initially primarily by new biomass co-generation plants. From 2011, some LFG is introduced, as well as the solar ‘power tower’ or central receiver. The latter takes over a much larger share of renewables towards the end, as its costs become competitive.

Additional undiscounted investments in the various renewable energy technologies amount to R 29.3 billion, of which just over half (51%) are made in the solar ‘power tower’, a third in new bagasse co-generation and one-tenth in wind. The discounted total system cost for the renewables case over the period is R 4.5 billion higher than in the base case. Together, renewable energy technologies avoid 180 Mt CO_2 over twenty-five years. SO_2 emissions are 1.6% lower than in the base case.

4.6 Liquid fuel: bio-fuel refinery

DST (2003) estimates that there is potential to produce 1.4 billion litres of biodiesel, equivalent to approximately 45 PJ, annually from sunflower oil without prejudicing food production (Wilson et al. 2005). Biodiesel refineries do not exhibit significant economies of scale (Wilson et al. 2005) and production from smaller units is feasible. Amigun & von Blottnitz (2004) evaluate biodiesel refinery sizes through an optimization framework and conclude that the optimal plant size is 48,000 litres per day. Assuming that the plant operates 300 days of the year this is equivalent to 1.44 million litres per annum. A plant of this size would require 96 tonnes of sunflower seed feedstock per day.

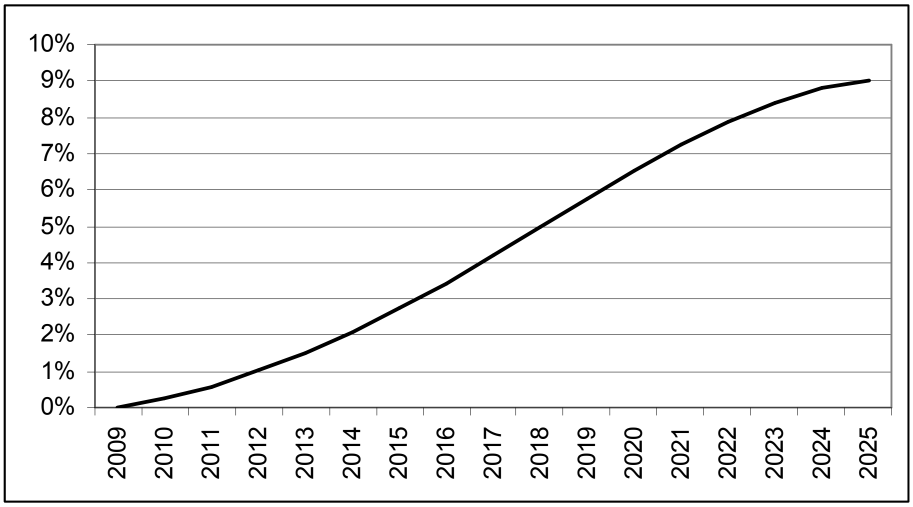
Based on Amigun & von Blottnitz (2004), we assume that a 48,000 litres per day plant would require an investment of 12 million Rands, have fuel cost of 35 Rands per GJ and operational costs of 50 Rands per GJ.

We assume that biodiesel production starts in 2010 and reaches 35 PJ by 2025 and that maximum year-on-year production growth is 30%. Diesel exports are fixed to the base case level to ensure that the biodiesel is used to replace diesel rather than boost exports.

The production cost of biodiesel translates to roughly 3 Rands per litre in 2010 compared to the inbound landed cost (IBLC) of approximately 1.70 Rands per litre for diesel. The price of biodiesel decreases somewhat over the period to 2.6 rands per litre in 2025 while the IBLC of diesel increases to 2.10 Rands per litre. In addition the tax on biodisel is 0.61 Rands per litre compared to 0.87 Rands per litre for normal diesel.

The resulting biodiesel share of total transport diesel demand is given in Figure 42. Relative growth in biodiesel production is highest in the early stages of introduction and slows down as cultivation moves in to increasingly marginal areas. Towards the end of the period biodiesel reach market share of 9% of transport diesel at an annual yield of 35 PJ.

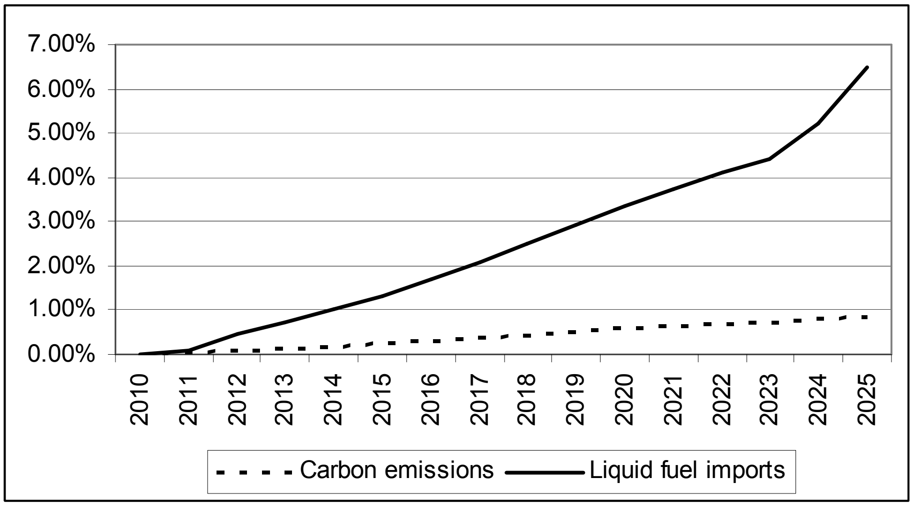
Figure 42: Share of biodiesel in marketed transport diesel



The harvesting of feedstock for biodiesel production is assumed to be on or below the sustainable yield (photosynthesis and respiration is in balance). Biodiesel is effectively a zero carbon energy source and its introduction will reduce the total carbon dioxide emissions. Total reduction in carbon dioxide emissions reaches 5 Mt CO_2 per annum in 2025 and cumulative savings are 31 Mt CO_2 for the entire period. There are also smaller reductions in local pollutants,

Biodiesel production also increases local production of transport fuels thereby reducing the need for imported petroleum products. The introduction of biodiesel also reduces the required crude oil refining capacity by an average of 4,500 barrels/day every year relative to the reference scenario. Figure 43 shows the relative reduction in total imports of liquid fuels and in carbon dioxide emissions.

Figure 43: Reduction in carbon emissions and liquid fuel imports



Present value of total system cost for this scenario is 2.4 billion Rands higher than for the reference scenario.

4.7 Fuel input tax

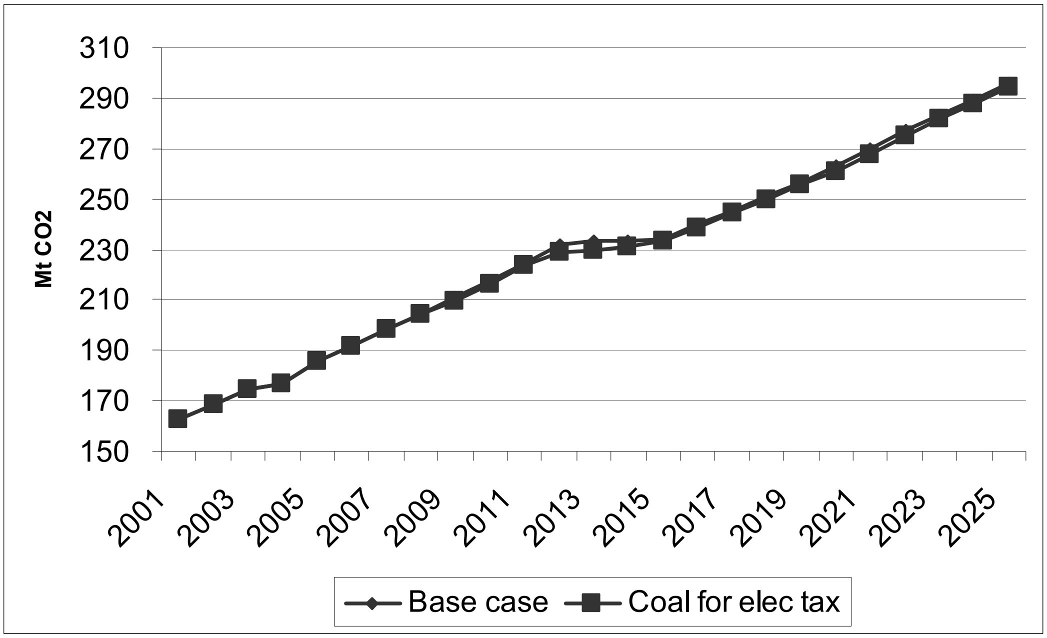
A fuel input tax is one of several environmentally-related tax instruments that might be considered for South Africa. Any such measures will have to be assessed against a framework for environmental fiscal reform {National Treasury, 2006 #2551}. The analysis here considers one possible option, others might be examined in future work (see section 2.8).

A tax on coal for electricity generation could be implemented at various levels. One point of comparison is the coal price, around R 60 / t coal in 2001 (see Table 37). A more positive perspective is that the costs of a tax could be off-set by electricity suppliers by selling emission reductions through the CDM. R 100 / GJ would represent a carbon price of € 6.46 / t CO_2 (at 20.1 GJ / t coal, 96.25 t CO_2 / TJ and an exchange rate of R 8 / € 1). Such a carbon price is substantially lower than the € 20-30 reported for the European emissions trading scheme in 2005. For certified emission reductions under the CDM, however, a lower price should be assumed. We assume a conservative estimate of R 25 / t CO_2 (roughly € 3 / t CO_2) starting in 2001. Expressed in terms of the fuel input, this is equivalent to R 50 / t coal , an increase of ca. 80% on the coal price. The tax can be thought of as a conservative estimate of the carbon revenues that could be earned by reducing emissions.

The tax is implemented in Markal by attaching an emissions tax of R 25 / t CO_2 applied to coal mined for electricity generation from 2005 onwards. This resource technology supplies all coal-fired power plants, but is separate from coal mining for SASOL and other uses (which have no tax attached).

The results show that the reductions of CO_2 emission from coal for electricity generation are small relative to the reference case. The emission projections in Figure 44 are hardly distinguishable, even though the abscissa has been set at 150 Mt CO_2 rather than zero.

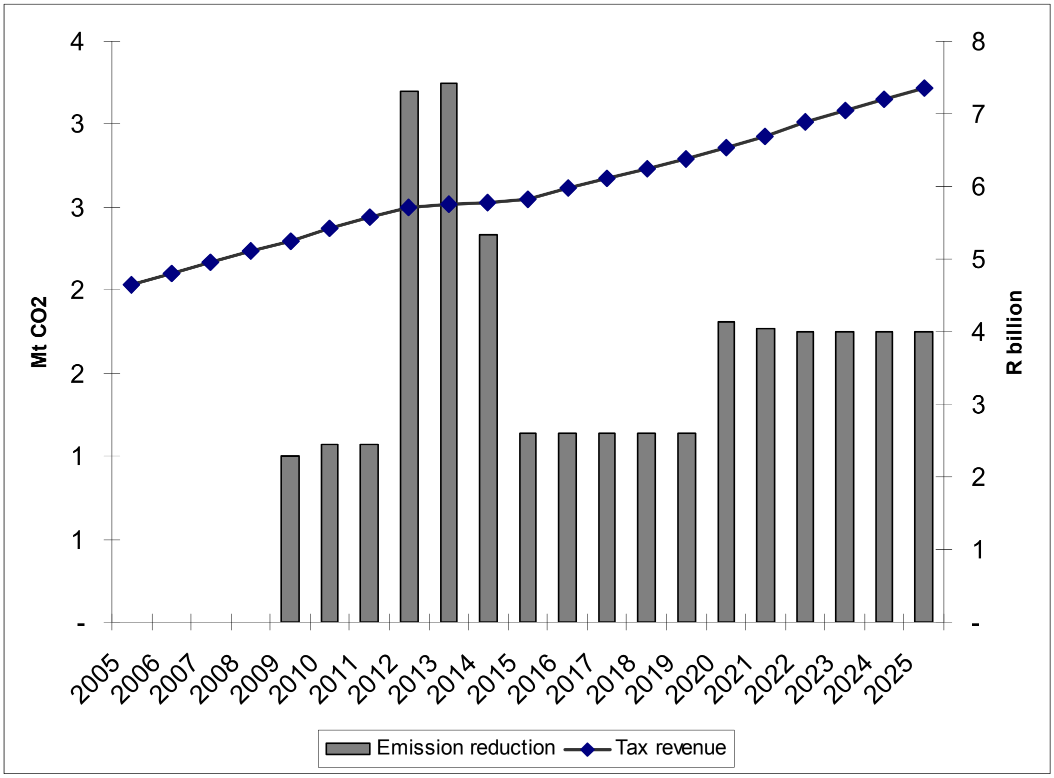
Figure 44: Emissions from coal-fired electricity in coal tax policy and reference cases



The fuel cost is a small component of the life-cycle cost of a new plant (see NER (2004a) for a comprehensive breakdown of costs). Taking into account all the investments in the energy system, the fuel costs are a small share of total energy system costs. Even a four-fifths increase in a cost component that only accounts for small percentage of total costs makes little difference to the technology chosen by a least-cost optimising model.

Nonetheless, the emission reductions (policy case minus reference) reach 3.25 Mt CO_2 in 2013-4 (see Figure 45, reductions shown here as positive numbers). Cumulatively, they add up to 28 Mt CO_2 over the period.

Figure 45: Emission reductions for coal tax compared to reference and undiscounted tax revenues



The line in Figure 45 shows that the revenues generated by the tax start even in early years, when there is little difference to the base case. Each ton of coal is taxed, regardless of whether it would have been used in the base case or not.

The difference in discounted total system costs over the period is R 67 million, while the discounted tax revenues generated add up to R 49 billion. The revenues are ambivalent – on the one hand, they add to the discounted total energy system costs (which usually reported net of taxes and subsidies), but they generated revenue which could be recycled in the economy and generate benefits. The increase in energy system costs will certainly impact on the affordability of energy for end-users, be they in industry or households, and therefore have implications for other government policies. Yet if revenues were used to shift the tax burden for those least able to cope with increased energy costs, the net social effect could be positive.

5. Energy indicators of sustainable development

The modeling results are assessed against a set of sustainable energy indicators. This list combines indicators from previous Sustainable Energy Watch reports (Spalding-Fecher 2001, 2002).and work done in reviewing IAEA indicators for sustainable energy development (Howells et al 2004). Indicators have been selected that can be quantified with the energy-economy-environment models. Other aspects may be discussed qualitatively, but detailed quantification would require efforts beyond the scope of the project. The indicators are grouped in the major dimensions of sustainable development.

Taken together, the energy indicators of sustainable development can be used as a tool to assess policy options and alternative energy futures. This method, we argue, provides the means for policymakers to identify synergies and trade-offs between options, and to evaluate them in economic, social and environmental dimensions. Using a modelling framework ensures that even while examining policy options in a particular part of the energy system, the dynamics of the whole system are taken into account in a consistent fashion. Using indicators of sustainable development helps make policy approaches more integrated across social, economic and environmental dimensions. The indicators presented here provide a reality check on some fairly aggressive policy options. Not only are the implications of 'what if' cases spelled out, but also the deeper policy analysis of the reasons why certain changes occur is encouraged.

An overview of the key results is provided as an Appendix (see Table 60). Results for each indicator are discussed in this section.

5.1 Environment

The fuel mix of the energy system is a key indicator affecting environmental impacts of energy supply and use. Table 47 shows how the mix of solid fuels, petroleum products, nuclear fuel and electricity change for three selected years in the policy case.

Table 47: Fuel mix for policies and selected years

	2005					*2015*					*2025*			
	Solids	*Petroleum*	*Renewables*	*Nuclear*	*Electricity*	*Solids*	*Petroleum*	*newables*	*Nuclear*	*Electricity*	*Solids*	Petroleum	Renewables	Nucle
Base case	78%	17%	1.9%	3.1%	0.2%	78%	18%	1.7%	2.5%	0.2%	78%	18%	1.5%	2.0%
Biodiesel	78%	17%	1.9%	3.1%	0.2%	78%	17%	2.3%	2.4%	0.2%	79%	17%	2.0%	2.0%
Commercial	78%	17%	1.9%	3.1%	0.2%	78%	18%	1.7%	2.5%	0.2%	78%	18%	1.6%	2.1%
Industrial EE	78%	17%	1.9%	3.1%	0.2%	77%	19%	1.8%	2.6%	0.2%	78%	19%	1.6%	2.2%
Gas	78%	17%	1.9%	3.1%	0.2%	77%	19%	1.7%	2.5%	0.2%	76%	20%	1.5%	2.1%
Hydro	78%	17%	1.9%	3.1%	0.2%	77%	18%	1.7%	2.5%	1.1%	78%	18%	1.5%	2.1%
PBMR nuclear	78%	17%	1.9%	3.1%	0.2%	77%	18%	1.7%	3.7%	0.2%	74%	18%	1.5%	6.2%
Renewables	76%	17%	3.3%	3.0%	0.2%	76%	17%	3.5%	2.4%	0.2%	77%	18%	3.1%	2.0%
Residential	78%	17%	1.9%	3.1%	0.2%	78%	18%	1.7%	2.5%	0.2%	78%	18%	1.5%	2.0%
Fuel tax	78%	17%	1.9%	3.1%	0.2%	78%	18%	1.7%	2.5%	0.2%	78%	18%	1.5%	2.0%

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

Greenhouse gas emissions in SA's energy sector focus mainly on carbon dioxide. Table 48 shows emissions reductions for the various policy cases. The first row gives the total annual CO_2 emissions for the base case as a reference value, while the emissions reductions (difference between that case and the base case) are shown in the rest of the table.

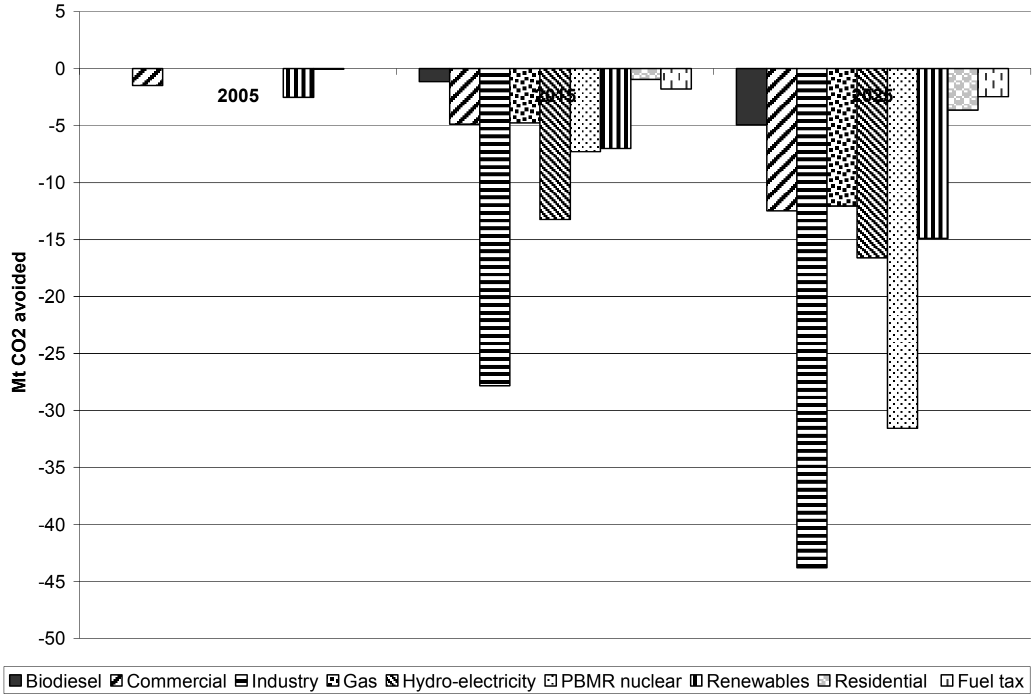
Table 48: CO_2 emission reductions for policy cases and base case emissions (Mt CO_2)

	2001	2005	2015	2025

Base	350	389	492	596
Biodiesel		0	-1	-5
Commercial		-1	-5	-12
Industry		0	-28	-44
Gas		0	-5	-12
Hydro-electricity		0	-13	-17
PBMR nuclear		0	-7	-32
Renewables		-3	-7	-15
Residential		0	-1	-4
Fuel tax		0	-2	-2

The largest reductions are shown for industrial energy efficiency. The PBMR and renewables have the same reductions by 2015, but by 2025 the PBMR has increased to a capacity where its reductions are higher. To compare across electricity cases, the installed capacity, load factor and associated costs need to be borne in mind. The PBMR has reached 4.48 GMW by the end of the period, while renewable energy technologies amount to 4.11 GW and gas 5.81 GW. Notably, however, imported hydro has reduces the total system costs, while the other three options increase it. The emission reductions are shown graphically in Figure 46.

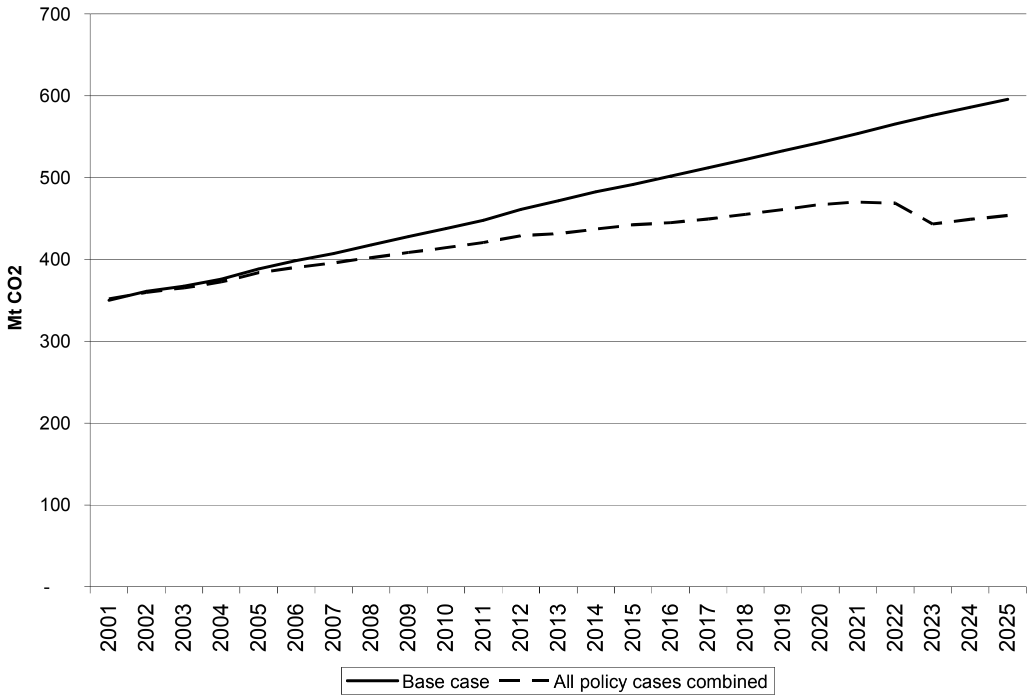
Figure 46: Emission reduction by policy case for selected years



Emission reductions increase over time. Several cases have no emission reductions by 2005, either because of lead times of technologies, or because the reductions have not yet reached the scale of Mt CO_2. The changes over the 25 years are shown in Figure 47. The individual policy case that contributes the most to this reduction is industrial energy efficiency.

Combined, the emission reductions achieved by the policies analysed here add up to 50 Mt by 2015 and 142 Mt CO_2 for 2025, 14% and 24% of the projected base case emissions for each respective year. Figure 47 shows that combining all the policies analysed here would reduce emissions below their projected growth. All policy cases were included in a combined scenario, to avoid double-counting within the energy system.

Figure 47: CO_2 emissions for base and with emissions reductions from all policy cases combined



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

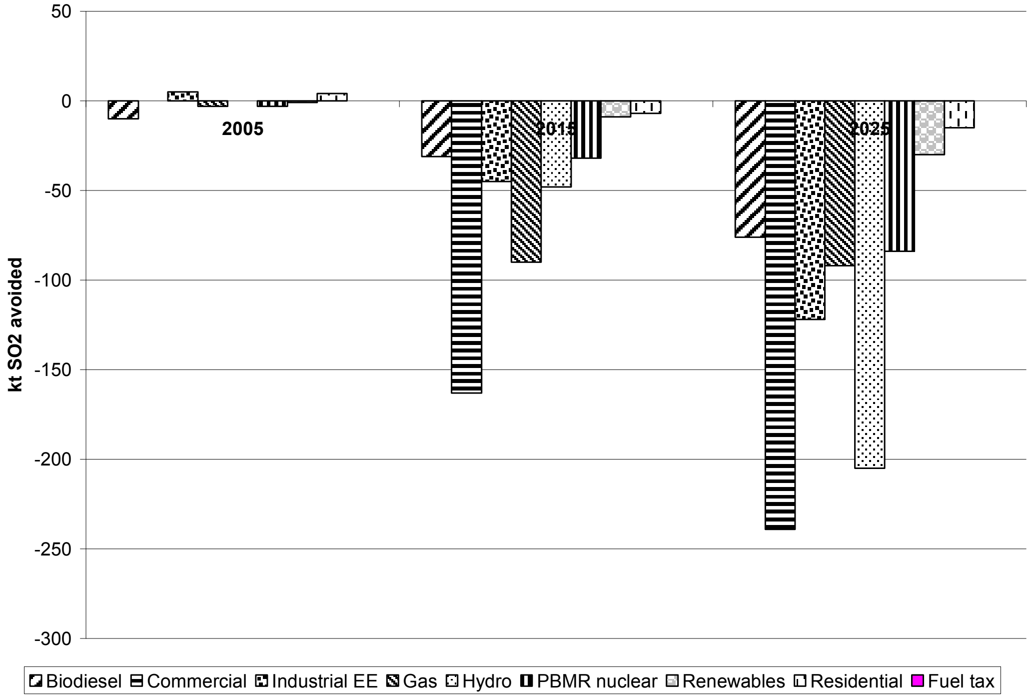
Turning to local air pollutants, the largest percentage reductions are achieved by industrial efficiency. Emissions factors for several local air pollutants were included in the database, and some of interesting and significant results are reported here. Reductions in sulphur dioxide emissions contribute to less acidification of water bodies and impacts on plantations. Since both coal-fired power stations and forestry plantations are located in the North-East of the country, these are significant.

Table 49: SO_2 emissions in the base case, reductions in the policy cases in absolute and percentage terms

Units: kt SO2	*2001*	*2005*	*2015*	*2025*	*Percentage reductions*			
Base	1491	1684	2226	2772	2001	2005	2015	2025
Biodiesel	0	0	0	0	0%	0%	0%	0%
Commercial	-1	-10	-31	-76	0%	-1%	-1%	-3%
Industry	0	0	-163	-239	0%	0%	-7%	-9%
Gas	4	5	-45	-122	0%	0%	-2%	-4%
Hydro-electricity	-3	-3	-90	-92	0%	0%	-4%	-3%
PBMR nuclear	0	0	-48	-205	0%	0%	-2%	-7%
Renewables	13	-3	-32	-84	1%	0%	-1%	-3%
Residential	-1	-1	-9	-30	0%	0%	0%	-1%
Fuel tax	4	4	-7	-15	0%	0%	0%	-1%

Table 49 shows SO_2 emissions almost doubling in the base case over 25 years. The largest reductions in percentage terms come from industrial energy savings (see Figure 48), amounting to 239 000 t SO_2 avoided in 2025.

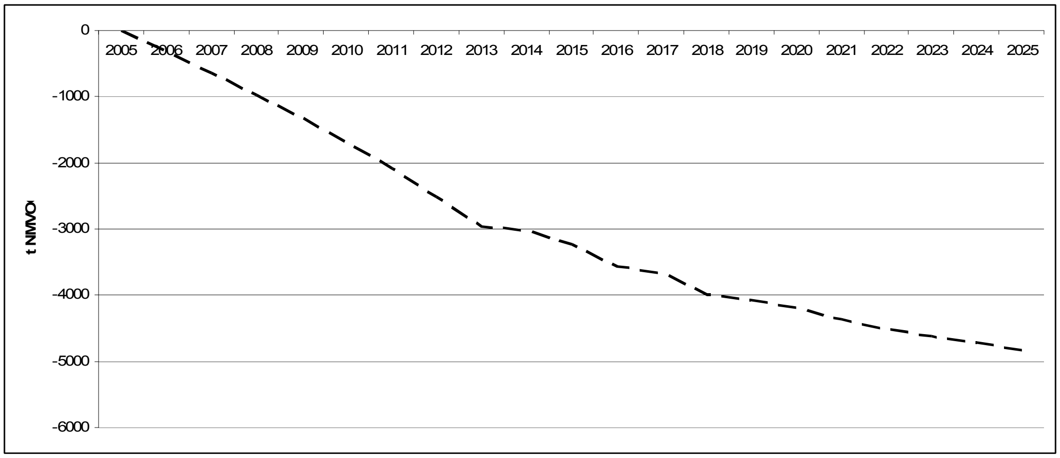
Figure 48: Avoided sulphur dioxide emission by policy case



If one adds up the emission reductions in the combined case, they amount to 614 kt SO_2 in the last year. Simple adding up would have yielded 863 kt SO_2 , so using the combined case does reduce double counting across policies. In other words, SO_2 emissions would still grow, but only to 2 158 kt SO_2, i.e. a little less that a quarter of the growth would be avoided (-22 %).

Following the pattern shaped by large energy savings in industry, Figure 49 shows a steady decline in non-methane volatile organic compounds, compared to the base case.

Figure 49: Reductions in NMVOC for industrial efficiency



For NO_x, base case emissions rise from roughly 1 million tons to over 2 million over 25 years. Substantial emission reductions around can be seen in 2025 for industrial and commercial demand-side measures, and all of the electricity supply options.

Table 50: Base case emissions and reductions of oxides of nitrogen for policy cases

kt Nox	*2001*	*2005*	*2015*	*2025*
Base	1,109	1,257	1,645	2,035
Biodiesel	0	0	-1	-3
Commercial	0	-5	-15	-36
Industry	0	0	-88	-136
Gas	2	2	-15	-39
Hydro-electricity	-1	-1	-43	-52
PBMR nuclear	0	0	-23	-98
Renewables	5	-3	-17	-42
Residential	0	-1	-4	-13
Fuel tax	2	2	-4	-6

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

5.2 Social

The implications of policies for social sustainability are most readily seen in the residential sector. In section 2.3, several important indicators were presented, capturing changes in residential fuel use patterns. Across all policy cases, we assume that the share of households with access to electricity rises to 99% in urban and 90% in rural areas. The share of other commercial fuels (LPG and paraffin) also increases, see Table 44.

To capture changes across all scenarios, the overall changes in residential fuel use patterns are shown in the following tables. These vary across policy scenarios, but do not distinguish household types.

Table 51: Changes in household energy consumption across policy cases, selected years

GJ / household	*2005*	*2015*	*2025*	*2005*	*2015*	*2025*
Base case	16.4	15.6	14.8			
	Reduction from base case			*Percentage reduction*		
Biodiesel	-0.04	-0.04	-0.05	-0.3%	-0.3%	-0.3%
Commercial	-0.04	-0.04	-0.05	-0.3%	-0.3%	-0.3%
Industrial EE	-0.04	-0.05	-0.05	-0.3%	-0.3%	-0.3%
Gas	-0.04	-0.04	-0.05	-0.3%	-0.3%	-0.3%
Hydro	-0.04	-0.04	-0.05	-0.2%	-0.3%	-0.3%
PBMR nuclear	-0.04	-0.04	-0.05	-0.3%	-0.3%	-0.3%
Renewables	-0.04	-0.04	-0.05	-0.3%	-0.3%	-0.3%
Residential	-0.01	-0.03	-0.11	0.0%	-0.2%	-0.7%
Fuel tax	-0.04	-0.04	-0.05	-0.3%	-0.3%	-0.3%

The reductions in household energy consumption are small in both absolute and percentage terms. Nonetheless, energy savings of small amounts can be significant for poorer households. Developing a deeper understanding of the implications for the energy burden for households (energy expenditure as a share of total household expenditure) requires further work. Either energy models have to be adapted to explicitly include households with characteristics such as income, geographical location and electrification status, or analysis needs to be conducted off-line.

We have argued that the household is an appropriate unit of analysis for the social dimensions of sustainable energy use. However, it is also useful to consider *per capita* consumption – to enable cross-country comparison, and because household size is declining (see 2.3.4.2).

Table 52: Per capita energy consumption across policy cases

	2005	*2015*	*2025*	*2005*	*2015*	*2025*
Base case	97.6	116.8	136.6	*Percentage reduction from base case*		
Biodiesel	97.7	116.5	135.1	0.1%	-0.3%	-1.1%
Commercial	97.4	115.6	134.2	-0.3%	-1.0%	-1.7%
Industrial EE	96.5	109.3	125.8	-1.2%	-6.4%	-7.9%
Gas	97.7	116.1	135.5	0.1%	-0.6%	-0.8%
Hydro	97.7	115.0	134.5	0.1%	-1.5%	-1.5%
PBMR nuclear	97.7	116.6	135.9	0.1%	-0.1%	-0.5%
Renewables	97.5	117.4	135.9	-0.1%	0.5%	-0.5%
Residential	97.7	116.6	136.3	0.1%	-0.2%	-0.2%
Fuel tax	97.4	116.5	136.5	-0.2%	-0.2%	0.0%

If one attributes the energy savings in industry to each South African, then reductions of almost 8 percentage points are seen, and approaching 2% for commercial.

Social sustainability is not only about access to fuels, however, but also about the affordability of using those fuels. Table 53 shows how monthly household expenditure varies across the policy cases. Note that this averages across household types, with variation for different types described.

The dominant trend shows rising monthly average household expenditure. Interestingly, some of the supply-side options can reduce the marginal cost of residential energy. However, it should be noted that these values represent the shadow price, that is the difference between the costs of the chosen technology and the optimal one. They do not represent market prices or tariffs, but provide a proxy estimate. Such estimates are useful in relative terms, giving an idea how actual monthly household expenditure might vary across time or policy cases. The absolute numbers may differ from actual expenditure.

Table 53: Proxy estimates of monthly average household energy expenditure across policy cases

*R / (HH * mth)*	***2001***	***2005***	***2015***	***2025***	*2005*	*2015*	*2025*
		Monthly household energy expenditure			*Percentage reduction*		
Base case	69.5	67.9	109.1	109.5			
Biodiesel	69.5	67.9	109.1	109.5	0%	0%	0%
Commercial	69.5	67.9	108.5	109.5	0%	-1%	0%
Industrial EE	69.5	67.9	80.5	108.7	0%	-26%	-1%
Gas	69.5	67.9	107.9	109.1	0%	-1%	0%
Hydro	69.5	67.9	107.5	109.5	0%	-1%	0%
PBMR nuclear	69.5	67.9	108.3	109.1	0%	-1%	0%

Renewables	69.5	67.9	108.8	109.5	0%	0%	0%
Residential	69.6	68.5	108.8	109.1	1%	0%	0%
Fuel tax	69.5	67.9	109.4	116.9	0%	0%	7%

Specific examples show that policy interventions in the residential demand sector provide cost savings to households. In particular, we calculated the subsidy required to make efficient houses economic to poorer households (Table 46) (which is smaller than the savings accrued to users).

Finally, at a broader societal level, energy security is an important consideration. Noting that energy security is capable of multiple definitions (Langlois et al. 2005), we focus on one particular aspect.

Figure 50: Import shares for policy cases over time

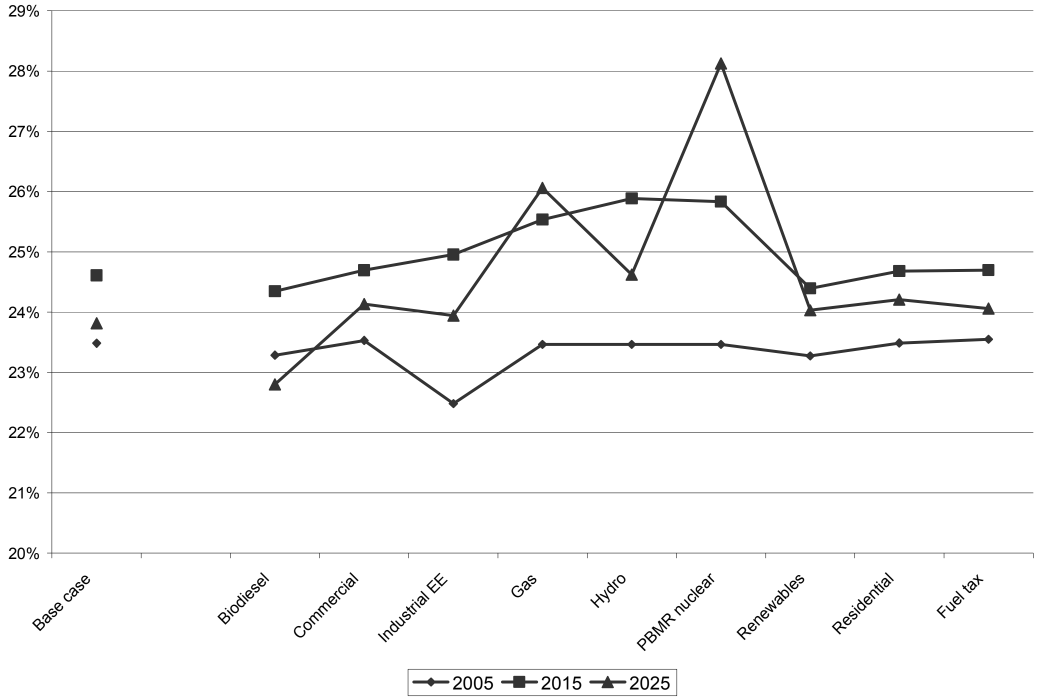


Figure 50 shows the share of impost in the base case at left, and then changing over time with each of the policy cases represented by a data point. The overall picture shows that the variation in import shares is relatively small. The imports of crude oil in the liquid fuel sector dominate the share of imports. However, some differences in the implications of policy cases are worth closer attention. Given SA's reliance on imported oil, net energy import dependency is an important indicator, shown in Table 54.

Table 54: Imported energy as share of total primary energy supply

	2005	*2015*	*2025*
Base case	23.5%	24.6%	23.8%
	Percentage point change		
Biodiesel	-0.2%	-0.3%	-1.0%
Commercial	0.0%	0.1%	0.3%
Industrial EE	-1.0%	0.3%	0.1%
Gas	0.0%	0.9%	2.2%

Hydro	0.0%	1.3%	0.8%
PBMR nuclear	0.0%	1.2%	4.3%
Renewables	-0.2%	-0.2%	0.2%
Residential	0.0%	0.1%	0.4%
Fuel tax	0.1%	0.1%	0.2%

Unsurprisingly, the imports of gas or hydro-electricity imply an increase in import dependency. Perhaps less obvious is that the import of nuclear fuel raises the share of imported energy by 4.3% of TPES in 2025 for the PBMR case, assuming that nuclear fuel is imported. Nuclear fuels, under certain circumstances, lend them selves to increased energy security because they are concentrated and readily stored. Domestic supply options, including renewable energy technologies, perform better in this regard.

5.3 Economic

Costs are important economic parameters. Costs can be reported at different levels, however, providing different imformation for policymakers. We report the costs in three different scales – the impact of policies on the entire energy system, the impacts of electricity supply options on the whole grid and the investment requirement for specific electricity options – new gas, renewables, nuclear or imported hydro electricity.

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

Table 55: Total energy system costs for base and policy cases

	Discounted total system costs over 25 years	*Difference to base case*	
	R billion	*R million*	*Percentage*
Base case	5,902		
Biodiesel	5,904	2,397	0.04%
Commercial	5,889	-13,078	-0.22%
Industrial EE	5,885	-17,011	-0.29%
Gas	5,902	95	0.00%
Hydro	5,890	-11,525	-0.20%
PBMR nuclear	5,905	3,706	0.06%
Renewables	5,905	3,488	0.06%
Residential	5,900	-1,136	-0.02%
Fuel tax	5,902	23	0.00%

Energy system costs over two-and-a-half decades add up to large numbers. Since the energy system is large, and the costing boundary is wide, individual policies which affect only one part of the energy system do not produce large changes in the bulk of the system or its structure. In this context, the cost changes are small in relative terms, but nonetheless are in the order of millions to billions of Rands. Table 55 shows that energy efficiency in the industrial, commercial and residential sector *reduce* system costs substantially (in that order). The other large potential saving is from imported hydro-electricity.

On the supply side, investing in domestic options – be they renewable energy or nuclear PBMR – increases the costs of the energy system. While these increases are only 0.06% of energy system costs, they are nonetheless over R 3 billion in both cases over the period.

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

A comparison with a somewhat narrower costing boundary is presented in Table 57. The table shows the total investment costs over the whole period, as well as the installed capacity that results in each policy case. The table makes clear that domestic investments in capacity in hydro case are lower (since investments in neighbouring countries are not included). The largest investments requirement is needed for the PBMR case. Installed capacity in that case is the same as for the base case. The additional investment needed for the renewables case lies between the base and PBMR cases. A larger electricity supply system is needed, given the lower availability factor.

Table 56: Investments in electricity supply options and total electricity generation capacity by 2025

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

Narrowing the costing boundary even further considers only the investment required for a technology in *its* policy case, e.g. the PBMR in the PBMR policy case, or various renewable energy technologies (biomass co-generation, wind and solar power tower)[20] in the renewables case. Table 57 shows three items – the discounted investment costs in the technology over 25 years (derived by summing annualised investment costs), the newly installed capacity of that technology over the period, and the cost per unit (kW) of new capacity.

Table 57: Investment requirements for specific electricity supply technologies in their policy case, capacity provided in 2025 and cost per unit

	Annualised cost of investment in the specific technology for its policy case, summed over 25 years, R bn	*New installed capacity of the technology in its case by 2025, GW*	*R / kW of new capacity*
CCGT in gas case	30.7	5.79	5,297
Imported hydro in hydro case	36.9	3.73	9,871
PBMR in PBMR case	55.7	4.48	12,430
RETs in renewables case	33.3	3.73	8,937

Note: Investment costs for hydro scenario do not include investment in stations in neighbouring countries.

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[20] As Figure 41 above showed, these are the renewable energy technologies that dominate the new capacity in the renewables case.

The PBMR shows the largest investment requirement. It also adds more capacity than renewables, but less than from gas or imported hydro. In unit cost, imported gas is cheapest, with hydro and renewables next at roughly similar levels. Note that these numbers are not identical to the upfront investment costs (also expressed in R / kW in Table 23 above). However, the general pattern of unit costs is consistent with the ranges shown there. Gas is significantly cheaper than other options by unit cost, followed by the renewables. The PBMR's costs per installed capacity (R/kW) are at the lower end of the range in the earlier table. The unit costs of renewables are an average of biomass co-generation, wind and solar power tower which are chosen by the model in the renewables case, and within the range of the investment costs in Table 23. The direct investment costs for new capacity in Mepanda Uncua were reported in section 2.6.4; they would suggest a slightly lower unit cost than shown in Table 57 at R 8,793 / kW.

The energy-intensity of the South African economy was noted in the introduction. An important indicator, therefore, is the energy intensity.

Table 58: Energy intensity over time and across policies

	2005	***2015***	***2025***			
Base case	226	238	261	***2005***	***2015***	***2025***
Reduction from base case				*Percentage reduction*		
Biodiesel	- 0.21	0.71	2.87	-0.1%	0.30%	1.10%
Commercial	0.57	2.37	4.57	0.25%	1.00%	1.75%
Industrial EE	2.69	16.28	22.34	1.19%	6.84%	8.57%
Gas	- 0.21	1.41	2.02	-0.10%	0.59%	0.78%
Hydro	- 0.22	3.74	3.94	-0.10%	1.57%	1.51%
PBMR nuclear	- 0.21	0.36	1.30	-0.10%	0.15%	0.50%
Renewables	0.32	- 1.18	1.23	0.14%	-0.50%	0.47%
Residential	- 0.19	0.44	0.54	-0.09%	0.19%	0.21%
Fuel tax	0.57	0.55	0.13	0.25%	0.23%	0.05%

The chief reductions in energy intensity are by the largest energy savings analysed in this study, i.e. through greater energy efficiency in industry and commerce.

The economic, social and environmental dimensions of sustainable development should be considered together to conclude on the sustainability of various technologies, policies and measures. An overview of some key energy indicators of sustainable development is provided in the appendix in Table 60. Based on that summary, and the findings of the present section, some conclusions are offered in the final section.

The global costs (discounted total energy system costs) for the combined scenario are lower than for the base case by some R16 billion over the full period. The impact of cost-saving policies on balance and over time is greater than that of positive-cost measures. This suggests that the savings of the combined efficiency measures outweigh the additional costs of investing in a diversified electricity supply.

6. Conclusions

This report has modeled a range of energy policies for sustainable development in South Africa. Demand- and supply-side policies exist that can contribute both to energy objectives, and also to broader sustainable development goals.

The base case presented 'current development trends' or a base case which is close to the Integrated Energy Plan (DME 2003a).and for electricity, the second National Integrated Resource Plan (NIRP) (NER 2004a). On the demand side, fuel consumption in industry and transport dominates, with the latter growing most rapidly among sectors. On the supply-side, electricity generation continues to be dominated by existing and new coal, supplemented by gas turbines and new fluidised bed combustion, using discard coal. Smaller contributions come from existing hydro and bagasse, nuclear, electricity imports, existing and new pumped storage and interruptible supply. Liquid fuel supply is met mostly from existing refineries and some expansion, little by imports of finished petroleum products. Emissions of both local and global air pollutants increase steadily in the reference case, over the period. Carbon dioxide emissions increase from 337 Mt CO_2 in 2001[21] to 591 Mt CO_2 in 2025 – an increase of 75% over the entire period.

A set of energy policy cases was modelled and compared to the base case. Table 59 provides a short summary of the technologies, policies and measures that were included in the scenario modeling.

Table 59: Summary of policy cases in residential and electricity supply sectors

Sector	*Summary of technologies, policies and measures*
Industry	Industrial energy efficiency meets the national target of 12% less final energy consumption than business-as-usual. This is achieved through greater use of variable speed drives; efficient motors, compressed air management, efficient lighting, heating, ventilation and cooling (HVAC) system efficiency and other thermal saving. Achievement of this goal depends on forcefully implementing the policy.
Commercial	New commercial buildings are designed more efficiently; HVAC systems are retrofitted or new systems have higher efficiency; variable speed drives are employed; efficient lighting practices are introduced; water use is improved both with heat pumps and solar water heaters. In addition to specific measures, fuel switching for various end uses is allowed. Achievement of this goal depends on forcefully implementing the policy.
Residential	Cleaner and more efficient water heating is provided through increased use of solar water heaters and geyser blankets. The costs of SWH decline over time, as new technology diffuses more widely in the SA market. More efficient lighting, using compact fluorescent lights (CFLs) spreads more widely, with a slight further reduction. The shell of the house is improved by insulation, prioritising ceilings. Households switch from electricity and other cooking appliances to LPG. The subsidy required to make interventions more economic for poorer households.
Bio-fuels	Biodiesel production increases to 35 PJ by 2025, at a maximum growth rate of 30% per year from 2010, displacing petroleum. Energy crops do not displace food production, and sustainable production means the fuel is effectively zero-carbon.
Electricity for renewables	The share of renewable electricity increases to meet the target of 10 000 GWh by 2013. Shares of solar thermal, wind, bagasse and small hydro increase beyond the base case. New technology costs decline as global production increases
PBMR nuclear	Production of PBMR modules for domestic use increases capacity of nuclear up to 4,480 MW (32 modules). Costs decline with national production and initial investments are written off
Imported hydro-electricity	Share of hydro-electricity imported from SADC region increases from 9.2 TWh in 2001, as more hydro capacity is built in Southern Africa.
Imported gas	Sufficient LNG is imported to provide 5 850 MW of combined cycle gas turbines, compared to 1 950 MW in the base case.
Tax on coal for electricity generation	The use of economic instruments for environmental fiscal reform is being considered by Treasury. We analyse the option of a fuel input tax on coal used for electricity generation. The policies could potentially be extended to coal for synfuel production and industrial use, or alternatively, the environmental outputs could be taxed directly, e.g. in a pollution tax

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[21] The base year number is fairly close to the CO_2 emissions reported in the Climate Analysis Indicator Tool (WRI 2005).for 2000 – 344.6 Mt CO_2. It is somewhat higher than the 309 Mt CO_2 from fuel combustion reported in the Key World Energy Statistics for 2001 (IEA 2003a).

On the demand-side, energy efficiency policies were found to be particularly important. The overall strategy of reducing final energy demand by 12% compared to business-as-usual can be implemented most effectively in the industrial sector. Industrial energy efficiency is effective both in lowering the cost of the energy system by 18 billion Rand, and reducing global and local air pollution. Carbon dioxide emissions are reduced by 770 Mt CO_2 over 25 years. Greater efficiency has benefits in delaying the need for investment in power stations, with new base load power stations postponed by 4 years, and peaking power plant by 3 years.

Realising the potential for industrial energy efficiency requires forceful, even aggressive implementation. Current practice is often not economically optimal and clear signals are needed to induce industry to 'pick up the $20 bill'. The agreement between industry and government to implement the energy efficiency strategy (DME 2005a) and the recent announcement of that a dedicated Energy Efficiency Agency is to be established bode well in this regard.

A strong legal and institutional framework is needed for the commercial sector. The modeling suggests that a 12% energy efficiency target is achievable and can save R 13 billion over 25 years. However the results also suggest that the cost optimal energy efficiency improvements are 2-3% lower than the 12% and that these savings thus come at a cost in the order of 5% of the investment costs (Spalding-Fecher et al. 2003). Government leading in making its own buildings and practices more efficient can play an important role.

The residential sector is particularly important for social sustainability. A sustainable development approach aims to deliver services meeting basic human needs, but in a cleaner and more efficient manner. Policy interventions focus on all end uses, using solar water heaters and geyser blankets (SWH / GB), LPG for cooking, efficient housing shell, and compact fluorescent lights (CFLs) for lighting. Making social housing more energy-efficient through simple measures such as including insulating ceilings, should be adopted as a general policy.

All policy cases assume near-universal electrification, and we find that the share of other commercial fuels (LPG and paraffin) also increases. Overall fuel consumption, however, is lowered compared to the base case (8.13 PJ less in 2025), with increasing efficiency and use of solar energy for water heating. Not all interventions are used by all household types – for example, efficient houses are only taken up by urban higher-income electrified households. Design of appropriate measure for poorer households is required, for example considering geyser blankets as well as solar water heaters. The lower cost – both upfront and per unit of energy saved – suggests that geyser blankets are appropriate policy interventions in poor electrified households.

Access to energy in physical terms needs to be accompanied by affordability in economic terms. While this issue deserves further analysis (translating it into an 'energy burden'), our findings suggest that a relatively small subsidy can make interventions economic for poorer households. The order of magnitude of the subsidy required to make efficient housing as affordable for poorer households as for richer ones is in the hundreds of Rands, but less than a thousand Rand.

On the supply-side, four policy cases focused on electricity supply – imported gas or hydro-electricity, or generating electricity domestically from PBMR nuclear or renewable energy technologies. Imported hydro potentially reduces investment costs, but increase the share of imported energy as a percentage of TPES. Imported gas increase the share of imports, while making little difference to total energy system costs. The PBMR case with imported fuel also shows an increase in this regard up by 4.3% of TPES in 2025. Domestic supply options, including renewable energy technologies, perform better in this regard. However, domestic supply options include substantial imported components. A sustained move to greater diversity, however, will require more than a single policy.

Investing in the PBMR and renewables options increases the costs of the energy system, while imported gas has a small effect and hydro imports reduce costs. While the increases are only 0.06% of energy system costs, they are nonetheless over R 3 billion in both the PBMR and renewables case over the period. In unit costs (R/kW of new capacity), gas is significantly cheaper than other options, followed by the renewable energy technologies (average of biomass co-generation, wind and solar power tower). However, the options do show quite substantial emission reductions – 246 Mt CO_2 for the PBMR and 180 Mt CO_2 for renewable energy technologies, both over the 25-year horizon. Both reduce local pollutants, notably sulphur dioxide, by 3 and 1.6% relative to the base case, respectively.

A key policy option addressing liquid fuels for transport is the supply of bio-diesel. The potential to produce 1.4 billion litres of biodiesel was modeled as starting in 2010, reaching a biodiesel reach market share of 9% of transport diesel by 2025. An average of 4,500 barrels/day of oil refining capacity can be avoided. Total reduction in carbon dioxide emissions reaches 5 Mt CO_2 per annum in 2025 and cumulative savings are 31 Mt CO_2 for the entire period. There are also smaller reductions in local pollutants. Present value of total system cost for this scenario is 2.4 billion Rands higher than for the reference scenario.

The results for a tax on coal for electricity generation show that the reductions of CO_2 emission from coal for electricity generation are small relative to the reference case. The economic difference lies less in system costs (R67 million over 25 years), but more in the tax revenues. These revenues both impose added costs on producers, but could also generated economic benefits if recycled. More detailed analysis is required of this policy option, possible extending the tax to coal for synfuels and industry as well, and quantifying the indirect economic effects of tax recycling and impacts on other policy objectives.

Combined, the emission reductions achieved by all the policies analysed here add up to 69 Mt by 2015 and 142 Mt CO_2 for 2025, 10% and 24% of the projected base case emissions for each respective year. One important conclusion is that significant emission reductions compared to business-as-usual are possible (or ‘avoided emissions’). This should be understood together with a second conclusion, however, namely that stabilising emissions levels (e.g. at 2010 levels) would require some *additional* effort from 2020 onwards. The tools used in this analysis – a modeling framework combined with indicators of sustainable development – provide a useful way of examining trade-offs, as well as the room for compromise.

Over the 25-year time-frame considered here, energy efficiency makes sense against indicators of sustainable development. Industrial efficiency in particular shows significant savings in energy, costs and air pollution, with commercial energy showing a similar pattern at slightly smaller scale. Residential energy efficiency is particularly important for social sustainability. Even small energy savings can be important for poorer households. In the short-term, then, energy efficiency is critical to making SA’s energy development more sustainable.

In the longer-term, transitions including the supply-side becoming important. Greater diversity will need a combination of policies, since single policies do not change ¾ share of coal in TPES by much on their own. The various electricity supply options show potential for significant emission reductions and improvements in local air quality. However, they require careful trade-off for the implications for energy system costs, energy security and diversity of supply.

The global costs (discounted total energy system costs) for the combined scenario are lower than for the base case by some R16 billion over the full period. This suggests that the savings of the combined efficiency measures outweigh the additional costs of investing in a diversified electricity supply.

Appendices

Table 60: Overview of energy indicators of sustainable development

ENVIRONMENT												
	2001	*2005*	*2015*	*2025*	*2001*	*2005*	*2015*	*2025*	*2001*	*2005*	*2015*	*2025*
CO2 emissions and reductions			*Mt CO2*		*Sulphur dioxide*		*kt SO2*		*Oxides of nitrogen*		*kt Nox*	
Base	350	389	492	596	1,491	1,684	2,226	2,772	1109	1257	1645	2035
Biodiesel	0	0	-1	-5	-1	-10	-31	-76	0	0	-1	-3
Commercial	0	-1	-5	-12	0	0	-163	-239	0	-5	-15	-36
Industry	0	0	-28	-44	4	5	-45	-122	0	0	-88	-136
Gas	0	0	-5	-12	-3	-3	-90	-92	2	2	-15	-39
Hydro-electricity	0	0	-13	-17	0	0	-48	-205	-1	-1	-43	-52
PBMR nuclear	0	0	-7	-32	13	-3	-32	-84	0	0	-23	-98
Renewables	0	-3	-7	-15	-1	-1	-9	-30	5	-3	-17	-42
Residential	0	0	-1	-4	4	4	-7	-15	0	-1	-4	-13
Fuel tax	0	0	-2	-2	0	0	0	0	2	2	-4	-6
SOCIAL												
	2005			*2015*			*2025*					
	GJ/Capita	*ZAR/GJ*	*GJ / household*	*GJ/Capita*	*ZAR/GJ*	*GJ / household*	*GJ/Capita*	*ZAR/GJ*	*GJ / household*			
Base case	97.62	225.90	16.36	116.80	237.83	15.57	136.57	260.68	14.76			
Biodiesel	97.71	225.69	16.32	116.45	238.54	15.53	135.08	263.55	14.71			
Commercial	97.37	226.47	16.32	115.65	240.20	15.53	134.21	265.24	14.71			
Industrial EE	96.47	228.59	16.32	109.32	254.11	15.53	125.79	283.02	14.71			
Gas	97.71	225.69	16.32	116.11	239.24	15.53	135.51	262.70	14.71			
Hydro	97.71	225.68	16.32	115.00	241.56	15.53	134.53	264.62	14.71			
PBMR nuclear	97.71	225.69	16.32	116.63	238.18	15.53	135.89	261.98	14.71			
Renewables	97.52	226.22	16.32	117.38	236.65	15.53	135.92	261.91	14.71			
Residential	97.70	225.71	16.35	116.58	238.27	15.54	136.28	261.22	14.65			

ECONOMIC						
Total system costs				*Share of imports*		
	R billion	R million	Percentage			
Base case	5,902	change	change	2005	2015	2025
Biodiesel	5,904	2,397	0.04%	23%	25%	24%
Commercial	5,889	-13,078	-0.22%	23%	24%	23%
Industrial EE	5,885	-17,011	-0.29%	24%	25%	24%
Gas	5,902	95	0.00%	22%	25%	24%
Hydro	5,890	-11,525	-0.20%	23%	26%	26%
PBMR nuclear	5,905	3,706	0.06%	23%	26%	25%
Renewables	5,905	3,488	0.06%	23%	26%	28%
Residential	5,900	- 1,136	-0.02%	23%	24%	24%
Fuel tax	5,902	23	0.00%	23%	25%	24%

Table 61: Projections of household numbers over the period

	2001	*2005*	*2010*	*2015*	*2020*	*2025*	*2030*
UHE	4,074,438	4,319,029	4,624,768	4,930,508	5,236,247	5,541,987	5,847,726
ULE	1,255,728	1,416,680	1,617,870	1,819,060	2,020,250	2,221,440	2,422,629
ULN	1,349,240	1,174,661	956,436	738,212	519,988	301,763	83,539
RHE	1,181,279	1,268,071	1,376,561	1,485,050	1,593,540	1,702,030	1,810,520
RLE	1,095,449	1,256,511	1,457,839	1,659,167	1,860,494	2,061,822	2,263,150
RLN	2,249,571	2,001,717	1,691,899	1,382,082	1,072,265	762,447	452,630

Table 62: Projections of energy demand by end use and household type (PJ)

COOKING	**2001**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
UHE	15.8447	16.9044	18.2290	19.5537	20.8783	22.2029	23.5275
ULE	1.4270	1.6230	1.8680	2.1131	2.3581	2.6032	2.8482
ULN	1.8230	1.5877	1.2935	0.9993	0.7051	0.4110	0.1168
RHE	1.7882	1.9196	2.0839	2.2481	2.4123	2.5766	2.7408
RLE	0.5916	0.6786	0.7873	0.8960	1.0047	1.1135	1.2222
RLN	3.0503	2.7142	2.2941	1.8740	1.4539	1.0338	0.6137
WATER HEATING	**2001**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
UHE	23.1604	24.7094	26.6456	28.5818	30.5181	32.4543	34.3905
ULE	4.3362	4.9319	5.6765	6.4212	7.1658	7.9105	8.6551
ULN	1.2064	1.0506	0.8559	0.6613	0.4666	0.2719	0.0773
RHE	2.8427	3.0516	3.3126	3.5737	3.8348	4.0959	4.3569
RLE	0.6706	0.7692	0.8924	1.0157	1.1389	1.2621	1.3854
RLN	5.3223	4.7359	4.0029	3.2699	2.5369	1.8039	1.0709
SPACE HEATING	**2001**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
UHE	16.3063	17.3968	18.7601	20.1233	21.4865	22.8497	24.2129
ULE	2.4165	2.7485	3.1635	3.5784	3.9934	4.4084	4.8234
ULN	1.9941	1.7367	1.4149	1.0931	0.7713	0.4495	0.1277
RHE	1.6832	1.8068	1.9614	2.1160	2.2706	2.4251	2.5797
RLE	0.5305	0.6085	0.7060	0.8035	0.9010	0.9985	1.0960
RLN	6.0526	5.3857	4.5521	3.7185	2.8850	2.0514	1.2178
LIGHTING in PJ	**2001**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
UHE	7.3896	7.8838	8.5016	9.1194	9.7371	10.3549	10.9727

ULE	2.6887	3.0581	3.5198	3.9815	4.4432	4.9050	5.3667
ULN	2.3475	2.0445	1.6657	1.2868	0.9080	0.5292	0.1504
RHE	4.1415	4.4458	4.8261	5.2065	5.5868	5.9672	6.3476
RLE	2.0251	2.3228	2.6950	3.0672	3.4394	3.8116	4.1837
RLN	4.1684	3.7091	3.1350	2.5610	1.9869	1.4128	0.8387
OTHER ELECTRICAL APPLIANCES	2001	2005	2010	2015	2020	2025	2030
UHE	12.5741	13.6854	15.1304	16.6397	18.2156	19.8604	21.5767
ULE	0.1085	0.1259	0.1486	0.1723	0.1972	0.2232	0.2504
ULN	-	-	-	-	-	-	-
RHE	3.2810	3.5930	3.9989	4.4230	4.8660	5.3285	5.8113
RLE	0.0771	0.0902	0.1073	0.1252	0.1439	0.1635	0.1840
RLN	-	-	-	-	-	-	-

Table 63: Total residential energy demand and end use total demands for selected years

TOTAL for all household types	2001	2005	2010	2015	2020	2025
COOKING	24.5248	25.4275	26.5558	27.6842	28.8125	29.9409
WATER HEATING	37.5386	39.2486	41.3861	43.5236	45.6611	47.7986
SPACE HEATING	28.9832	29.6831	30.5580	31.4329	32.3078	33.1827
LIGHTING in LUs	22.7608	23.4641	24.3432	25.2224	26.1015	26.9806
OTHER ELECTRICAL APPLIANCES	16.0407	17.4946	19.3853	21.3603	23.4227	25.5757
ALL RESIDENTIAL ENERGY DEMAND	113.8073	117.8232	122.8431	127.8630	132.8829	137.9028

Table 64: Projections of electricity capacity by plant type (GW)

Tim, can you please make this table fit onto one page?

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Existing coal	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.9	32.2	30.3	30.3	30.3
Nuclear PWR	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Bagasse	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Diesel gas turbines	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Hydro	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interruptible supply	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Pumped storage	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Imported elec	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Mothballed coal	-	-	-	-	0.4	0.8	1.5	2.8	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
New coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	0.9	1.7	2.5	3.3	4.2	6.1	9.2	10.2	11.2
New OCGTdiesel	-	-	-	-	-	0.2	0.6	1.4	2.1	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
New CCGT	-	-	-	-	-	-	-	-	-	0.6	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
New FBC	-	-	-	-	-	-	-	-	-	-	-	-	0.8	1.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
New pumped storage	-	-	-	-	-	-	-	-	-	-	-	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

Table 65: Total fuel consumption by demand sector (PJ)

	2001	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*
Agriculture	73	78	74	75	77	78	79	80	81	82	83	84	85
Commercial	85	87	90	93	95	97	100	103	107	111	113	116	119
Industry	1,151	1,162	1,176	1,180	1,205	1,220	1,235	1,250	1,265	1,281	1,297	1,312	1,329
Non-energy	-	-	-	16	32	32	32	32	32	32	32	32	32
Residential	183	188	189	190	192	194	195	196	197	196	197	198	199
Transport	613	642	659	677	698	717	735	753	771	789	807	825	843

	2014	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*
Agriculture	86	86	87	88	89	90	91	92	93	94	95	96
Commercial	124	129	133	137	141	145	150	154	159	164	169	175
Industry	1,345	1,362	1,379	1,396	1,414	1,432	1,450	1,469	1,488	1,503	1,518	1,533
Non-energy	32	32	32	32	32	32	32	32	32	32	32	32
Residential	201	204	205	206	208	209	210	211	212	214	215	216
Transport	861	878	895	911	928	945	960	975	989	1,004	1,019	1,034

Table 66: Investments required in energy supply by case and years

	2,001	2,002	2,003	2,004	2,005	2,006	2,007	2,008	2,009	2,010	2,011	2,012	2,013	2,014	2,015	2,016	2,017	2,018	2,019	2,020	2,021	2,022	2,0
Base case	1,074	382	1,541	318	445	712	992	2,269	1,832	1,249	2,110	2,236	2,033	1,889	1,735	1,465	1,288	1,124	981	841	1,700	2,379	92

Biodiesel	1,074	382	1,541	318	445	712	992	2,269	1,832	1,355	2,119	2,118	2,014	1,869	1,714	1,444	1,267	1,104	963	825	1,687	2,368	91
Commercial	1,074	374	1,205	310	439	436	754	2,157	1,851	1,016	2,028	2,168	1,067	1,687	1,498	1,260	1,146	1,010	882	750	1,593	2,290	79
Industrial EE	1,074	382	1,538	318	259	562	562	878	666	640	678	1,903	726	628	1,029	1,231	738	1,193	1,186	1,499	1,686	2,428	1,1
Gas	1,074	382	1,531	318	445	712	992	2,269	1,832	1,274	2,335	2,370	1,379	1,285	1,176	980	858	754	661	697	1,677	2,355	92
Hydro	1,074	382	328	294	259	227	201	251	349	555	641	1,867	447	236	1,502	1,754	1,581	1,439	1,276	1,120	1,625	2,313	71
PBMR nuclear	1,074	382	1,541	318	445	712	992	2,269	1,832	1,249	2,110	2,236	2,565	2,584	2,258	1,891	1,608	1,359	1,147	953	1,750	2,409	96
Renewables	1,074	1,268	1,788	318	760	685	933	2,329	1,963	1,128	2,226	2,666	1,500	2,029	1,845	1,523	1,345	1,175	1,014	861	1,709	2,475	90
Residential	1,074	395	1,211	320	456	594	800	2,226	1,823	1,174	2,037	2,181	1,849	1,750	1,610	1,344	1,186	1,041	909	782	1,663	2,347	84
Fuel tax	1,074	382	1,541	318	445	712	841	2,245	2,325	1,140	2,110	2,368	2,033	1,889	1,735	1,466	1,282	1,129	981	841	1,455	2,377	92

Direct CO_2 emissions from Fischer-Tropsch process at Secunda

Most of the GHG emissions are in the form of carbon dioxide, with much smaller amounts in nitrous oxide and methane. This is consistent with both SASOL's reporting and the GHG inventory. Indirect emissions, i.e. those related to electricity generation at SASOL, are not included here, because they are captured under electricity in GHG inventories. Indirect emissions are smaller than direct, less than 10% of total GHG emissions. The emissions from the chemical process at Sasolburg are not included here. Emissions from South African operations are the only ones considered, not the SASOL group internationally.

The best available data for direct CO2 emissions from Fischer-Tropsch process at Secunda indicates that total direct emissions are approximately **50 Mt CO_2** for 2003.

- This is a round number in between the values for SA operations only in 2002/3 (49.1 $MtCO_2$) and 2003/4 (52.2 $MtCO_2$) (Kornelius 2005). It also corresponds to a figure of 49.6 $MtCO_2$ which was verified with Fred Goede (Lloyd 2005; Mako & Samuel 1984).citing (Mako & Samuel 1984).
- A higher level of emissions is consistent with more recent reporting of 32 Mt CO_2 at Secunda at 90-98% concentration in a study for carbon capture and storage (Engelbrecht et al. 2004).
- The emissions are significantly higher than the 10.7 Mt CO_2 reported in the 1994 inventory (Van der Merwe & Scholes 1998). While there is a gap of almost ten years in the reporting year, it does seem that this number was too low, probably attributable to using an emission factor of 9.03 t CO_2 / TJ in that study.
- These emissions in SA represent 78% of the direct CO_2 emissions reported for SASOL as a group, including its international operations (Sasol 2004b).

The emission factor for this process is **56 tCO2/TJ**. The energy contained in the coal fed into the Fischer-Tropsch process at Secunda is 894 PJ (energy output at 35% efficiency is 313 PJ)(DME 2003a). Of the total carbon in the coal input to the process, some 64% are emitted as CO_2 to the atmosphere (27% in concentrations around 10-15%, 37% in high concentrations of 90-98%), 32% go into products and 4% are ‘lost’ as tars or phenols (Lloyd 2005).

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