The potential contribution of renewable energy in South Africa

Final Report

Douglas Banks and Jason Schäffler

prepared for

A project of Earthlife Africa Johannesburg

Project commissioned by:

Sustainable Energy & Climate Change Project (SECCP)
A project of Earthlife Africa Jhb
P O Box 11383
Johannesburg, 2000
Tel: +27 11 339 3662;
Fax: +27 11 339 3270
www.earthlife.org.za

Project funding:

The SECCP is funded by DANIDA
Royal Danish Embassy

Authors:

Douglas Banks
RAPS Consulting (Pty) Ltd
P O Box 34921,
Glenstantia, 0010
Email: doug@raps.co.za
Tel +27 12 998 3375
Fax +27 12 998 6172

Jason Schäffler
Nano Energy (Pty) Ltd
Email: Jason@nano.co.za

Last edited 15 April 2005

Foreword by Earthlife Africa Johannesburg

This study was commissioned to establish the viability of a just transition to sustainable energy in South Africa, complimenting two previous studies: 'Policies and Measures for Renewable Energy and Energy Efficiency in South Africa' (EDRC with ERI, UCT, April 2003) and 'Employment Potential of Renewable Energy in South Africa' (AGAMA Energy, November 2003). It is also intended as an input into the Integrated Energy Planning process being conducted by the DME and as a stimulus to encourage further long-term scenario work, considering energy and development in general over a time-scale consistent with the anticipated lifespan of major energy investments (e.g. thermal power plants).
This is an independent study and thus not a reflection of positions taken or targets advocated by Earthlife Africa, the commissioning organisation. It is not a prediction or proposal, rather the study explores the potential of RE within constraints such as realistic rates for technology development, deployment and market penetration, as well as resource availability. Further analysis of the full costs and benefits of increasing the total share of renewables in the national energy mix (currently total energy use is about 75% coal-based) would provide a clear mandate for the specific targets for technology and resource deployment that are needed to realise the potential of renewable energy, including its potential for job creation.

The level of energy demand (or anticipated consumption) projected in the study is not considered desirable or optimal. It was selected for illustrative purposes and easily allows for high rates of economic growth. Realising the full potential for efficiency and conservation would result in lower demand than projected, delivering the same level of output (energy services, production, etc.) from lower input. However, study of the long-term potential of energy efficiency is beyond the scope and budget of this study, and thus assumptions regarding efficiency gains are moderate. Should greater efficiency be achieved, there can be a further reduction in the use of fossil fuels.

This study clearly demonstrates the credibility of a target of 50% of total energy from renewable resources by 2050, however unlikely this may appear under current market conditions (and lacklustre policy implementation). The detailed composition of the non-renewable component of future energy supply has not been addressed, but vested interests will certainly need to be subject to standards and pollution charges if their domination and adverse impacts are to be reduced. The required financing of renewables will certainly be easier if South Africa stops wasting public/state-controlled money on speculative high-cost and high-risk ventures such as the nuclear PBMR programme.

Given the 40-year lifespan of proposed new thermal power plants (plus at best a 5 to 8 year lead time), not to mention the cumulative impacts of business as usual, it is high time that energy planning considered some scenarios that look beyond the 20-year period of current plans and cost analysis. An ambitious and forward-looking approach to a more sustainable energy mix should consider how we prepare for the 2020's, when the majority of current generation capacity will need to be replaced, and what resources should remain available for our grandchildren and beyond. We also need to consider the implications of possible higher increases in prices for stock or concentrated energy (oil etc,) than the 1% assumed in this study, as well as the opportunities this would provide for financing more local utilisation of available resources.

Climate change – both South Africa's contribution to global warming and our vulnerability to the escalating impacts of an overheated climate system – provides one set of reasons for a departure from business as usual. Developing local industries in renewable energy technologies (RETs) and empowering communities to participate in energy service delivery would make a major contribution to achieving our national priorities of employment growth and poverty reduction. Yet social cost-benefit analysis has not been factored into Integrated Energy Planning to date. Realising constitutional rights also requires quantification of environmental impacts, based on cradle-to-grave analysis, at the local as well as global level.

It is sincerely hoped that this study will prompt a more responsible, forward-looking and optimistic approach to energy planning. For too long, vested interests have kept renewables restricted to niche applications while persuading our decision-makers that the exploitation of stock energy, with its higher short-term profit to investors, is the only possible route to development. Yet if the next major phase of energy investment goes to conventional energy (extraction of stock energy), we may well see massive stranded assets as fossil fuel prices escalate and the poor remain dependent on a centralised energy system that they cannot raise the cash to access.

Energy development over the coming 20 years must provide us with the possibility and thus the foundation - the technological, skills and production base - for rapid deployment of the sustainable options. Even if the climate change impacts considered most probable by the vast majority of scientists, with their implications for national security, do not materialise, the pursuit of the Millennium Development Goals require a transformation of the energy sector. Public spending for public benefits will yield macro-economic benefits even within a 20-year horizon. Without it we may be caught in a fossil addiction, unprepared for scaling up the use of our abundant renewable resources.

The required policy and market interventions needed to achieve a just transition to sustainable energy have been well researched and advocated for years at local, national and international levels. They are discussed in other documents available from the Sustainable Energy and Climate Change Project and other sources. We do not have to wait for modelling to quantify the exact scale of public benefits that can be achieved, but any modelling that contributes to Integrated Energy Planning must consider such direct benefits and weigh them against the trickle-down benefits that continue to be assumed for conventional and centralised energy development premised on extractive industries.

Achieving the reduction in our dependence on coal and imported oil will require that energy planning be considered in a similar light to national security. As discussed in this report, financing requirements in the energy sector will be enormous, regardless of which technologies and resources (fossil or renewable) are prioritised and subsidised. In South Africa we have the opportunity to direct such finance in the public interest. This is particularly true in the electricity sector where one state-owned enterprise dominates and where the local development of RET industries can realise predictable cost reductions (as well as job creation), thus opening up opportunities in other energy sectors.

A just transition to sustainable energy in South Africa is a real possibility if it is initiated in the short term. Reduction of our dependence on conventional energy is inevitable over the long term, but will be at far greater cost and with little prospect of a just distribution of costs and benefits, if South Africa does not plan for it. The opportunities and resources are within our reach. Application of the ‘polluter pays’ principle and accountability of corporate and international financing institutions are necessary conditions. What is needed most is political commitment.

Richard Worthington,
SECCP Project Co-ordinator, April 2005

Acknowledgements

The authors wish to thank the funders (DANIDA) and managers of the Sustainable Energy and Climate Change Project for the opportunity to work on this stimulating and challenging project. It has been extremely interesting to look a little further into the energy future of our country, covering the full scope of energy options, and gaining some idea of the magnitude of energy transition that is required if we are to achieve a sustainable energy future.

The project manager Richard Worthington provided valuable guidance and comment throughout the project process. An early stage project presentation was made to a group of workshop participants from government, NGO and private sector stakeholders, who engaged actively with the problems and challenges presented. We would also like to thank a group of Energy Research Centre staff (UCT) who provided the lead author with an opportunity to present the work and receive feedback. Reviewers Richard Worthington, Professor Dieter Holm and Rob Short provided helpful comments on the draft report. Keith Sanderson and Abhijit Bhattacharya assisted with language editing. Martin Grosskopf, a member of the project steering committee, contributed to the shaping of the project. We were greatly saddened by his untimely death.

Douglas Banks and Jason Schäffler, April 2005

Executive Summary

Introduction

South Africa has an energy-intensive economy, currently using more than 4000 PJ primary energy per annum. The economy relies on low-cost electricity and coal to power energy-hungry industries such as mining and metals processing. Although growth in energy consumption has, for the last two decades, been slower than was anticipated in the late 1970s, more recent economic growth and improved distribution of electricity to households have resulted in significant increases in electricity demand. The country also relies on coal and liquid fuels for chemical processing, heating, transport and other activities. The renewable contribution to energy supply is relatively limited, with biomass being estimated to contribute 9 to 14 percent of energy needs and hydropower about 1 percent.

This report explores future energy scenarios (up to 2050), and attempts to understand the implications of growing power demand, changing technologies and an evolving energy environment. The focus is on the potential contribution of renewable energy and the path to achieve a more sustainable energy mix. The scenarios look far into the future, and the work has been undertaken with limited resources. The specific choices and projections made can certainly be questioned, and some will probably be proven incorrect. However, the trends and core elements are in line with international work, and we consider them to be highly plausible. The document's purpose is to stimulate thought and debate, and in doing so, help us prepare for the uncertain future.

Demand Scenario

In the next 50 years, as economic development takes place, energy demand is expected to grow significantly, driven particularly by important changes in livelihood patterns of the millions of people who live at or below the poverty line. There is a projected tripling of total energy and electricity requirements if current government planning projections (up to 2022) are extended to 2050. However the population growth rate is expected to reduce during the next 50 years. This, coupled with a greater awareness of energy efficiency and a shift away from an energy-intensive economy (gradual decoupling of economic growth from energy demand growth), could reduce the rate of increase in energy demand. We have therefore used a total energy demand of 6 700 PJ by 2050 against which to explore the potential contribution of renewable energy. Electrical energy demand comprises 1 279 PJ (366 TWh) of the total energy demand. The final scenario presented in the report uses the same 6 700 PJ total energy demand, but allocates a higher proportion of total demand to electricity (600 TWh).

Why Renewable Energy?

Growth in demand is not the only reason to consider alternative energy supply options. Firstly, current energy supply in South Africa is primarily coal-based and, although these resources will last for more than a century if used at current rates, large power plants will need to be replaced over the next 30 years. Secondly, coal has many other uses, and we need to conserve this resource for future use. Thirdly, coal and other fossil fuels, including oil, produce Carbon dioxide when burned to produce energy. It is now widely accepted that climate change, partially caused by human-generated Carbon dioxide, represents an extremely serious environmental threat to the world as a whole. Human-induced climate change is already being blamed for the higher-than-usual incidence of extremely damaging weather experiences (e.g. storms, droughts, melting polar ice-caps). Local air pollution is strongly related to energy supply options, with coal and oil products being major contributors to urban and rural air pollution and acid rain.

Renewable energy options are a sustainable energy supply option that can significantly reduce reliance on fossil fuels. Other advantages include employment creation, proximity to point-of-use and, in many cases, less reliance on concentrated sources of energy (and political power). Greater use of renewable energy would also reduce South Africa's economic vulnerability to the variable (and escalating) costs of imported fuels. International and local communities are increasingly trying to find ways to shift economies towards greater reliance on renewable energy. We anticipate that policy and regulation, as well as voluntary schemes such as the 'Clean Development Mechanism' and Renewable Energy Certificates will provide increased support for an expanded role of renewable energy in the economy.

Renewable Energy Potential in South Africa

Several renewable resources have the potential to contribute significantly to South African energy supplies. In particular:

- Solar thermal (for heating), solar thermal electricity generation and solar photovoltaic electricity generation. South Africa has an excellent solar resource.
- Wind electricity generation. South Africa has fair to reasonable wind resources by international standards.
- Biomass (heating, cooking, electricity and, in particular, liquid fuels for transport and cleaner cook stoves). Biomass already contributes between 9 and 14 percent to the total energy requirement, but it could be utilised more efficiently, and current use is not always sustainable.
- Hydropower. South Africa is not particularly well endowed with hydropower potential, but there is potential to import hydropower & to develop locally significant micro-hydro potential.
- Wave power. This is a new technology, but one from which South Africa could benefit, as there is an extensive coast-line with high wave energy potential. Ocean currents, thermal gradients in the sea, and even ocean grown biomass could also play a future role.
- Other resources, such as geothermal, may play a lesser role.

Resource/Technology Potential Contributions

Solar photovoltaic

Photovoltaic modules are already widely used in South Africa, serving perhaps 200 000 households (e.g. lighting, television, telecommunications) along side several thousand rural institutions and water pumps. At present, the solar modules are expensive, although their cost has been steadily declining. In the scenarios described, we envisage PV technology playing an extremely important role (up to 14%) in electricity supply by 2050.

The major drawback for solar generated electricity is that it is difficult to store. For off-grid systems, current storage technologies require significant running costs (due to their limited life). However, new technologies such as super capacitors, flywheels and fuel cells, as well as improved chemical batteries, are expected to reduce storage costs significantly. Currently grid-connected applications are the main international market for PV technology. In this case, the 'grid system' can be used as storage along with distributed storage options and pumped storage systems.

Solar thermal electric

Solar thermal electric technologies use the sun's heat to drive either conventional steam turbine-drive power plants, or to power more unusual engines such as the Stirling engine. In the medium term, these are expected to be cheaper than photovoltaics, but this comparison is uncertain 40 years into the future. However, solar thermal electrics have an advantage in that single plants can be built on a multi-megawatt to gigawatt scale. There is also some potential for energy storage in thermal energy stores (e.g. molten salt). This allows some solar thermal plants to run well into the evening, or even 24 hours a day. Gas hybridisation options are also practical. Solar thermal electricity generation is thus likely to play a larger role than PV in the medium term.

Solar thermal heating

Solar water heaters, process heaters, space heating systems and even solar cookers are all currently used in South Africa. The water heater market in particular shows significant signs of maturity and growth potential. However, as a country, South Africa is behind best practice norms with regards to utilising this resource. Neighbouring Botswana is far ahead and countries such as Israel use solar energy to heat 60 percent of their water. A recent study indicates that up to 43 TWh of electricity could be displaced by solar resources by 2030.

Wind energy

Wind energy conversion systems currently convert the energy in moving air to electricity. In the longer term, this energy could be converted to even more versatile energy carriers such as Hydrogen. Wind prospecting is in its infancy in South Africa and descriptions of this resource vary from 'abundant', through 'significant by international standards upon which wind industries have been built', to merely 'modest'. This study, pursuing a progressive yet plausible transition to a sustainable energy future, has included an annual contribution of 66 TWh and 80 TWh for the two renewable energy scenarios presented.

Focussed along the extensive coastline and the lowland/highveld escarpment, wind energy is a potentially abundant resource which could be readily extracted and converted to useful energy using off-the-shelf technology. As with other technologies seeking to harvest distributed resources sustainably, wind energy systems promise significant benefit in terms of building increasingly flexible, robust, secure, stable and cost-effective energy supply systems.

Hydro-power

Water scarcity concerns are often used to dismiss out-of-hand the potential for hydropower in South Africa. In reality, energy derived from extracting the potential energy of elevated water during its descent has an important role to play. This is especially important when one considers the huge volumes of water that are moved around the country in balancing the supply and demand for water, and the fact that the energy content of this water is seldom considered.

This study has considered the role of approximately 4 700 MW of domestic installed hydro capacity over and above existing national and imported capacity. Imported hydropower could add a further 7 000 MW – or even more, but there are concerns regarding supply security and political stability.

Biomass energy

Biomass energy is currently the largest renewable energy contributor in South Africa, estimated at about 9 percent (some data indicates as high as 14%). Most rural households and several hundred thousand low-income urban households rely on fuelwood for cooking and space heating. Biomass by-products are used in boilers by the sugar and paper industries to generate electricity. The South African government and other large stakeholders (e.g. Sasol) are currently developing the capacity to produce liquid fuels from biomass, with an estimated potential of 20 percent of the national liquid fuels requirement (45.7 PJ). The production of bio-ethanol, for possible use as a safer household fuel, is also receiving increased attention. In the longer term, we anticipate biomass contributing between 9 and 16 percent of the energy requirement.

Extensive use of biomass raises significant environmental concerns. The large-scale use of bio-energy would require vast areas of land to be converted to 'energy crops'. In the first of the two renewable energy scenarios described we have limited the area allocated to new energy crop production (for electricity generation) to be of the same order of magnitude as existing sugar plantations. The high renewable scenario uses higher figures, which would need better verification in terms of environmental impact.

Landfill gas

Landfill sites generate methane gas as a result of the decomposition of the biomass components in municipal waste. Landfill gas has a potential for 7.2 TWh of electricity generation, perhaps growing to 10.8 TWh by 2040. If the gas were to be used for process heat, then the energy extraction would be higher.

Wave energy

The ocean breakers crashing onto our shores have an average energy intensity of approximately 25 MW/km over about 900 km of coastline. If 75 percent of this coastline were suitable for converter installation, then a total generating capacity of about 18 000 MW could be installed. Eberhard and Williams (1998) estimated that a more conservative annual average of 8000 MW could be generated, with a winter average of 10 000 MW. This could yield up to 70 TWh per year.

Wave technology is receiving increased international and national attention and has better base load characteristics than many other renewable energy technologies.

Other forms of renewable energy

A number of other possible renewable energy options can be considered. Geothermal energy, located in the Western Cape, may be able to contribute about 500 MW, and ocean currents, such as the Agulhas stream, could also be exploited to generate electricity. These options have been grouped together in the scenario analysis in a 'Wave and Other' category. They are assumed to start coming on stream only after 2015, and by 2050, are assumed to yield 33 TWh per year (medium renewables scenario) – or in the case of the high renewable scenario 69 TWh/year.

Storage, distributed generation and energy efficiency

Energy storage is a critical element of energy planning, both for the electricity sector and for other energy options. Storing electricity in large quantities poses many difficulties. Electricity storage is especially critical in renewable energy systems due to the intermittent nature of many renewable energy sources and the variability in electricity load requirements. This combination of problems represents one of the most important challenges facing the widespread (small and large-scale use of renewable energy.

The scenarios in this study use pumped storage as the main storage technology. Existing capacity is approximately 1.5 GW and there is potential for 7 to 10.3 GW of new capacity, increasing total potential storage to 11.8 GW by 2050. A key limiting factor for pumped storage technology is its environmental impact. Meanwhile, other technologies are being developed, including redox batteries, flywheels, super capacitors, super conductors, and compressed air options. It is our opinion that adequate capacity will exist to be able to put the necessary storage in place as required. There will, however, be a cost penalty.

As the electricity supply sector evolves, there is likely to be greater use of distributed generation, and many of the renewable energy technologies lend themselves particularly well to distributed generation applications. This can help to reduce transmission and substation investments and can, to some extent, mitigate the requirement for storage.

Scenarios for Future Energy Supply

Three scenarios were reviewed for electricity generation: *business as usual*, *progressive renewable*, and a *high renewable* scenario. The 'business as usual' scenario (Figure S1) assumes very little support from decision-makers for renewable generation technology. The scenario clearly illustrates the huge increase in capacity of fossil plants that would be needed between 2022 and 2038. This raises major environmental and economic warning flags. It also highlights the opportunity that we have as a country to prepare for the capacity crunch, and to have alternative solutions in place for implementation on a large scale. The renewable energy contribution in this scenario reaches a maximum of 4 percent.

Figure S1: Business as usual - energy demand matching[1]

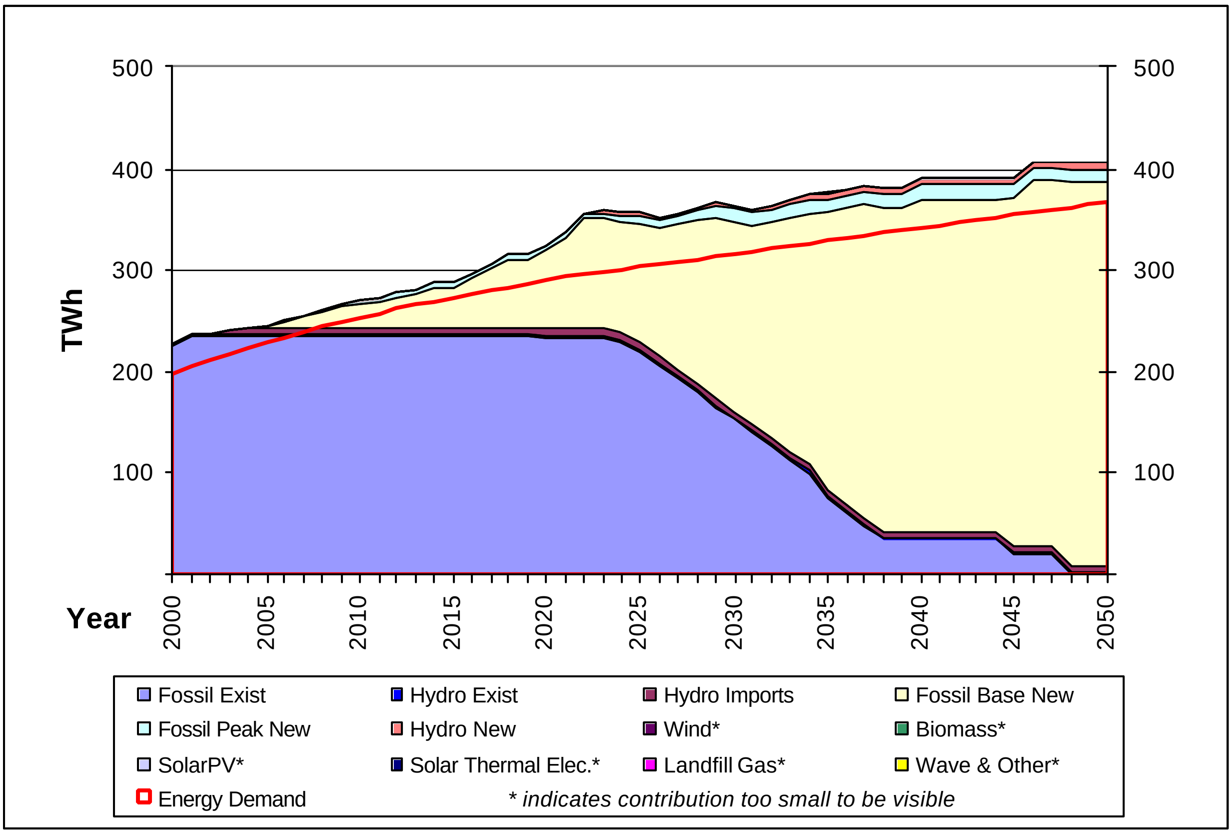
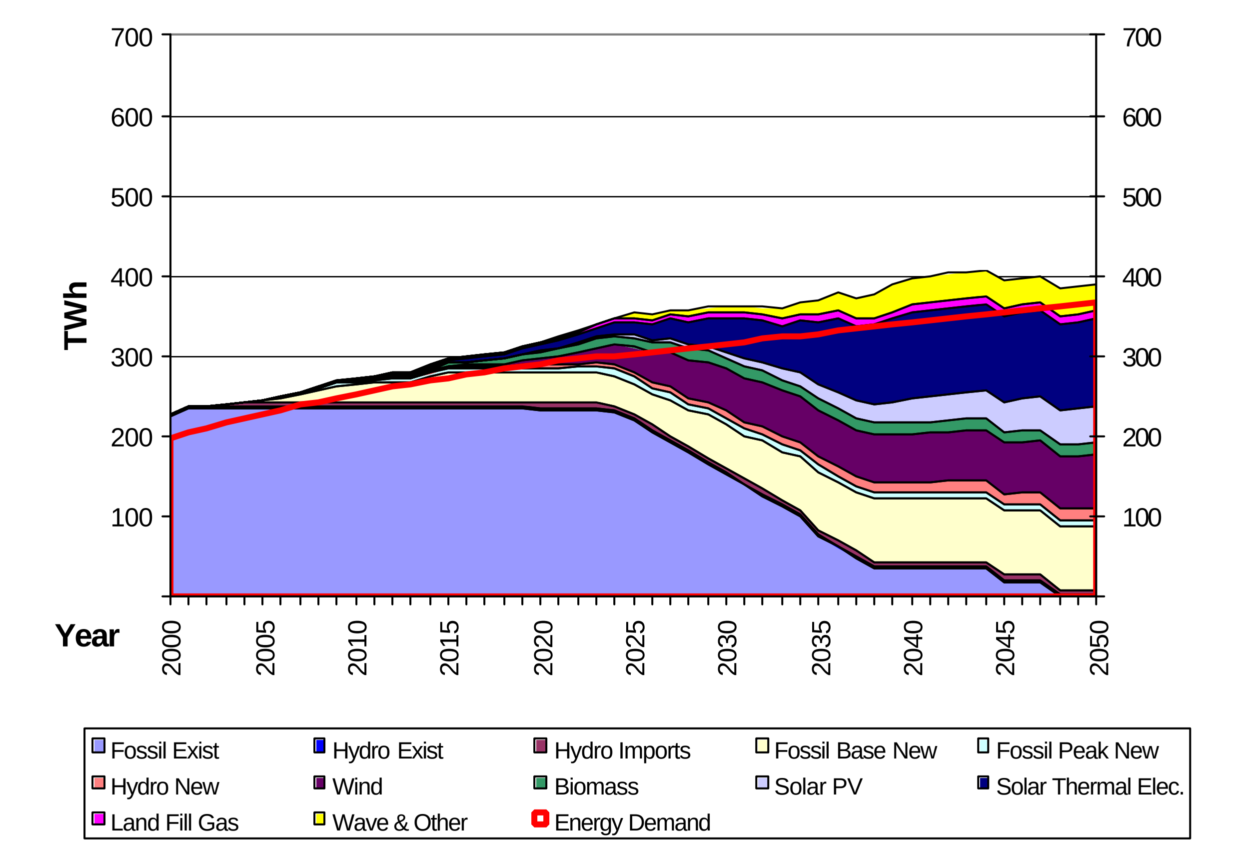


Figure S2 illustrates a 'progressive renewable' future in which renewable energy plays a moderate role in electricity generation by 2020 (about 13.3 percent contribution) and contributes about 70 percent by 2050. The pre-2020 installations would place the country in a strong position to expand capacity rapidly from 2022 onwards, as coal plants are decommissioned. Such preparatory work would be important for local capacity development and job creation. However, it may also be critical to secure the potentially realisable cost reductions in renewable energy technology.

[1] Supply is shown as being higher than demand because of the need to provide extra or reserve capacity to deal with peak demand periods or generation plant shutdowns for maintenance. In practice some of the generation equipment would be turned off or run at reduced output so that supply matched demand.

Figure S2: Progressive Renewable Scenario:
Illustration of how electricity energy demand would be met[2]



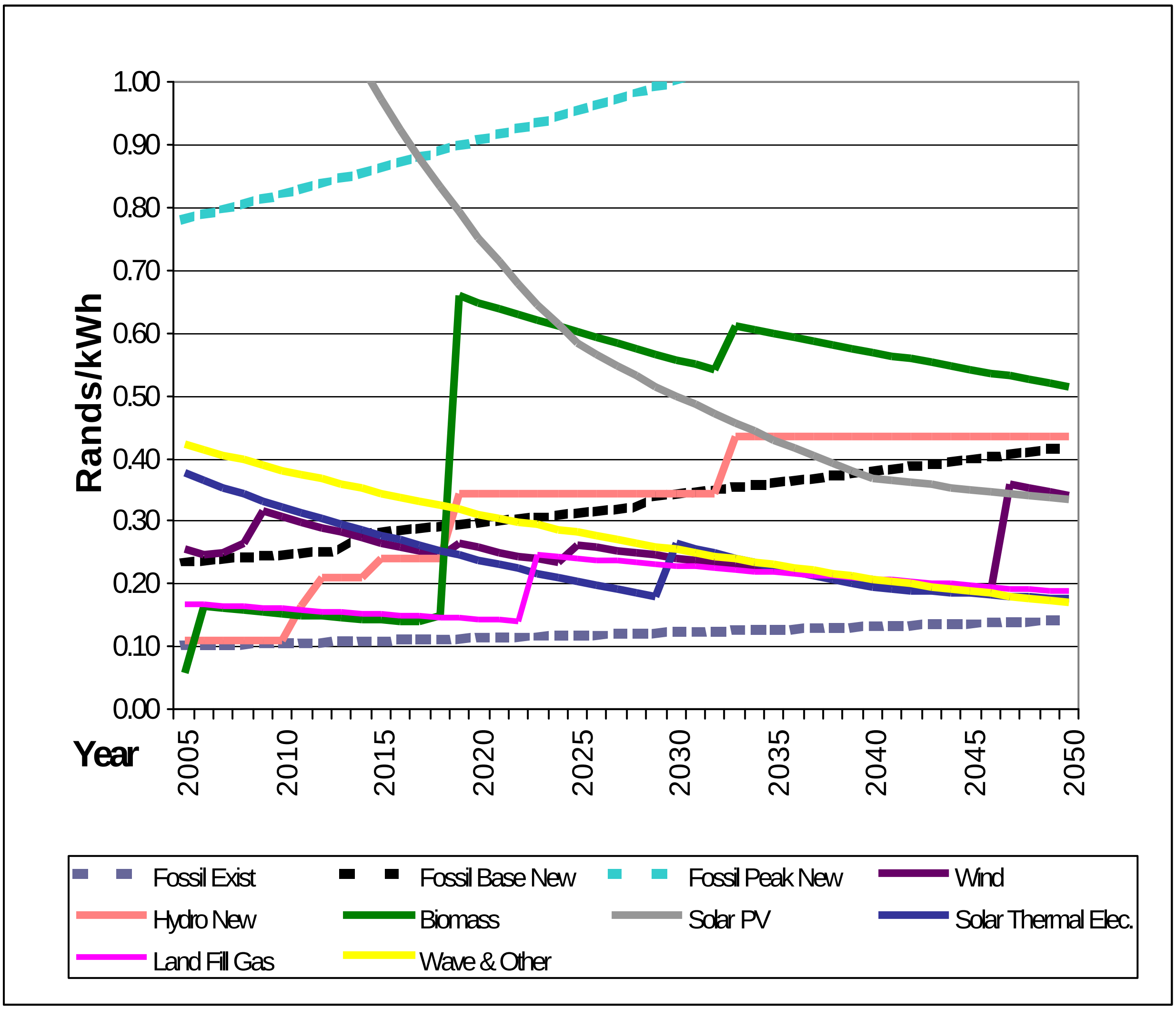
Both the above scenarios illustrate how short time really is, particularly in the light of the required growth rates for emerging industries such as solar PV, wind and solar thermal electricity. Effective large-scale industries will take time to develop and, even at a 20 percent annual growth rate, it will take several years before they can start to add energy capacity to the grid on the scale required.

Lower cost options, such as biomass, landfill gas and selected wind sites, are initially more attractive than solar and large-scale wind. However, these low-cost options have a limited resource base and it becomes important to balance development effort - harvesting the lowest cost resources but, at the same time, developing the necessary technical capacity to harness the larger-scale solar and possible wave technologies.

Although speculative, Figure S3 highlights, somewhat surprisingly, that renewable energy options are likely to be the most cost-effective options for energy supply in the future. Fossil fuel pricing is particularly difficult to predict (e.g. oil price in 2004/5), but if prices do continue to rise, it will not be long before solar thermal technologies in particular present a large-scale, economically viable power supply option.

[2] For colour version of this figure see Figure 5-4 on page 42.

Figure S3: Progressive Renewable Scenario: Illustration of the possible changes in cost per unit energy over time[3]



Electricity is of course only one part of the total energy requirement. The contribution of different resources to total final energy demand in the 'Progressive Renewable' scenario is illustrated in Figure S4. Four main renewable energy components are shown, together accounting for 35 percent of final energy consumption by 2050:

1) Biomass is expected to continue to play an important role as a direct source of energy, although the continued growth indicated in the graph is possibly not sustainable with respect to environment and food security.
2) Solar water heaters are shown to contribute approximately 150 PJ per annum by 2030. This would entail significant growth of the solar water and process heat market.
3) Biofuels (biodiesel, ethanol and other options) are shown as an additional biomass contribution, also contributing about 150 PJ by 2030. Note that this would have significant environmental impacts. At a production rate of 120 GJ/ha, this would require a land area of 12 500 km^2. This is about 1% of the South African total land area, and about as large as current forestry plantations.
4) The renewable energy component of electricity supply is illustrated.

[3] For colour version see Figure 5-6 on page 43.

Figure S4: Progressive Renewable Scenario: Illustration of final energy supply (in PJ), by resource

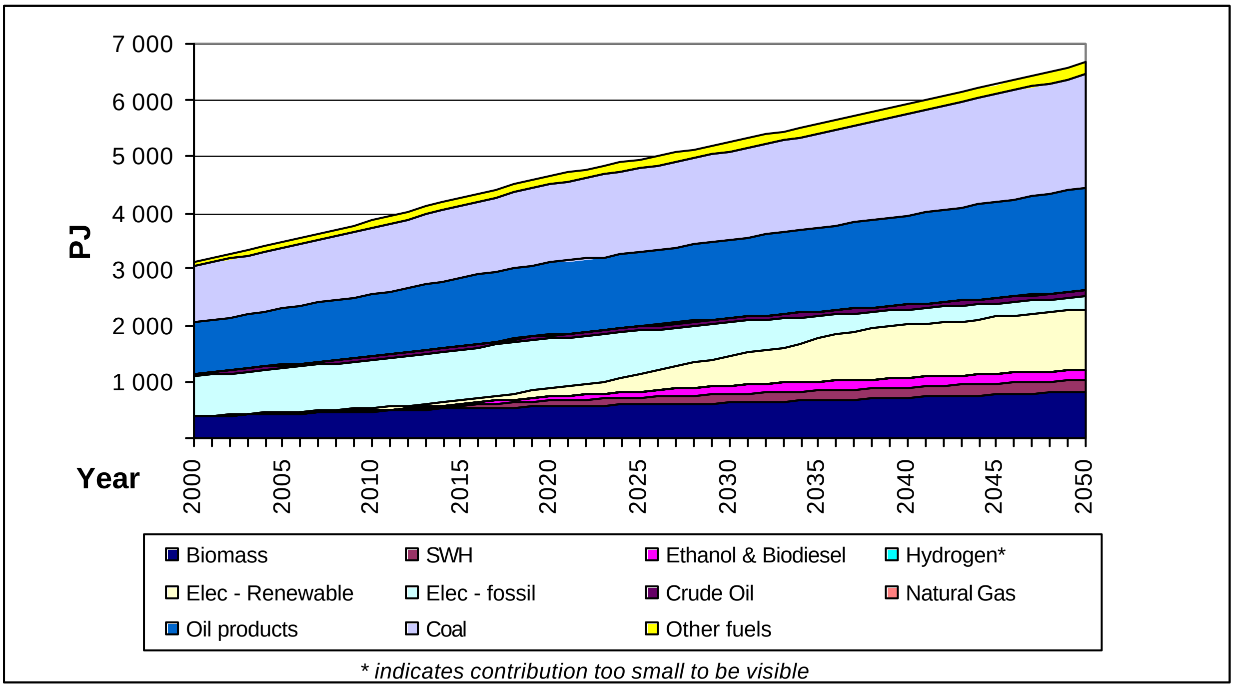
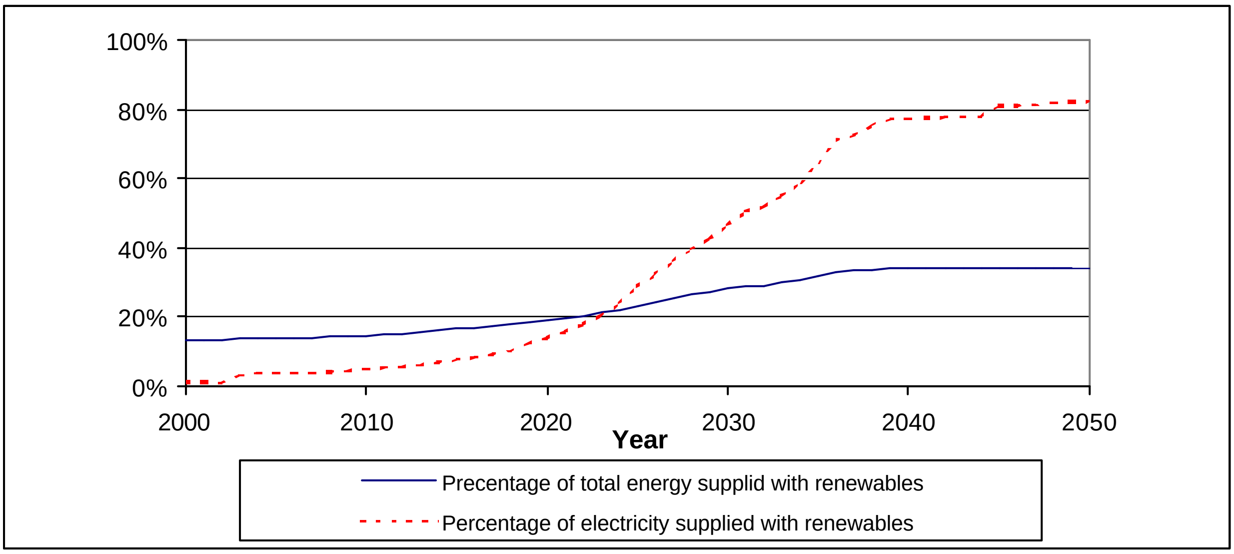


Figure S5: Progressive Renewable Scenario: Percentage renewable contribution to total final energy demand and to electricity supply



These scenarios and the resource assessment indicate that there are sufficient renewable energy resources in South Africa to provide about 15 percent of the electrical demand by 2020, and easily 70 percent or more by 2050. From a total energy perspective, the medium term contribution of 15 to 20 percent is quite feasible. However in the longer term, it will be difficult to achieve more than a 35 percent contribution by 2050 using the options discussed above. Indeed, it should be noted that the total consumption of fossil fuels increases from 2005 to 2050 in the 'Progressive Renewable' scenario, with obvious concerning implications for climate change, fossil resources and the environment. Note: the total energy scenario illustrations shown indicate that biomass currently contributes about 14% to final energy demand. If the biomass contribution is closer to the 9% indicated by some data, then the renewable energy contribution to total energy will have to be reduced by about 5%.

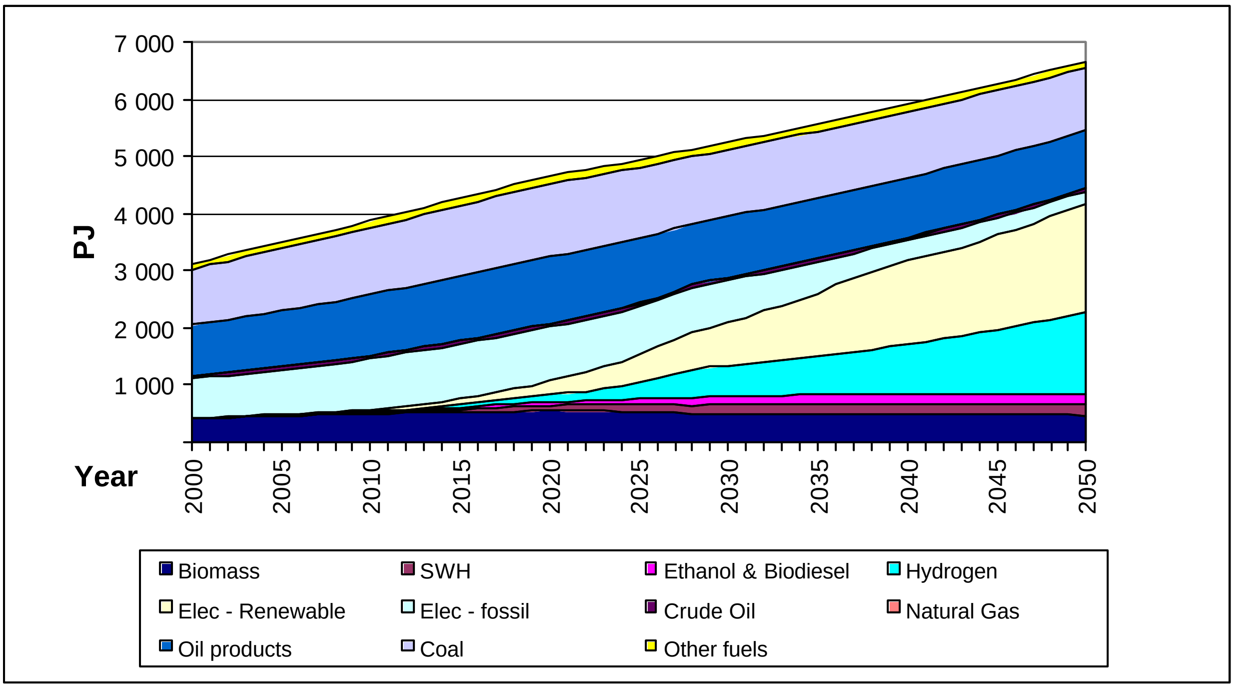
A third scenario called the 'High Renewable' scenario was then developed. This scenario looks at the options to achieve a net reduction in fossil fuel consumption by 2050, and could be considered as a 'climate change' driven scenario. It differs in two primary ways from the 'Progressive Renewable' scenario:

- it is assumed that a large proportion of the current non-electrical energy demand in South Africa (e.g. transport, coal or oil based process energy supply in industry) can be met by electricity (produced using renewable resources)
- it is assumed that Hydrogen can be generated from renewable resources on a large scale. This can be stored and transported and used as required, much like coal, oil and natural gas – thereby replacing a significant part of the remaining non-electrical demand.

The total energy demand has *not* been reduced, thus leaving a similar allowance for economic growth to that given in the *business as usual* and *progressive renewable* scenarios.

Figure S6 shows this *high renewable* scenario. It should be noted that total electricity demand has risen significantly (to 600 TWh, or 2108 PJ), and direct use of Hydrogen or other renewably produced energy carriers contributes 1400 PJ to the total energy demand by 2050. With these (or similar measures) it will be noted that the percentage contribution of renewable energy to the total final energy demand rises to 60% by 2050. Furthermore, there is a net reduction in fossil fuel contributions, thereby allowing South Africa to reduce its CO_2 emissions in line with the requirements for developed countries set out in the Kyoto Protocol.

Figure S6: High Renewable Scenario: Total energy supply mix[4]



The authors regard achieving the *progressive renewable* scenario to be extremely challenging. For South Africa to make the necessary shifts in the energy economy to achieve something like the *high renewable* scenario would be significantly more difficult. However, if the total energy requirement of the country is allowed to increase to 6 600 PJ[5] over the next 50 years then investments in energy supply will in any event be very large. If it is possible to develop the economy using approaches that do not require such an increase in energy consumption, and if energy efficiency can be effectively promoted at all levels- then the average annual growth in

[4] For colour version see Figure 5-11 on page 50.

[5] This is an average annual increase of only 1.5% over the 50 year period. Current National Integrated Energy Planning processes have energy demand growth rates in excess of 2.8% for some sectors – see Figure 2-3

energy demand could be reduced, or even pushed into the negative. This would obviously make it far easier to reduce the total fossil fuel contribution, without stretching the renewable energy resources and technology production facilities as much as indicated in the *progressive renewable* scenario.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ASSA	Actuarial Society of South Africa
CaBEERE	Capacity Building in Energy Efficiency and Renewable Energy (Danida funded project at DME)
COE	Cost of Energy
CSP	Concentrator Solar Power
DME	Department of Minerals and Energy
DST	Department of Science and Technology
GDP	Gross Domestic Product
GJ	Gigajoule
GWh	Gigawatt-hour
IEP	Integrated Energy Plan
MW	Megawatt
MWe	Megawatt electrical
MWh	Megawatt-hour
NER	National Electricity Regulator
NIRP	National Integrated Resource Plan
PV	Photovoltaic
SA PPI	South Africa Produce Price Index
SARB	South African Reserve Bank
SWH	Solar Water Heaters
Toe	Tonne oil equivalent (net, low heat value)
TW	Terawatt
TWh	terawatt-hour
Wp, kWp, MWp	Watt-peak, kilowatt-peak, megawatt-peak.

Energy Units

Power

MegaWatt (MW) — A unit of power (rate of energy consumption)
1 MegaWatt is equal to 1 000 000 Watts

GigaWatt (GW) — 1 GigaWatt is equal to 1 000 MegaWatts.

Energy

KiloWatt hour (kWh) — A unit of energy consumption. Unit used in domestic electricity billing

GigaWatt hour (GWh) — 1 GWh is equal to 1 000 MWh is equal to 1 000 000 kWh

TeraWatt hour (TWh) — 1 TWh is equal to 1 000 GWh is equal to 3.6 PJ

PetaJoule (PJ) — The Joule is the basic unit of energy, a PJ is 10^{15} Joules.

Note:
1 TWh of electricity and 1 TWh of Coal would be considered equivalent only if one were talking about final demand for energy or useful energy in each case. However, if a fuel such as coal is used to *generate* electricity, then typically only about 35% of the energy in the coal can be converted to useful electrical energy. It would therefore take 2.8 TWh (10.08 PJ) of coal to generate 1 TWh of electricity. For this reason it is common to use Watt hours (Wh, GWh, TWh) to represent *electrical* energy, and Joules (or PetaJoules) to represent the energy in fuels such as coal or liquid fuels. Another reason for sometimes citing both unit types is that the GWh and TWh are units for which electricity users have a better feeling of magnitude.

Conversion Table

From \ To	Gigajoule	Petajoule	Toe	GWh	TWh
Gigajoule	1	10^{-6}	$2.38x10^{-2}$	$2.78x10^{-4}$	$2.78x10^{-7}$
Petajoule	10^{6}	1	$2.38x10^{4}$	$2.78*10^{2}$	$2.78*10^{-1}$
Toe	42	$42x10^{-6}$	1	$1.16x10^{-2}$	$1.16x10^{-5}$
GWh	3.6	$3.6x10^{-6}$	86	1	$1x10^{-3}$
TWh	$3.6x10^{6}$	3.6	$8.6x10^{-4}$	$1x10^{3}$	1

Prefixes

Prefix	Symbol	Power
Kilo	k	10^{3}
Mega	M	10^{6}
Giga	G	10^{6}
Tera	T	10^{12}
Peta	P	10^{15}
Exa	E	10^{18}

A Glossary appears on page 59.

1 Introduction

Energy is the ability to do work, it enables things to move, and it is necessary for manufacturing, material processing, agriculture and mining. Energy enables us to cook food, and to keep warm on a cold night. Energy is required if we are to have light, power up a television set, talk on the telephone, or drive a car. Energy is essential to life itself as our bodies use energy to breathe, move and function. Energy is frequently taken for granted. We assume that someone will ensure there is enough petrol to buy, more wood in the communal forest, and electricity available at the flick of a switch.

In the following pages, we will explore a plausible and probable future, as we seek to understand what the best energy supply options for South Africa could be. We start with a brief overview of the current South African energy supply and consumption situation. We then use recent national studies to understand what the energy requirements will be over the next 20 years, and consider what the requirements for South Africa might be in 40 or 50 years time. We briefly explore what impact this may have on our environment, the resource base and the planet.

This sets the scene for one of the greatest challenges of our time: How will South Africans plan and invest for their future energy supply, and what energy sources will they use? This is a complex challenge and will require South Africans to use their minds, resources and hearts wisely. Fortunately, it is a challenge that we share with other countries in the region and throughout the world. Although the specific situations within each country are different, the global challenges are the same, and many of the solutions are applicable in a variety of situations.

For several reasons (discussed in more detail later), renewable energy options present perhaps the only truly long-term solution to humanity's energy supply dilemma. The focus of this report is to present information on the potential role that renewable energy resources could play in solving this challenge. To enable us do this:

- We need to build a clear picture of what those resources are, how they can be converted into useful energy, and how much energy they could produce.
- We need to determine the costs (in financial, economic and environmental terms) of using renewable energy on a large scale, and to compare these with the costs of continuing to use alternative fossil-based fuels.

Our approach in undertaking this research and writing this report is to use analyses and arguments that are as transparent as possible, and that can be presented in a clear and simple form. Time and resource constraints have regrettably made it impossible to undertake detailed rigorous analysis. In particular, we have not been able to explore costs in enough detail. Development of a long-term energy solution for South Africa is an unfolding process, with many different levels of input and commitment required.

2 Background Information

2.1 Current Energy Supply and Consumption

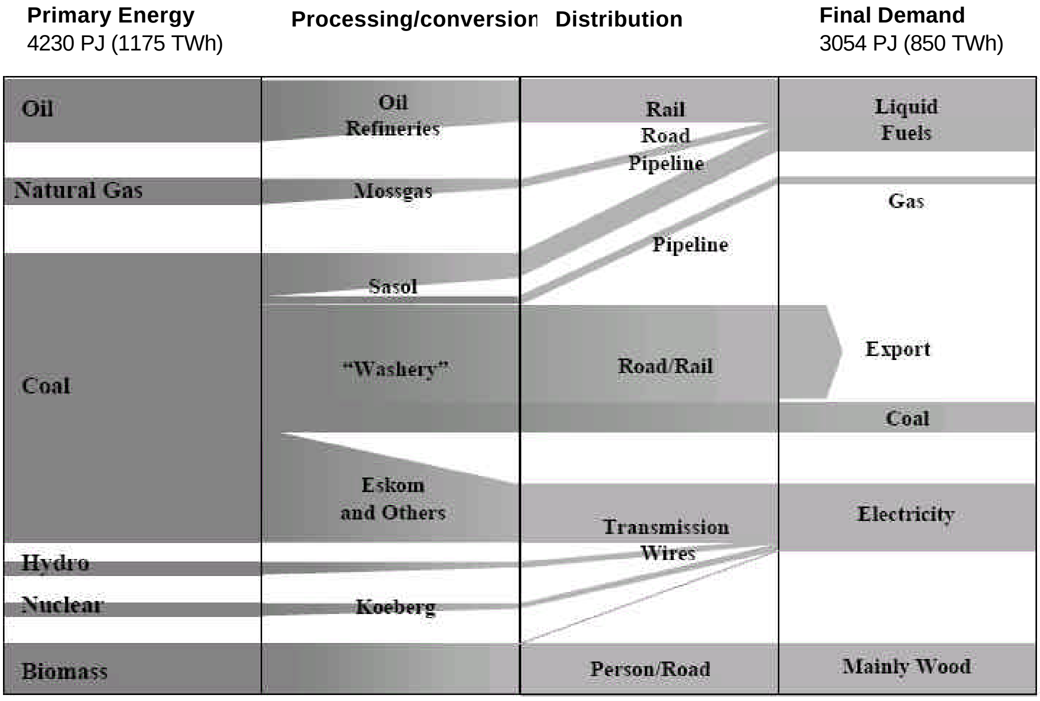
South Africa has the highest energy consumption per capita in Africa, with total energy consumption in 2003 being of the order of 4 230 PJ. This is equivalent to the amount of energy required to lift 215 596 billion 20-litre containers of water[6] (each weighing 20 kg) up a flight of stairs 100 m high! On a personal level, if each person living in South Africa were to use an equal share of this energy each year, it would be about 26.7 MWh (equivalent to the energy required to carry 5 million 20-litre containers up that 100 m high staircase).

[6] In rural areas of South Africa, households typically collect water in 20-litre plastic containers

Figure 2-1 illustrates energy flow in the economy. South Africa has a very high reliance on coal and crude oil; in 2000, these two combined to contribute about 88 percent or 3 720 PJ of input energy. Although South Africa has extensive coal reserves, and exports half as much again as is used internally, oil reserves are small and the country imports almost all crude oil requirements. Biomass (renewable if sustainably harvested) provides 9 percent the input energy, or about 106 TWh. Of this amount, it is estimated that 86 PJ (24 TWh) is from fuelwood used mostly in rural communities (WEC, 2003, p39)[7].

Figure 2-1 Energy flow in the South African economy

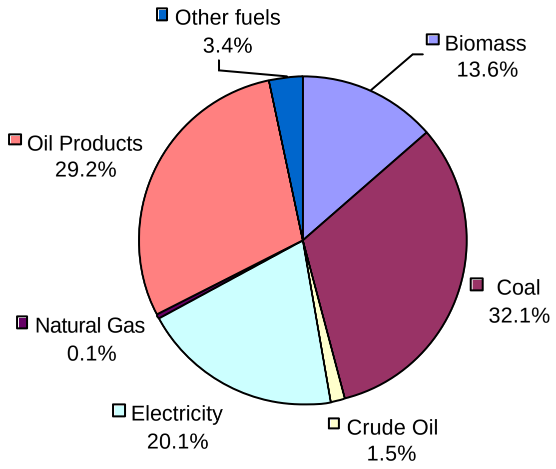
The thickness of each band gives an approximate indication of the quantity (DME, 2003, p. 6). Note that final energy demand figures do not take end use conversion efficiency into consideration. Thus the same services could often be delivered with far less energy.



A significant part of the primary energy supplied to the economy is converted to other forms of energy before being made available to users. For example, most of the coal, all the hydropower and all the nuclear energy is used to generate electricity. Coal is also used to produce liquid fuels (e.g. diesel and petrol). When energy is converted from one form to another, there are conversion and distribution losses, so the final available energy becomes far less, about 3054 PJ (850 TWh) in 2000 (Kenny 2002) (Figure 2-2). Although electricity may be regarded by many as the most important final form of energy, it should be noted that the country uses more energy directly from oil (mostly for the transport sector) and coal (mostly for chemical production and industrial process heat) than it does electricity.

[7] This is a 'rough' estimate, as biomass consumption is not easily measured. Electricity and oil consumptions are far more accurately known.

Figure 2-2 Final energy demand by fuel, 2000 (Kenny, 2002, p. iii)



Note: The data presented does not distinguish between primary and final demand for biomass. The above figure therefore indicates a relatively high percentage of energy provided by biomass, but it should be noted that the useful energy received is far less (much of this is used for cooking). The electricity component includes some renewable electricity (about 1%).[8]. It is useful to personalise the above figures, imagining that each one of us is responsible for using our 'share' of the above energy pies directly. Table 2-1 translates final demand by fuel into per capita figures, assuming that there were 44 million people in South Africa in 2000.

Table 2-1: **Per capita energy consumption expressed by energy carrier**

Fuel/energy carrier	MWh equivalent used per year	Amount of fuel consumed per year
Natural gas	0.019	3 litres
Oil products	5.630	526 litres
Crude oil	0.289	27 litres
Coal	6.189	1.114 tonnes
Biomass	2.622	555 kg
Other fuels	0.656	–
Electricity	3.875	1.899 tonnes (coal to generate)
Total	19.28	
Water for electricity		4 900 litres
Greenhouse gases (CO_2) equivalent released		8.61 tonnes

Based on these figures, the 'average South African' burns about three tonnes of coal a year and more than 500 litres of liquid fuel. These are non-renewable fossil fuel resources. One might be tempted to say that much of this consumption is for industrial and commercial use rather than for personal use. However, it must be remembered that industrial and commercial activity only takes place because we, as individuals, want the products and services (or export revenue) they provide. It is our individual purchasing and consumption decisions that ultimately drive this energy consumption. It is also important to remember that most people reading this report are responsible for far higher energy consumption than the South African average. Pause for a

[8] There is some uncertainty about the exact contributions of different fuels to final energy demand. For example, DME 2002, p 5 has electricity 26%, Coal 30%, Renewables and Waste (including biomass) 9%,Petroleum products 33% for the year 2000.

moment to consider the change in total energy consumption that would occur if every poor South African were to be able to live the resource-intensive lifestyle that many readers of this report enjoy.

South Africa consumed more than 200 TWh of electricity in 2002, with a peak demand of almost 32 GWh. Over 92 percent of the electricity used is generated from coal, and about 18 percent of that electricity is used in households (WEC, 2003, p. 33).

2.1.1 The Renewable energy contribution to South African energy

The current renewable energy contribution to South Africa's energy needs has not been accurately quantified, with the major uncertainties being biomass and solar water heaters. Table 2-2 provides an assessment of current renewable energy contributions.

Table 2-2: **Current renewable energy contributions (total grid electricity data is provided for comparison only)**

	Existing mixed-Grid production	Hydro-power	SWH (2002)	PV (2002)	Wind	Biomass
Capacity (MW)	39 493	641	242	12.1	29 (including 23 MW boreholes)	Not applicable
Annual prod, (GWh)	207 000	1057	511	21	60	106 000
Reference	NER 2002	Barta 2002 DME energy balance, 2001	Cawood & Morris 2002, p 15	Cawood & Morris, 2002, p. 27	Tripod & Oelsner, 2003 in World Bank 2004	WEC, 2003, p. 39. Note, expression of biomass in GWh does not imply 100% conversion to useful energy.

Table 2-2 shows that the current contribution by wind and solar PV is minute in energy terms. There are, however, hundreds of thousands of PV installations and wind pumps, so the contribution to service delivery is significant. The contribution of solar thermal heaters is more significant, but still less than a quarter of a percent of the energy supplied by the national grid. Hydropower has a more significant contribution at approximately 0.5 percent of total electricity demand.

The South African government has a set a target of 10 000 GWh (or 10 TWh) of electricity to be produced by renewable energy (excluding large-scale hydro) by 2013 (with the cumulative counter starting in 2003 when the White Paper was approved). The Integrated Resource Plan of the National Electricity Regulator (NER) (NER, 2004b, p. 28) includes, as an option to the preferred plan, the installation of solar thermal electrical power plants, with a total capacity of 300 MW, plus 20 MW of wind turbines. Together, these would produce about 2TWh per year from 2008 onwards, only 1 percent of current grid consumption. Other options under consideration include the large-scale use of biomass power generation and the harvesting of land-fill gas.

2.2 How Much Energy is Needed?

The formal demand prediction of electricity (or energy consumption) is a complex task, usually undertaken with the aid of models such as LEAP (Long-range Energy Alternatives Planning). It is necessary to quantify growth in population, changes in housing and the economic situation of households, national gross domestic product, plans for large-scale industrial development and many other factors. All these factors will influence energy consumption. The National Integrated

Energy Plan used a predictive model to develop four energy demand scenarios. The model used several input variables and assumptions, with key assumptions listed below (DME, 2003a, p. 13):

- Twenty year planning period (2001 to 2020)
- Process performance data and costs and commodity prices at 1 January 2001 values
- US$1 = R8 (1 Jan 2001)
- Net discount rate: 11 %
- Inflation rate: 5.5 % (SARB target 3 – 6 %)
- Population growth: 2000 = 44 million, 2010 = 50 million (1.3 % p.a.), 2020 = 57 million (0.87 % p.a.)
- GDP growth: 2.8 % average annual growth over the period
- Gas generally available from South Africa, Namibia and Mozambique at $2.5/GJ escalating at SA PPI
- 20% coal price increase for Sasol from 2008
- At least 15 % Sasol coal/liquid process replaced by gas/liquid process by 2015
- Coal supplied to industrial and other processes (except electricity generation) at R6/GJ.

The National Integrated Energy Plan (IEP) assumption of significant population growth by 2010 is far higher than that predicted by other sources, such as the Actuarial Society of South Africa (ASSA) AIDS 2000 model. The latter takes account of the HIV/AIDS epidemic and indicates no significant growth (and possibly a decline) in population up to 2015. Projections from several population models are listed in Table 2-3 (summarised from Health Systems Trust, 2005). If the effects of HIV/AIDS are as serious as models such as the ASSA 2000 indicate, this will reduce energy consumption growth, partly because of lower population growth and partly because of the likely impact on economic growth.

Table 2-3: **Population projections (summarised from Health Systems Trust, 2005)**

Projection source / projection year	Total population (million)	Comment
ASSA 2000 No change, 2015	46.6	ASSA 2000 model published in 2002 by Actuarial Society of South Africa; assumes low level of intervention
ASSA 2000 Change, 2015	47.3	ASSA 2000 model; assumes medium level of intervention
Metropolitan: 2021, low	53.6	Based on the Doyle model presented by Metropolitan in 2001
Metropolitan: 2021, high	67.7	
Metropolitan: 2031, low	54.9	
Metropolitan: 2031, high	76.4	

Figure 2-3 shows the baseline scenario used in the DME's National Integrated Energy Plan (to 2022), with the growth rate of each sector extended from 2022 to 2050 at the same rate. With these assumptions, energy consumption would more than triple by 2050. In order to meet this demand, energy supply options would need to increase significantly. Note that the figure includes non-energy applications (such as conversion of coal to chemicals). Figure 2-4 illustrates possible growth patterns for each of the primary energy sources, assuming each source retained its share of the market. Resources such as Solar Water Heaters (SWH), ethanol and biodiesel, although listed, are not visible because their current contribution is so small.

Figure 2-3 Energy demand by sector- baseline projection: (DME, (2003 p16) to 2022, and then extended to 2050 using the pre 2022 rates of growth)

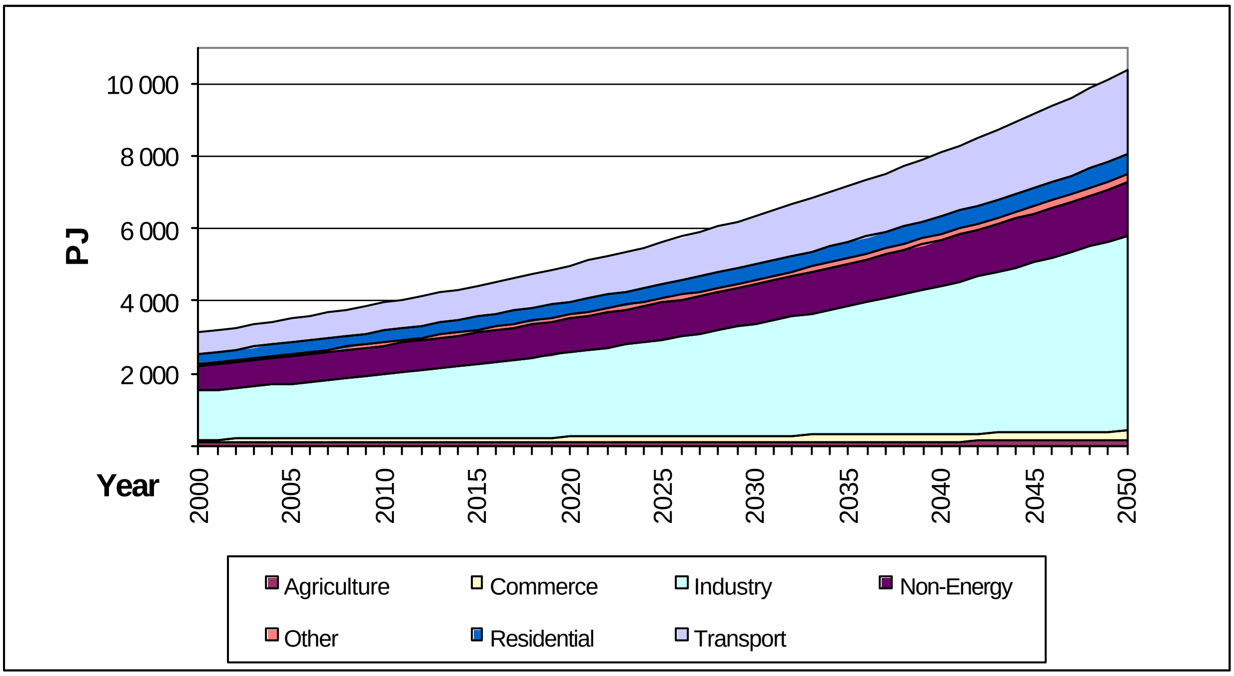
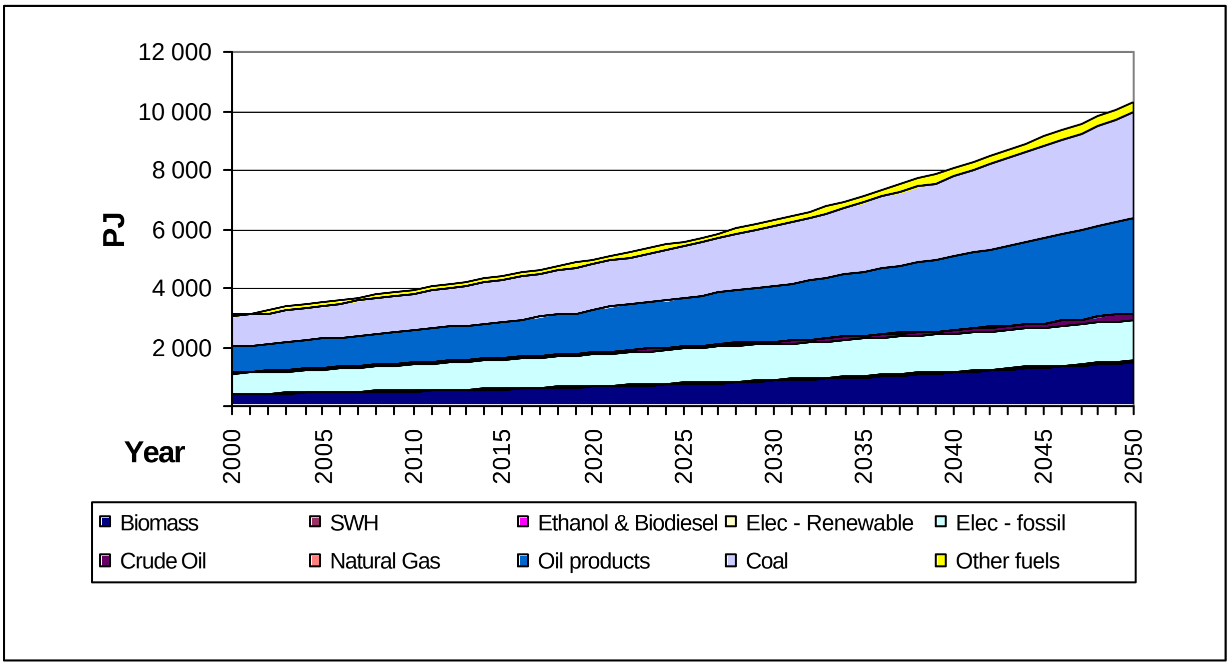


Figure 2-4 Projected energy demand by source



Such proportional growth for the different energy sources is, of course, unlikely. The National Integrated Energy Plan anticipates greater use of natural gas over the next few years. Biomass consumption is unlikely to grow at the rate indicated, unless it is specifically targeted as a renewable resource. The modelling necessary to explore differences in non-renewable energy source growth rates is, however, beyond the scope of this report.

This magnitude of expansion in energy demand is, in our opinion, neither feasible nor sustainable. It would simply have too great an impact on the natural environment. In order to reduce the growth in demand, energy conservation, wiser use of scarce resources and the introduction of energy efficiency measures must be brought to bear within the next few decades, but at the same time allowing improvements in quality of life and economic growth. For these reasons, we have used a total energy demand scenario that grows to a maximum of 6700 PJ, as illustrated in Figure 5-7.

These energy demand scenarios will be revisited in Section 5, when we take account of the potential contribution of potential renewable energy.

2.2.1 Growth in electricity demand

The NER coordinates a regular process to update a National Integrated Resource Plan for electricity supply. NER (2004a, p. 5) uses an electricity demand projection model to estimate electricity requirements to 2022. Table 2-4 summarises the projected rate of increase for low, medium and high demand scenarios. We have used our own estimates for the period 2022 to 2050. For reasons discussed more fully in Section 4.5 of the report, we have used the last column, 'Energy Conscious model', as the basis for the *business as usual* and the *progressive renewable* demand scenarios discussed in Section 5.

The Energy Conscious demand growth model is intended to provide sufficient increase in capacity to allow economic growth and effective service delivery to households, provided that:

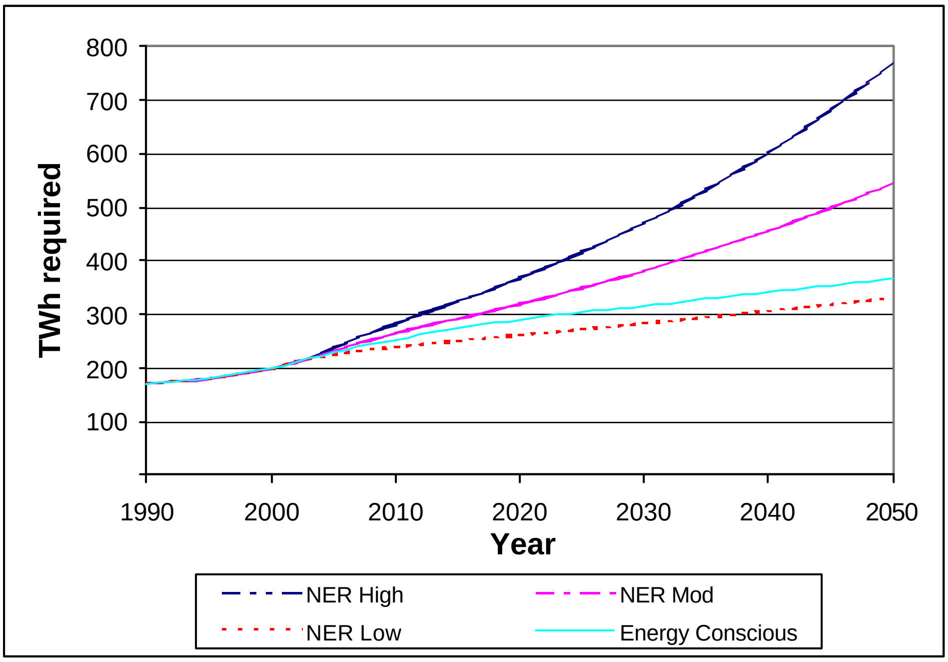
a) There is wise use of resources
b) Energy efficiency measures are encouraged
c) The existing international trend towards less energy intensive industries is replicated in South Africa.

Table 2-4: **Average growth in demand over intervals. (Sources: Unshaded cells = NER, 2004a, p. 13, shaded cells = RAPS Consulting projections**)

Year	NER NIRP (high) % growth	NER NIRP (medium) % growth	NER NIRP (low) % growth	Energy Conscious model
2003 – 2008	4.30	3.20	1.60	2.40
2008 – 2013	3.10	2.30	1.00	1.80
2013 – 2018	2.60	1.80	0.90	1.40
2018 – 2022	2.50	1.80	0.80	1.20
2022 – 2030	2.50	1.80	0.80	0.80
2030 – 2040	2.50	1.80	0.80	0.80
2040 – 2050	2.50	1.80	0.80	0.70

The increase in electricity supply required for each of the above scenarios is illustrated in Figure 2-5. The 'NER High' curve illustrates the concerning implications of continued growth in demand at levels of more than 2 percent, with total consumption of electricity more than tripling by 2050.

Figure 2-5 NER IRP and RAPS Consulting scenarios for electricity supply growth



South Africa enjoys one of the lowest electricity prices in the world. Linked with an excellent minerals resource base, this has made the country attractive for energy-intensive mining, metals processing and beneficiation industries. The consumption of electricity per unit gross domestic product has steadily increased from 1950 to the late 1990s, with a marginal decrease thereafter (NER, 2004a, p. 16).

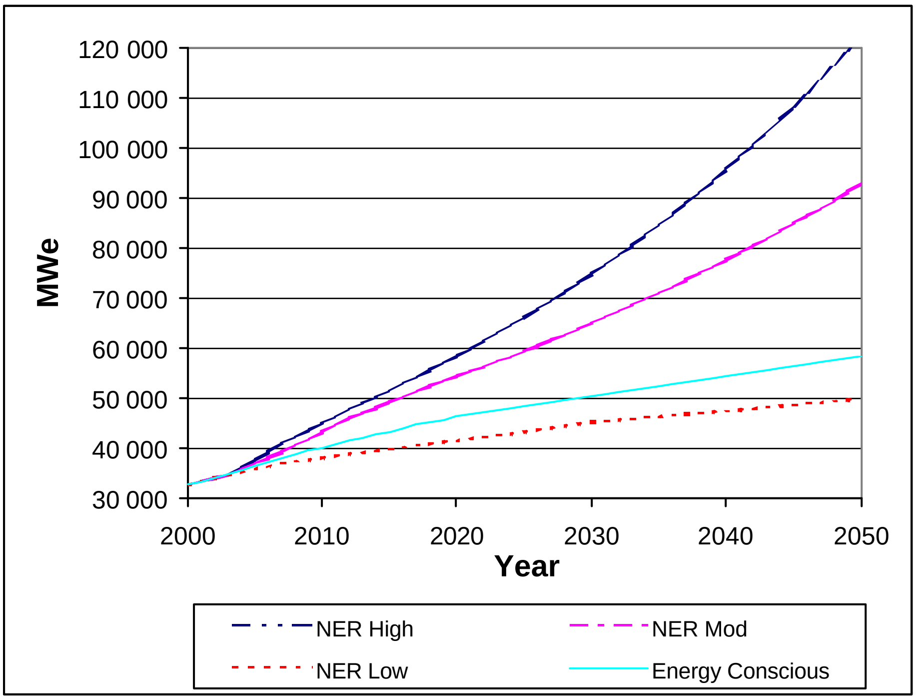
Energy-intensive industries often have significant opportunity to save through energy efficiency. Therefore, there is some potential to reduce the growth of energy consumption. Furthermore, there is an international and national trend towards a greater share of the GDP being generated through lower energy intensity and added value services, rather than from primary material production. A balance of these factors could assist economic growth, while at the same time holding energy demand growth rates closer to the NER 'medium' or the 'Energy Conscious' scenarios.

2.2.2 Growth in peak demand for electricity

In addition to planning for total annual electrical energy requirements, an equally important requirement is to ensure that sufficient generation capacity is available at all times to meet the peak demand for power. There are two daily peaks in electricity consumption. The first is a lower peak occurring in the morning, and the second is a higher, steeper peak occurring in the evening. These are primarily related to domestic activity at these times, and also to industrial and commercial plant start-up. There are also seasonal peaks, with the highest consumption occurring in winter during 'cold snaps'. In considering different technologies and resources, it is therefore critical to investigate their ability not only to produce a particular amount of energy over the year but also their ability to produce power when needed.

For the purposes of this study, we have assumed that the load factor (ratio of peak demand (MWe) to total energy demand (GWh)) will remain similar to current values for the planning period. This is likely to be the worst case, as ongoing efforts by Eskom, the NER and other parties seek to move loads from peak periods in the day and year to off-peak periods, thus improving the system load factor. Figure 2-6 illustrates the peak demands associated with the total energy consumption curves of Figure 2-5. Note that the load shifting and energy efficiency measures required to meet the peak demand would entail a significant level of effort from all parties involved, with government policies and measures playing a key role.

Figure 2-6 Peak Demand growth scenarios (assuming a constant ratio between peak demand and total energy consumption



2.3 Why renewable energy?

The energy production and consumption patterns described represent the current situation in South Africa. However, the South African economy needs to grow and its population will probably continue to grow. There are also great efforts to provide the people with better services and resources, not the least of which are access to electricity, access to modern cooking fuels, increased employment (more industry and commerce) and improved mobility. This report is concerned with the future energy supply for South Africa. It might initially be expected that the future energy supply options would be similar to those listed in Section 2.1, but just 'more of the same'. The country will simply mine more coal, buy more oil, generate more electricity – or will it?

The three major areas of concern which affect the country's ability to supply more energy to its people, and which will (or should) influence decision-making, are as follows:

1) The current high reliance on fossil fuels is unsustainable in the longer term (refer to Box 1):
   - o Oil is running a finite resource. Many studies suggest that we have reached the peak of possible production, and there have already been significant price increases.
   - o Although there are ample reserves of coal to last a century or more at current rates, this fuel will eventually become more scarce and more expensive, with diminishing returns on capital and energy invested for recovery of less accessible deposits (e.g. through underground 'gasification').
   - o Large fluctuations in energy prices for industry and households have huge economic and social consequences.
   - o We should not simply burn all our hydro-carbon resources, which may be of far greater value and varied application to our children, and our grandchildren.
2) Fossil fuel use has a significant negative impact on the local environment. Every MWh of electricity generated in South Africa requires an average of 1270 litres of water (nearly 5 000 litres per capita per year). Coal and biomass burned in homes and industry cause pollution which affects both health and vegetation. Coal mining leads to environmental degradation in the mining areas.
3) Fossil fuels are all Carbon-based, and as currently used, they result in the emission of carbon dioxide into the atmosphere. These emissions are responsible for global warming as

a result of the 'greenhouse' effect. Global warming has a significant impact on weather patterns, agriculture and sea levels. South Africa emits 379 million tonnes of carbon dioxide equivalent greenhouse gases per year (WEC, 2003, p. 49), or 8.61 tonnes/capita, and is one the top 20 greenhouse gas emitters in the world. Refer to Box 2.

There are six main opportunities that South Africa can explore in an effort to provide enough energy to fuel a growing economy and to meet household needs in a manner that addresses the consequences of high reliance on fossil fuels:

1) Convert fossil fuels more efficiently into the final energy forms that are needed, thereby stretching limited resources further to allow more time to develop alternatives (e.g. more efficient coal power stations, more efficient coal-to-oil conversion technologies)
2) Trap greenhouse gases and store them (carbon capture and storage or sequestration); this only helps to reduce climate change, and there is still reliance on fossil fuels
3) Use fewer services requiring energy (e.g. less transport, more reliance on public transport, turn lights off when not needed)
4) Use energy more efficiently, achieving similar or even better levels of service, but in a more energy-efficient manner (e.g. energy-efficient lights, more efficient transport)
5) Use nuclear energy
6) Use renewable energy instead of fossil fuels.

Only options 5 and 6 allow a truly significant departure from the current reliance on fossil fuels, and in the longer term, these two represent the primary hope for global energy supply. Several authors regard nuclear energy as being an important component of future large-scale energy supply, allowing South Africa and the world to reduce reliance on fossil fuels. Significant nuclear fuel resources are available, and nuclear power stations have very low greenhouse gas emissions. However, there are many attendant problems with nuclear energy, including the risk of nuclear accident, nuclear waste transport, waste disposal (short- and long-term) and the risks of nuclear terrorism and nuclear weapon proliferation. This report does not explore these debates, but rather focuses on the potential for *renewable energy* to contribute to a more sustainable energy future for us all.

Box 1: Fossil Energy Prices

Under current market conditions, many renewable energy technologies in South Africa are not financially competitive when compared with fossil fuel options. The cost of mining coal is relatively low, and with the current strength of the Rand, the country has been relatively cushioned against recent increases in liquid fuel import costs. However, as discussed elsewhere in this report, prices for most renewable energy technologies are expected to decrease over the next few decades. On the other hand, fossil fuel prices are subject to a number of factors which may lead to increases in the effective price payable:

- Fossil resources are finite and, as they become increasingly scarce, real costs of finding and extracting them will increase.
- Global demand for fossil fuels continues to increase and, coupled with supply constraints (particularly for oil), this will lead to price increases. For example, the International Energy Agency's (IEA) assumptions for long-term oil demand growth are projected at an average of 1.9%, from 77 million barrels/day in 2001 to nearly 121 million barrels day by 2025. Linked to its growth projection, IEA projected a gradual price increase of 0.7% per annum, reaching $27/barrel by 2025 (IEA 2004, p. 28). Recent planning documents (e.g. DME, 2003) used long-term oil costs of $24/barrel. During 2004, the price reached $50/barrel and has not yet dropped back below the 'high' scenario projected in the IEA document (about $38/barrel). Recent price hikes are partially due to the depreciation of the US dollar, but real concerns of supply/demand imbalances are being raised.
- Although its own coal reserves partially buffer South Africa against oil volatility, persistently high oil prices will result in increased export coal prices, with a corresponding increase in the price that can be charged locally (as it is possible to produce liquid fuels from coal).
- Climate change concerns mean that fossil fuels effectively carry a Carbon surcharge (the amount payable for Certified Emission Reductions, CERs). At present, CERs carry a value of between 2 and 10 US dollars per tonne of CO_2 equivalent. However, as opportunities to reduce Carbon dioxide emissions are taken up, it is probable that CO_2 savings will become more highly valued.
- Local and regional air pollution from fossil fuel combustion (especially in power stations, vehicles and cooking devices) is significant. As 'polluter pays' principles become more entrenched, this is likely to result in upwards pressure on prices for energy derived from fossil resources.

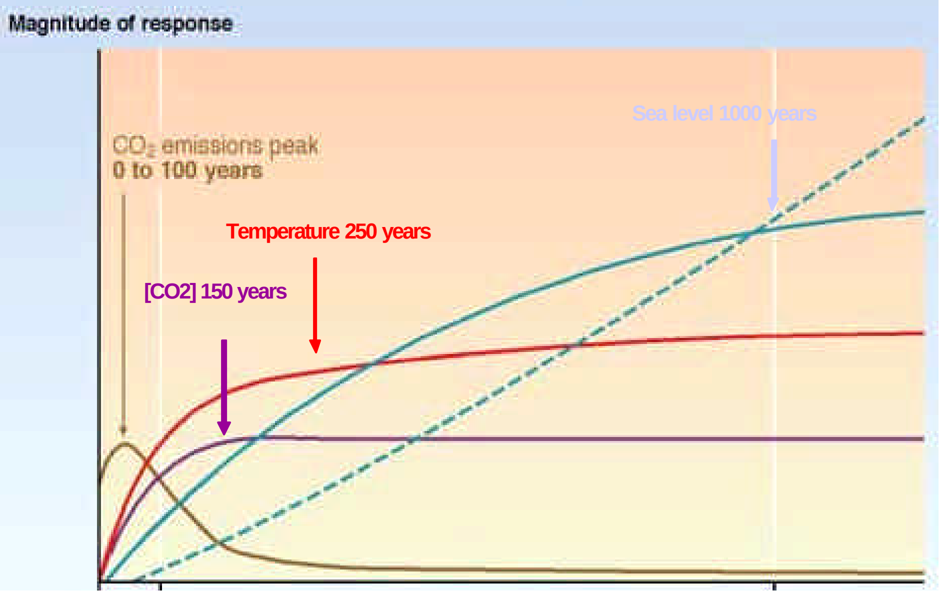
Box 2: Climate Change - Global Threat with Local Consequences

South Africa has an energy-intensive economy that is very reliant on fossil fuels. As a result, per capita CO_2 (and other 'greenhouse' gas) emissions are amongst the highest in the world, and the country ranks among the 20 highest contributors to CO2 emissions overall. South Africa produces approximately 2% of global GHG emissions, and yet has only 0.7% of world population, and produces 0.9% of world GDP.

Over the last decade, increasing evidence has been gathered to show that human-induced emissions of CO_2 and other greenhouse gases are having a noticeable impact on global climate. This is leading to a gradual increase in temperature, gradual melting of the ice caps, rising sea levels and a host of related climate change symptoms. Already, large 're-insurers' are claiming that weather-induced natural disasters have been more severe in the last ten years than previously recorded. Governments, insurance companies and consumers are realising that something has to be done. The recent ratification of the Kyoto Protocol heralds a new era, in which a growing number of countries have committed themselves to reductions in greenhouse gas emissions. As a developing country, South Africa has not made a formal commitment to reducing emissions below current levels. However, several financial incentive measures are already in place (through the 'Clean Development Mechanism' and other processes) to encourage a reduction of greenhouse gas emissions. Further, it is anticipated that international pressure from governments, civil society and consumers of South African goods will grow and persuade South Africa to commit to reduction targets. As citizens and organisations within South Africa become more aware of the profound impact of climate change, there will also be growing internal motivation to reduce the release of CO_2 and other greenhouse gases into the atmosphere.

Given the growing economies and populations, global CO_2 emissions are still increasing. Figure 2-7 is taken from a presentation by Scholes to the JHB + Two Conference and illustrates the long time lags associated with the climate change phenomena. Even if global efforts were able to reverse the current trend of increasing emissions in the next 50 years, total CO_2 levels in the atmosphere would continue to increase for 150 years, and temperatures would continue to rise for even longer. The model indicates that sea levels will continue to rise for more than 1000 years! Further, large-scale energy investments take a long time to realise. It is therefore critical for policy-makers and decision-makers to act now, as the costs of delay are likely to have a disproportionate impact in the longer term.

Figure 2-7 : Long term impacts of CO2 emissions (Scholes 2004)



3 Renewable Energy Resources and Technologies

Sorenson (1979) defines renewable energy as energy that is converted from resources that are used at a rate no faster than that at which they are replenished:

> "On a time-scale of human relevance, they will not be exhausted, unlike the effectively limited stocks of fossil fuels (coal, oil, gas), which have been laid down over geological time and are not being renewed at the rate at which they have been consumed since the Industrial Revolution."

The following renewable energy resource options could have a significant role in South Africa:

- Solar energy, converted into other useful forms through:
  - Solar photovoltaic technology: electricity generation
  - Solar thermal for heating: water, space, cooking, process heat
  - Solar thermal electric technologies: using heat from solar energy to drive 'heat engines' that can drive electricity generators or provide mechanical power
  - Sunlight: itself a critical source of lighting and space heating in homes and workplaces

  Solar energy is also the primary driver for all the other energy sources listed below (except geothermal and tidal)
- Wind energy: electricity generation on both small- and large-scale, water pumping and, more rarely, other mechanical power applications
- Hydro-power: the size of hydropower plants ranges from as little as 50 W to several gigawatts)
- Ocean wave and tidal power: wave power in particular is receiving more interest at present
- Biomass:
  - Electricity generation: typically through conventional combustion in boilers to drive steam turbines; other options include gasification
  - Household energy fuels: used for cooking, space heating
  - Biofuels: used either directly (e.g. biodiesel), or as an additive in transport and other liquid fuels
- Landfill gas: methane gas produced at landfill sites from organic material (this is included here consistent with government practice, but should not be taken to indicate that current levels of waste production or management methods are sustainable).
- Geothermal energy: where the heat in the earth is used to drive heat-engines.

There are a number of other 'future' technologies, such as direct photosynthesis linked production of electricity, which may play a role in the longer term. Although these could be relevant by 2050, they have not been reviewed for this study.

The theoretical potential for renewable energy in South Africa is enormous, many times greater than current or projected demand. However, although renewable energy resources are continuously replenished, there are limits as to how much can be extracted at any one time, or during the course of a year. These limits typically relate to the area of land or sea that can be used to harness the resource, the intensity of the resource and the timing of resource availability.

In this chapter, we review the most important renewable energy resources and the conversion technologies needed. This will enable us to quantify the potential contribution that the different forms of renewable energy can make, taking into account:

- Resource locations
- Resource intensities (how much energy is available per km^2 of project site)
- Resource timeframes (when is the renewable energy resource available)
- Availability of land and other key physical constraints to the use of renewable energy
- Typical and possible future conversion technologies and processes.

Potential renewable energy contributions are usually predicated on some assumptions regarding either financial or economic viability. This depends not only the on the cost assumptions used for the renewable technologies, but also on the cost assumptions used for comparable non-renewable technologies. It is partially as a result of differing perceptions of economic viability, financial viability and technical viability that different studies tend to come up with widely different numbers for the potential contribution.

A key constraint of many existing studies of renewable energy potential is that they consider current state-of-the-art conversion technologies. While this is important for short and medium-term planning, in the longer term we need to consider new technology developments and technology cost reductions that are expected to occur as manufacturing and installation processes are improved. For each of the technologies discussed, we have provided some insight into probable cost changes.

3.1 Solar Energy

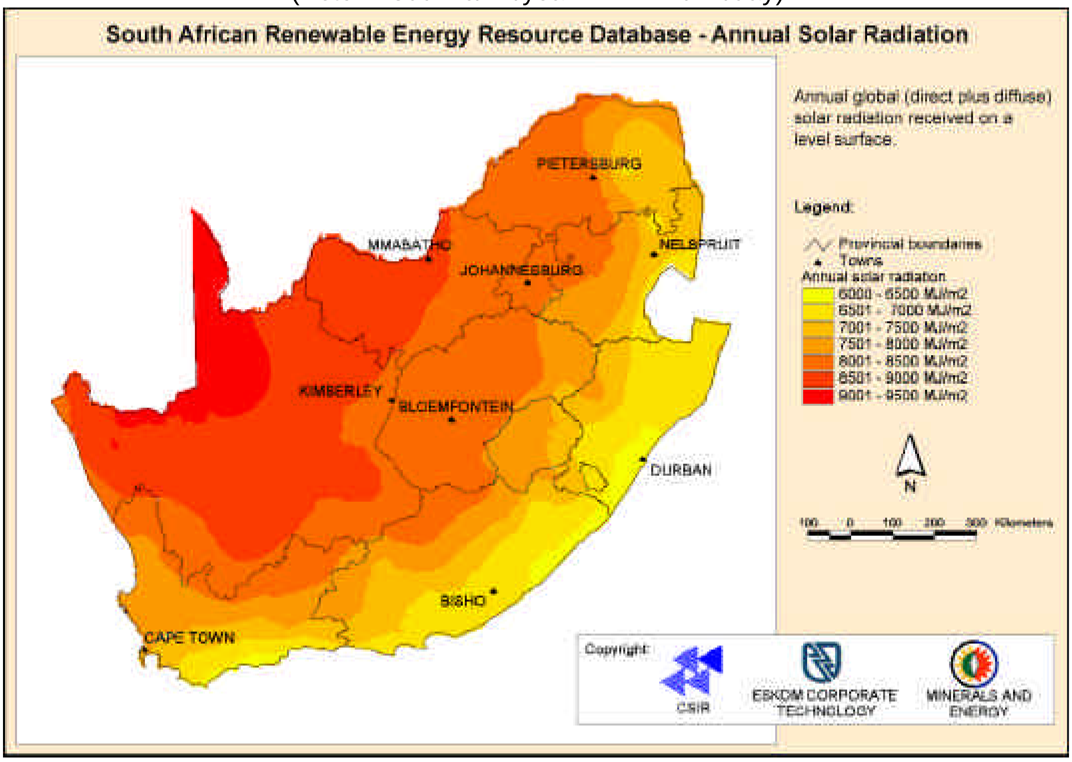
3.1.1 The solar resource in South Africa

Solar radiation levels in South Africa are amongst the highest in the world. Average daily solar radiation varies between 4.5 and 7 kWh/m^2. Even in winter, parts of the country receive more than 6.5 kWh/m^2 per day. The annual radiation received in South Africa is illustrated in Figure 3-1. It will be noted that the central and western regions have an excellent radiation resource, and even the eastern and southern coastal areas have good radiation exposure, especially when compared with European radiation levels.

Most areas of the country receive so much solar energy that an area of only 75 m^2 would be required per person to meet the 'per capita' energy demand listed in Table 2-1 (assuming 13 percent conversion efficiency). Only 3 000 km^2 would be required to meet the entire country's total energy demand. If we consider electricity requirements alone, then only 730 km^2 would be required for current needs, increasing to 1300 km^2 for the 2050 'energy conscious' demand scenario (still assuming a 13% conversion efficiency).

Figure 3-1 Solar radiation in South Africa (CSIR, ESKOM, DME 2004)

(Note: 1300 MJ/m^2/year = 1 KWh/m^2/day)



Solar energy can be used to generate electricity (photovoltaics), to heat water (solar water heaters), to provide process heat and even to provide heat for cooking (solar cooker). Sunlight contributes significantly to both lighting and space heating in buildings and solar-aware building design can significantly enhance this contribution.

Solar energy is also the primary energy resource driving other renewable energy sources such as wind, hydropower, wave and biomass. The realisable potential of the solar resource is discussed further in Sections 3.2 and 3.3.

3.2 Solar Photovoltaic Electricity Generation

3.2.1 Introduction to the technology, and overview of its use in South Africa

Photovoltaic (PV) panels convert solar radiation directly into electricity using the photovoltaic effect. A photovoltaic module has no moving parts and existing products have manufacturers' warranties of the order of 20 years. The technology is already widely used, even though current costs are high when compared with grid electricity or the use of diesel or petrol generator sets.

In South Africa, PV panels are primarily used to provide electricity for telecommunications, lighting and electronic media in areas that are remote from the grid. There are already approximately two hundred thousand 'off-grid' installations in the country. A recent review found only ten grid-connected installations in the entire country (DME/CaBEERE ,2002, p. 29).

However, in countries such as Germany, Japan and the United States (in particular California), incentive programmes have promoted the interconnection of PV panels with the national grid, and the grid market is now far larger than the off-grid market. With our more favourable climate, we could surpass their achievements, given the same government policy. In 2003, the solar PV world market grew by 32 percent, with a total of 574 MW being installed. This may seem a small amount, but the market is currently dominated by Germany and Japan (145 and 219 MW each respectively) (Marketbuzz, 2004). The Earth Policy Institute estimated that cumulative world production had reached 3 145 MW by November 2004, with annual production rates of the order of 742 MW (RE Focus, 2004). The real price of PV modules has steadily dropped by about 5 percent per annum.

Short-term demand growth rates are currently so high that demand for PV modules has exceeded supply, affecting module availability for South African projects. The mentioned incentive programmes have been able to steadily reduce the subsidies paid per kW installed, mainly because the markets, particularly in Japan, are gradually approaching full commercial viability. PV technology is considered by many to be the most promising long-term option for energy supply, with some international scenarios indicating that 50 percent of energy could come from PV by 2100.

Although the current PV market in South Africa is relatively small (about 12 MWp installed, refer to Table 2-2), there are recent signs of significant expansion. In 2002, the overall sales volume (including exports) was estimated at 3 to 3.5 MWp, with a market turnover of approximately R200 million to R225 million (Cawood & Morris, 2002, p. 38). At that time, a manufacturer indicated expected production of 8 MWp for 2003. By the end of 2004, one manufacturer had exported approximately 25 MWp during the year, and was targeting a production of 40 MWp for 2005. This manufacturer alone has thus reached nearly ten times the 2001-2002 production figure.

3.2.2 Typical applications

Photovoltaic modules can be used in a wide variety of applications, particularly in situations where no grid or alternative power source is available. These include telecommunication relay stations and customer equipment, power for institutions, households, water pumps and security systems. The existing South African off-grid concession programme will see about 80 000 households electrified with PV on a fee-for-service basis. There are already approximately 100 000[9] privately-owned household lighting systems installed.

There is not consensus within South Africa regarding the most appropriate solution for meeting the targets of universal access to electricity as set by the government. However, we believe it is reasonable to anticipate that PV technology will most cost effectively serve between 500 000 and one million of the more than two million households currently without grid access in South Africa.

As previously noted, the main future market for PV technology is as distributed generation, connected to the grid. The most common application is likely to be as part of housing and commercial building roofs and facades. There are many instances where PV technology can serve a dual purpose as roofing material (e.g. tiles, flexible water-proof membrane), as a source of shade, as a durable and attractive building façade, or as a sound barrier along highways. Such applications help to reduce fossil fuel use, transmission line capacity requirements, pollution and even space requirements. There are also international examples of dedicated PV power plants.

3.2.3 Cost indications

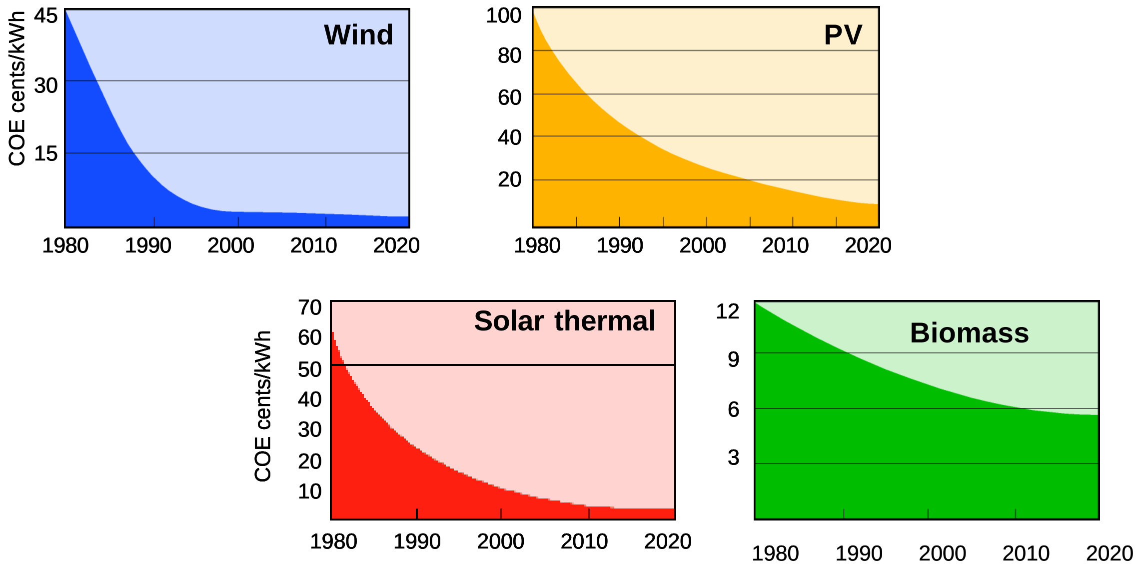
The price of PV modules is naturally highly dependent on volume. There is also a current shortage of material on the international market as a result of the huge expansion in grid-connected markets. Nevertheless, the South African off-grid concession companies have paid as little as R18 000/kWp for modules (uninstalled), with prices of R26 000/kWp being more common. The additional costs of the grid connection interface and installation would add perhaps a further 50 percent to the overall cost, yielding a readily achievable cost of R39 000 per installed kW. This corresponds to an energy price of about R1.80/kWh[10].

Figure 3-2 illustrates historical and anticipated cost reductions for several renewable energy technologies, including PV. It will be noted that, by 2020, the production costs of PV generated electricity are anticipated to be less than half the current costs, although the cost estimates are still of the order of US 8 cents/kWh (about R0.56 at R7/USD). The German Advisory Council on Global Change (WBGU, 2003) anticipates that, for an 'exemplary scenario', the installed cost of grid-connected PV systems (with associated system components) would be €1/Wp by 2020, resulting in an electricity cost of €0.12 per kWh *in Europe.* In high-sunshine regions, the cost would decline to €0.06 per KWh (R0.48 at R8/€).

[9] The existing household installation base is not well documented, and this figure is an own estimate and subject to confirmation.

[10] R39 000/kWp, amortised over 20 years:, assume installation falls in medium radiation band of 7800 MJ/year, 8% discount rate, 20 year life.

Figure 3-2 Cost reduction curves for renewable energy technologies



Source: NREL Energy Analysis Office
Updated: June 2002

A recent International Energy Agency publication anticipates a reduction in solar technology costs of the order of 30 to 50 percent per decade for each of the next two decades as a result of learning and market growth (IEA, 2003, p. 18). For example, trial production is currently underway at the University of Johannesburg of a novel PV cell manufacturing process that may help reduce the costs of modules by a further 20 to 50 percent in the next few years. This innovation would create a more rapid cost reduction than those indicated in Figure 3-2 and, if the venture is successful, it is likely to have major implications on the development of PV technology in South Africa.

As with other electricity generation devices, PV modules require energy to manufacture. Grid connection systems in Europe currently have an energy payback time of about three years. The payback time would be about 50 percent shorter in the high radiation areas of South Africa, and there is also room for further optimisation or the technology to reduce the payback time further (WPGU, 2003, p. 65).

3.2.4 Potential contribution

The potential contribution of PV to the electricity market is *not* limited by the solar resource availability or space availability (Section 3.1.1). In the medium term, the main limitation is likely to be the ability of global (and local) industry to supply the materials and components required to manufacture cells on the scale demanded. Although some technologies rely on small amounts of potentially scarce materials (indium and tellurium), the main ingredient required is silicon which is the second most common element in the earth's crust. Current technical developments are also achieving a reduction in material usage.

The fact that PV cells only generate power when the sun shines is the most critical limiting factor for widespread application. As PV becomes a more significant component of the total grid supply (say 10 percent), it will become necessary to ensure that there are adequate energy storage systems in place (or alternative peak power supply options) to accommodate the variability of PV generation. This crucial area is discussed in more detail in Section 4.

Even with a predicted halving of costs for PV technology, the cost of PV does not compare favourably with the long run marginal cost of electricity (about R0.31c/kWh by 2015 according to World Bank 2004, p. 71) and, at first sight on financial cost alone, it seems unlikely that PV could ever play a major role in grid-connected power generation. There are, however, several important reasons why PV is expected to play a highly significant role:

- Ease of use: PV modules represent one of the easiest ways to implement renewable energy. The power source itself is extremely robust, requires no maintenance apart from occasional cleaning, and is one of the few products in the world that regularly carries a 20-year warranty. As has already been illustrated in the international market, it is relatively simple to install thousands of grid-integrated systems on domestic and commercial building rooftops. PV technology is also extremely well suited to off-grid applications.
- Electricity is generated at point of use: PV systems can be installed almost anywhere, and can be readily integrated into the grid distribution system. They represent an opportunity for individuals, commercial enterprises and other parties to take steps at their own premises to contribute directly to a more sustainable energy future.
- Technologies are rapidly being developed that allow the integration of PV cells or modules into dual-purpose coverings and fabrics such as:
    a. Roof tiles and roofing membranes for flat roofs
    b. Durable building cladding
    c. Fabrics for clothing and tents
    d. Portable product surfaces (watches, cell phones, radios, etc.)
    e. Noise barriers on highways.
- The resource is well distributed and it is relatively easy to estimate how much energy will be produced at particular locations
- The long term marginal cost of electricity generated by fossil fuel resources is expected to increase, partly because the resources are finite and partly because of increased internalisation of the environmental impacts.

For the purpose of the scenario exercise (Section 5), we have assumed no fixed limitation on the potential PV contribution, but have ensured that there is adequate energy storage and peak generation plant.

3.3 Solar Thermal Electric

3.3.1 Introduction, and overview of South African experience

If solar energy is concentrated using mirrors or lenses, it is possible to achieve high temperatures suitable for driving heat engines or conventional steam-turbine generator sets. At present, 'Concentrator Solar Power' (CSP) technology has the lowest costs for large-scale power generation (Solar Paces, 2005). Several plants exist with a capacity of more than 350 MW, with the bulk of production being from plants in California, which have operated for more than 10 years. For many years, these plants represented 90 percent of the world's installed solar electricity generation capacity, and have only recently been overshadowed by PV.

There are three main CSP technologies that are currently in use and under further developed:

1) **Parabolic trough:** A reflective parabolic trough concentrates sunlight onto a tube located along the trough's focal line, heating a fluid in the tube which is then pumped to a steam turbine / generator or can be used to provide process heat. The troughs are normally designed to track the sun to maintain the focus point on the tube. Fluid temperatures range up to 400°C. This technology is used for the California SEGS plants. Although it can be applied on a small scale (for process heat) in electricity generation configurations, plant size would typically be in the multi-megawatt range (50 to 200 MW or even more).
2) **Power tower systems:** Mirrors or heliostats reflect and concentrate sunlight onto a central tower-mounted receiver where the energy is transferred to air or some other heat transfer fluid. This is then used to drive turbine power systems. As with trough systems, power tower units are typically designed to operate in the multi-megawatt range.
3) **Dish concentrator systems:** These are smaller machines (from perhaps 50 watts to 25 or 50 kW). A parabolic dish (or array of dishes) focuses light onto a receiver, where it can be used to generate electricity directly in a small 'heat engine' (typically a Stirling engine). More

rarely, the receivers are connected to a central generation plant using a heat transfer fluid. Dish systems are particularly attractive for small-scale distributed generation options. However, they may also compete favourably in large-scale plants, where arrays of several hundred (or thousand) machines would generate power.

A fourth option, the 'solar chimney' or 'Green Tower' concept uses a very tall chimney (1 to 2 km high!) with a green house collector surrounding it on the ground. The hot air rises in the chimney, and the resultant draft can be used to drive wind turbines to generate electricity. If appropriately designed, this technology can produce power on a 24-hour basis, while also providing agricultural produce grown in the 'greenhouse'.

An important advantage of CSP technologies is that thermal energy storage (using molten salts or other heat stores) can be integrated into the system, thereby allowing power generation during short cloudy patches and during the evening. Gas or other fuel burners can also be integrated into the power generation equipment, so that the system can run on solar plus gas, or even on gas alone. This allows the plant to provide guaranteed power, as required by the grid.

South African experience of CSP technology is relatively limited. There is a 25 kW demonstration plant at the Development Bank of Southern Africa (DBSA). Plans are currently well advanced to commence construction of a 100 MW 'power tower' system in the Upington area by 2009. This would generate electricity at a cost of about R0.40/kWh (Darroll, 2004). While this cost is high, it is not unreasonable, given that it would be the first large-scale unit of its type to be built in South Africa. Also note that a CSP plant could have a high local content, as the materials and technology use are relatively standard.

3.3.2 Cost indications

Although the current contribution of CSP to total solar electricity generation is already in the hundreds of MW, this is a consequence of the large size of the plants built. Relatively little repeat production experience has been gained, and there is thus still room for considerable improvement as volume manufacturing processes become established. As noted in the experience curve in Figure 3-2, the technology is projected to be the lowest cost solar electricity generation option for some time to come.

In the recent Integrated Resource Plan developed by Eskom and the NER, a levelised power cost in the range R0.33 to R0.96/kWh is indicated, depending on the assumptions used for discount rate, load factor and other costs. In our opinion, these cost figures are over-stated and do not adequately take account of the potential for cost reductions as the technology develops.

3.3.3 Potential contribution

As with PV technology, the CSP contribution is not limited by resource availability. Furthermore, the materials used to construct CSP plant are readily available and land use is not a significant constraint. CSP plants can generate 25 to 40 MW/km^2 (WBGU 2003, p. 66) and require far less land per MW than most large-scale hydroelectric dams. Given that thermal storage options can be linked to CSP technologies, they can also more readily match the supply/demand needs of a national grid. For the purpose of this study, we have therefore assumed no limit to CSP potential contribution, but have sought to balance its use with other technologies (see section 5.2.4).

3.4 Solar Thermal for Heating (Water, Space, Process)

Solar water heaters (SWH), solar cookers, solar dryers, solar process heating systems, trombe walls, solar space heating systems, and even simple glass windows all allow solar energy to be trapped and used to heat water, air, food and even industrial processes. Provided that buildings are appropriately designed, it is quite feasible to reduce or eliminate winter space heating bills, with significant reduction in electricity or other space heating fuel usage. Almost half the energy in domestic households is used for water heating and thus presents a highly significant potential for reducing both peak demand and energy consumption. This is particularly important for winter peak demand limitation on the electricity grid.

South Africa has a moderate sized SWH industry, with 19 manufacturers identified by Cawood and Morris (2002), and only 11 identified in a market survey conducted by SolaSure in 2005. Two main types of panels are sold:

- Low temperature unglazed panels, mostly used for swimming pools
- Glazed medium temperature panels, used for domestic or commercial water heating.

Although the unglazed market has been steadily growing at about 4 percent per year to reach about 54 000 m^2 per annum in 2002, the glazed market has not performed well. The 13 000 m^2 production of 2002 was far less than the market peak of more than 25 000 m^2 in the early 1980s (Cawood and Morris, 2002). Solar water heaters are thus not achieving high volume sales in perhaps the most important potential market, low and medium-income domestic water heating.

Cawood and Morris (2002) estimated that approximately 484 000 m^2 of SWH collectors had been installed in South Africa by 2002 (Cawood and Morris, 2002). This translates into an effective installed capacity of 242 MW, or 511 GWh per annum. A market survey conducted by SolarSure in 2005 indicated approximately 756 000 m^2, delivering approximately 993 GWh/annum[11].

Cawood and Morris suggest that the reasons for the poor performance of the glazed collector market are:

- The low cost of electricity
- The high initial purchase price of SWH
- The explicit absence of promotion of SWH by government and parastatal organisations, while they promote geyser insulation, high efficiency lights etc
- Lack of funding for demonstration and training programmes
- The absence of a viable SABS standard.

Many of these factors are in the process of being corrected and a vibrant SWH industry could occur in the near future.

Specialised solar space heating solutions have not been extensively explored in South Africa. There is, however, considerable potential for energy-efficient housing design, including maximising solar gain in winter and reducing solar gain in summer (to keep homes cool).

3.4.1 Cost indications

Solar water heaters (SWH) are currently economically and financially viable for applications such as swimming pool heating. However, this is a relatively limited market when compared with the potential for domestic water heating. Studies on the financing of domestic solar water heating indicate mixed results, mostly because current purchase/installation costs are relatively high and electricity is cheap. Conningarth Economists (DME 2004, p. 94) indicates effective costs of R0.33 to R0.41/kWh for residential applications, with commercial (larger scale) costs dropping to as low as R0.17/kWh. Although these costs are lower than most other renewable energy options, R0.33 per kWh is not sufficiently attractive to motivate residential homeowners to purchase SWH on a large scale. Several policy and financial options are currently being explored to improve the market potential for SWH.

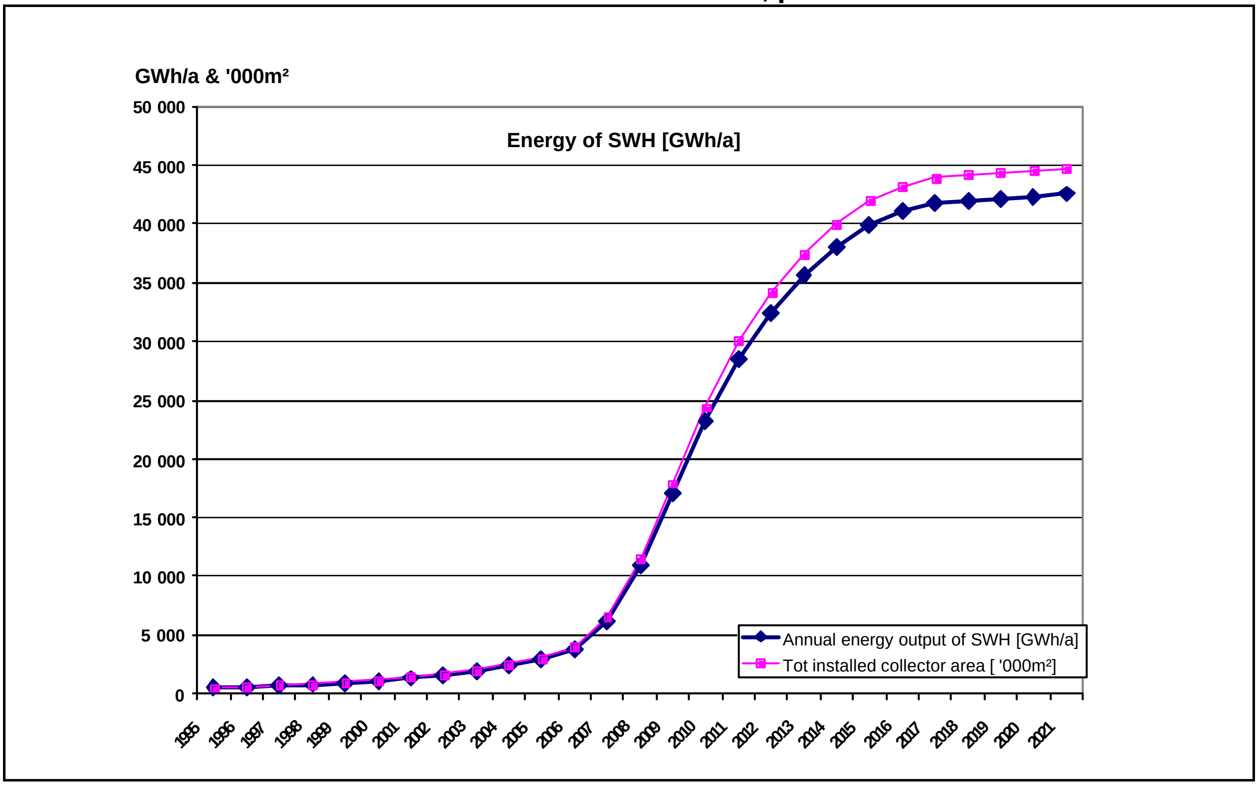
3.4.2 Potential in South Africa.

DME (2004a, p. 88 and p. 94) indicates a potential for SWH to displace between 4.9 and 5.9 TWh of electricity in residential applications, and 2.0 TWh in commercial applications (a total of possibly 7.9 TWh). These calculations use current electricity loads from water heating as a base, and do

[11] Note: the difference in the data from the above studies in part reflects market growth, but is also attributable to the difficulties faced in gathering reliable data on renewable energy installations in South Africa.

not take into account population growth and hoped-for transitions in rural and low-income urban household access to hot water. A recent World Bank study (World Bank, 2004, p. 61) indicates far more significant potential, with up to 43 TWh/year being produced in a scenario for market transformation by the year 2021 (Figure 3-3).

Figure 3-3 Energy from solar water heating (GWh/year)
Source: World Bank 2004, p: 61



For the purpose of the scenarios under review, we have used the World Bank study as a guide, but have conservatively assumed that levels of 42 TWh/annum of displaced electricity consumption could be achieved by 2030 (not 2021). We have assumed that this could grow to 55 TWh by 2050.

3.5 Wind

3.5.1 Introduction to the technology and overview of South African experience

Winds are an indirect form of solar energy, as it is the energy from the sun that drives the great weather patterns and cyclic movements of water vapour and air. Approximately 2 percent of incoming solar radiation is converted into the kinetic energy of wind. Wind energy conversion systems usually convert the energy in moving air to electricity. In the longer term, this energy could be used to produce more versatile energy carriers, such as Hydrogen. Wind turbines generating electricity range from battery-charging systems of the order of 100 W up to large multi-megawatt systems supplying power to electrical networks. These larger turbines are usually combined in wind farms with capacities ranging from 10 MW to 100 MW and beyond. Innovative suggestions for wind technologies that are not yet proven include turbines tethered like kites to the ground by transmission lines, operating far higher than the first 100 m layer of air, and ‘turbines’ with no moving parts based on piezoelectric principles.

Wind energy is currently the fastest growing energy industry in the world, and large wind farms are being established on- and off-shore in several countries. By the end of 2003, cumulative installed capacity reached 40 GW (Jones, 2004).

Wind powered water pumps are common in South Africa, with an estimated 30 000 systems installed. It is reported that these systems (originally imported) are now produced locally to such a high standard that they have made significant inroads into the export market. It is feasible that a similar pattern of local industry development could emerge in the large-scale wind turbine market. A small number of turbine manufacturers produce mainly battery-charging turbines, but are also building larger systems suitable for mini-grid and hybrid applications (where two or more generation technologies are integrated in one system).

The Darling wind farm, to be established in the Western Cape, is an example of a potential South African independent power producer. This DME-supported 'National Demonstration Project' has a planned initial capacity of approximately 5 MW, and could be extended to 10 MW. Eskom started to generate electricity from three wind turbines at the Klipheuwel site in 2002 with a view to investigating the potential of large-scale wind energy for bulk electricity generation in South Africa. The Klipheuwel site is not an optimum wind site location, which is unfortunate, as poor results could prejudice future wind investments. These two projects and some seven others are in the early planning stages and will use large imported wind turbines in the 1 to 2 MW class. Each of these would be able to supply enough electricity for around 1 000 middle-income households.

3.5.2 Cost indications

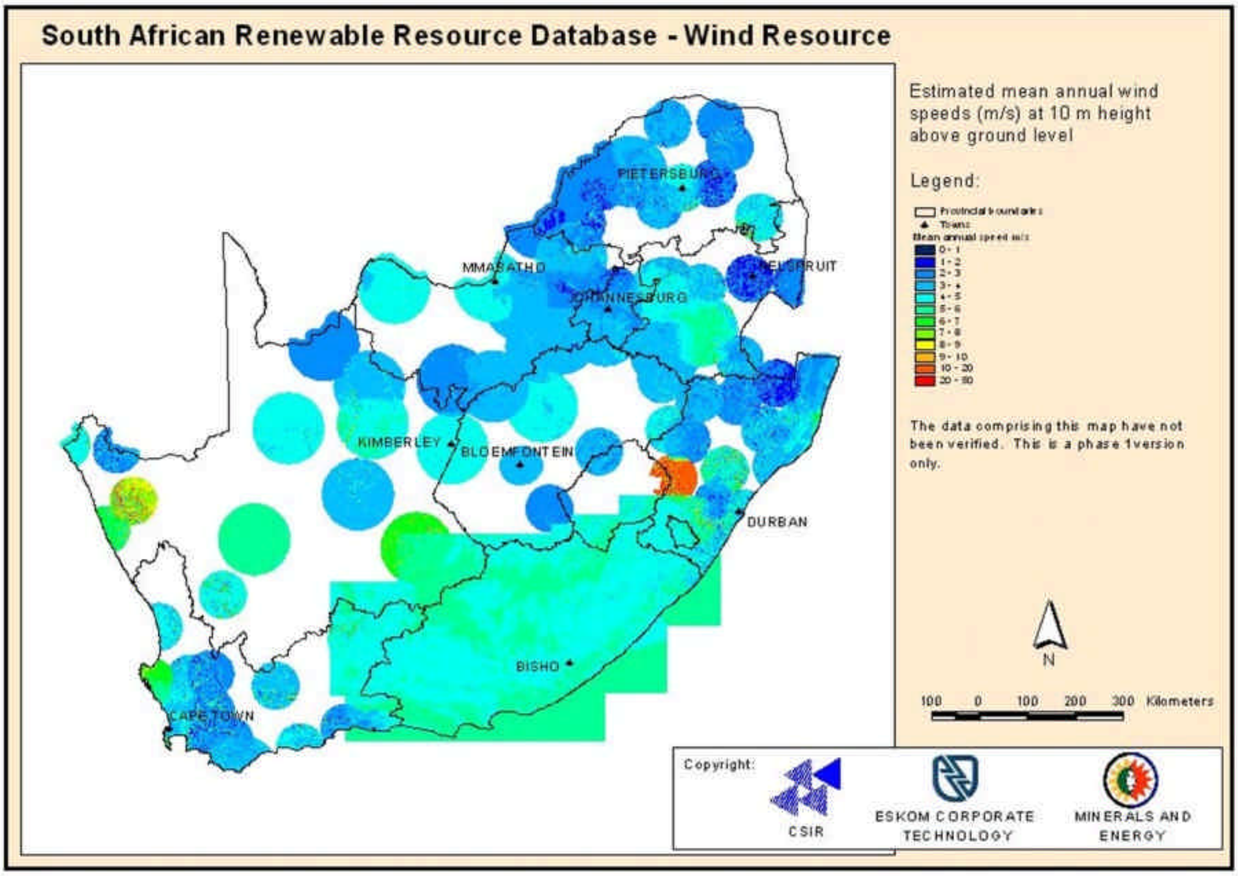
The estimated total capital cost of large multi-megawatt wind-based electricity generation plants range from R6 million to R8 million per Megawatt. Electricity generation costs would range from about R0.27 to R.70c/kWh per unit depending on the wind regime in which the turbine operates (DME 2004a). International experience indicates a cost of less than US$0.04 per kWh (IEA, 2003, p. 25). This cost indication makes wind one the most financially viable renewable energy based generation technologies, and in favourable conditions wind can compete directly on commercial terms with conventional energy options. These costs are also projected to decline by as much as 40 to 50 percent over the next 15 to 20 years (see Figure 10 and IEA, 2003, p. 18).

3.5.3 Potential contribution

The total energy available from wind is proportional to the cube of the wind speed. Thus, an area with average winds of 6 $m.s^{-1}$ could deliver eight times as much energy per km^2 as an area with an average wind speed of 3 $m.s^{-1}$. Therefore the resource at a prospective wind farm site must be accurately known if energy output is to be estimated with any reliability. This is also crucially important for business plan development.

Wind prospecting is in its infancy in South Africa and descriptions of the resource vary from abundant, to 'significant by international standards upon which wind industries have be built', to merely modest. The two most frequently quoted resource assessments are the Diab (1995) South African Wind Atlas, and a more recent SABRGEN product (Figure 3-4). The Diab study relies primarily on wind speed measurements from weather stations and airports installed at 2 m and 5 m high, with some at 10 m. The locations of these stations are not ideal and the masts are too low. The SABRGEN results were generated primarily through wind modelling, and supported by similar weather station data as used by Diab.

Figure 3-4 South African wind resources



In 2003, a South African renewable energy strategy formulation team (DME, 2004a) estimated the total wind generation potential to be 60 TWh per annum. Their resource assessment used wind speed data from the above sources and combined these with assessments of the physical land area available in high wind speed zones. However, they adopted a conservative approach to land availability. Of the 410 000 km^2 exposed to wind speeds of more than 6.5 m.s^{-1}, they assumed that only 1 174 km^2 could be allocated to wind farms. Even in these allocated areas, the turbines themselves would only take up about 1 to 2 percent of the land area, equivalent to about 0.003 percent of the total resource area, with normal farming continuing under and around the turbines.

The DME is currently establishing seven high (30 m) monitoring masts, which will provide a more accurate assessment of the potential resource in the regions close to their location. However, it seems that uncertainties about land availability, both on- and off-shore, will need to be resolved for the longer term.

For the purpose of this study, we have assumed that 1 percent of the land area in each of the first five wind class zones assessed in the DME 2004a study could be allocated to wind farms. This gives a land area of up to 4 100 km^2, and a resource potential of about 50 GW, yielding 106 TWh at capacity factors between 24 and 37 percent. An off-shore area could be added to this, perhaps adding tens of GW to the capacity (the available literature does not provide estimates). However, due to concerns about visual impact and land availability, electrical energy storage and peak load management, this resource level is not fully utilised in the scenarios discussed.

For comparative purposes, Denmark, with a total land area of only 16 000 km^2 (less than the area covered by Classes 1 to 4 described in the South African wind resource assessment) has approximately 7000 turbines which account for 18 percent of its installed electricity generation capacity and currently generates 5.9 TWh. Certain Danish provinces already produce as much as 40 percent of their regional supply from wind resources.

One of the primary negative factors levelled against wind-based electricity generation systems is the problem of intermittency, or, 'what happens when the wind does not blow?' International experiences indicates that a contribution of up to 20 percent of total electricity supply can be added to electrical grids such as that in South Africa, without significant changes being required to system operating procedures or distribution and transmission networks. It should also be remembered that because weather systems move considerably slower than wind gusts at a single location, the larger the area over which turbines are distributed, the smaller the average fluctuation in energy generated will be. As will be discussed in Section 4, future technologies will be able to deal with the intermittency problem more effectively.

The low energy densities which characterise wind energy and most other renewable resources are also cited by opponents as being problematic, implying that large areas of land are required to generate significant quantities of energy (typically 0.06–0.08km^2 per megawatt (EUREC Agency, 2002)). However, there is no reason why land on which wind power plants have been installed should not continue to be used for agricultural purposes, so that the actual land use (e.g. foundations, access roads) is only about 1 per cent of the above figure (WBGU, 2003).

In summary, although there is still some uncertainty about the total wind resource in South Africa:

- Exploitable opportunities already exist.
- The international industry is well developed, and the commercial, planning and implementation experience is internationally available to establish wind farms with a high degree of certainty regarding outcomes.
- Assuming that 1 percent of the land in 'windy' areas could be used, it would be feasible (although in some cases expensive) to establish wind farms capable of supplying 50 GW, producing at least 106 TWh of energy for the national grid.

As with other technologies seeking to harvest distributed resources sustainably, wind energy systems promise significant benefit in terms of building increasingly flexible, robust, secure, stable and cost-effective energy supply systems.

3.6 Hydropower

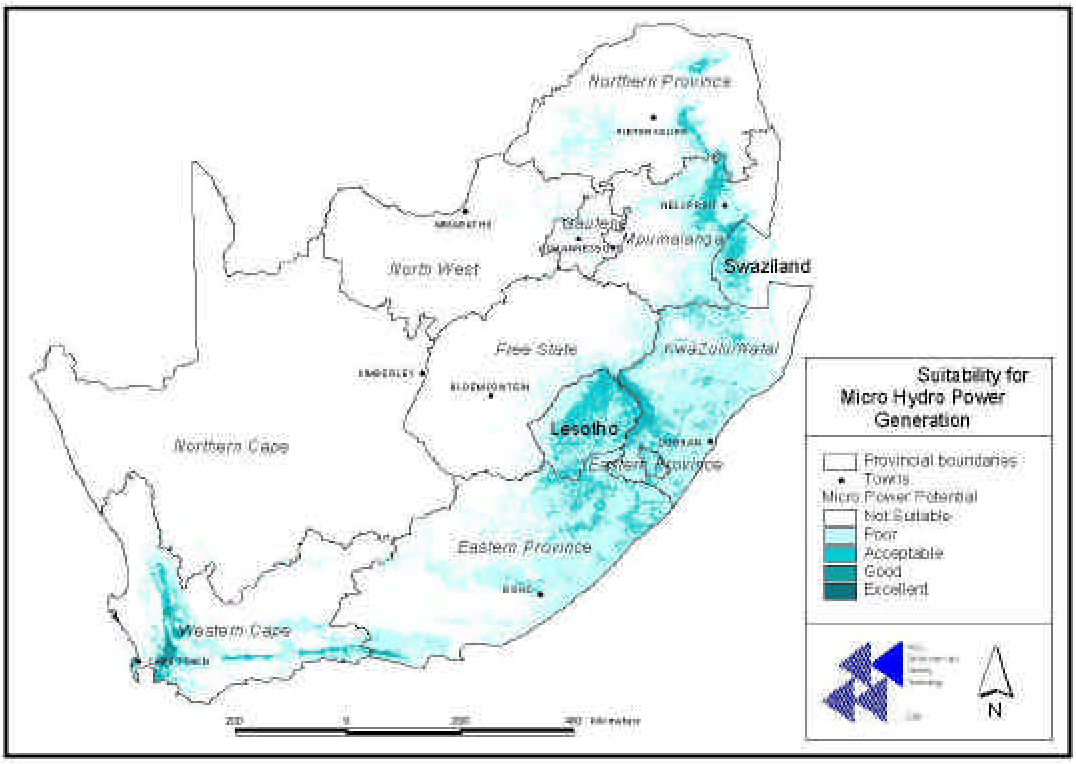
3.6.1 Introduction and overview of South African experience

Hydropower is also an indirect form of solar energy. The sun-driven vaporisation/ condensation cycle forms rain that replenishes the mountain catchments and gives rise to rivers that can be harnessed to generate hydro-electricity. Figure 3-5 indicates the regions of the country that have reasonable hydropower potential. Estimation of the energy available from hydropower resources is very dependent on the geographical terrain through which rivers flow, as the energy available is a function of the water flow rate and the change in height as it flows downhill. As South Africa is a water-stressed country, the resource is relatively limited.

Hydropower plants have been developed over the full power range, from as small as 50 W pico hydro systems as used in individual households in Nepal and China, to the multi-Gigawatt installations such as those used at Cahora Bassa and planned for projects such as Grand Inga in the Democratic Republic of Congo.

South Africa currently has an installed capacity of 668 MW. Of the installed capacity, 68 MW is produced by eight 'small hydro plants', each of less than 10 MW. Three of the 'small hydro plants' are privately owned. It is estimated that there are also approximately 0.2 MW of installed mini hydro capacity that are primarily powering isolated mini-grid systems (Barta, 2002). There are also pumped storage schemes with a capacity of 1 580 MW installed.

Figure 3-5 Hydropower resources in South Africa



3.6.2 Cost indications

Costs for hydropower are highly variable, depending on the geography of the physical sites used for power generation. The cost range is in the order of 11 to 58 c/kWh (World Bank, 2004). Although the technology is relatively mature, the International Energy Agency anticipates cost reductions of about 5 - 10 percent in each of the next two decades (IEA, 2003, p. 18).

3.6.3 Potential contribution

Several previous hydropower potential estimates were concisely collated in the 'Baseline Study: Hydropower in South Africa' (Barta, 2002). The study concluded that large (>10 MW) hydro generation systems have a potential of 5 091 MW. Those systems smaller than 10 MW have a potential of 69 MW. The small systems are usually those with fewer environmental and social impacts and more readily considered as renewable. Barta also identified resources that could be developed in the longer term, providing an additional 1 994 MW of hydropower. The total hydropower potential is therefore 7.841 GW, which is significantly higher than the estimate of only 300 MWe as provided in the National Integrated Energy Plan (DME, 2003, p. 21).[12]

The Eastern Cape Province alone possesses 'a very major asset to [its] economy and it is considered that [the hydro potential in the region] should be developed to the optimum of its potential to assist the area and reduce fiscal loads. About 20 percent of the total run-off in South Africa occurs in the Mzimvubu and Tugela basins' (Olivier, 1986). Barta (2002) estimates that the Thukela and Mzimvubu to Keiskama catchments alone have a combined potential of 4 950 MW of large hydro, 23 MW of small hydro (<10 MW).

[12] "There are limited unused hydro reserves in South Africa (approximately 300 MWe) with other opportunities for pumped storage. Imported hydro electricity still requires development." (DME, 2003, p. 21)

There are 3500 to 5 000 potential sites for micro hydropower generation concentrated in areas along the eastern escarpment. Realisable small-scale hydro generation potential is approximately 9 900 GWh per annum (DME, 2003b).

The medium-term potential for job creation only from the development of pico/micro/mini and small hydropower schemes is estimated at about 3 000 jobs. Some 1 100 permanent jobs would be created by the operation, manufacturing and administration of hydropower development (Barta, 2002, p. iv).

Theoretical *regional* large-scale hydro potential amounts to a massive 100 GW or more (outlined in Appendix B.2). Analysis of the period during which this potential could be included in the energy supply mix for South Africa is beyond the scope of this study and has only been brought in as an option for the *high renewable* scenario. Consideration of this import potential would include attempting to determine what proportion of the capacity installed would supplement South Africa's energy supply rather than the energy supply of other countries in the region. Some authors suggest that a large proportion of any development of this huge regional potential would initially be taken up by South Africa until such time as the rate of economic growth elsewhere in the region increases. A large Zambian-DRC transmission interconnector, which is currently being upgraded from 220 MW to 500 MW capacity, is reportedly being driven by supply to the SAPP in general rather than just to South Africa.

How much imported hydro might reach South Africa by 2050? Mozambique's Cahora Bassa scheme experienced a 16-year lead time and bad debt in attempting to supply 2 GW of hydropower. If the Cahora Bassa scheme is anything to go by, then it would be prudent to assume that imports would be limited to about 5 to 10 GW in the scenario period reviewed.

The potential for new pumped storage capacity was estimated in Barta (2002) at approximately 7 000 MW, with an additional 3 200 MW of capacity realisable in the long term. If this is combined with existing pumped storage capacity, there is a total potential of 11.8 GW.

3.6.3.1 Limitations to the use of hydropower

Although the fact that hydroelectricity can be generated at any time of day or night makes it a very attractive renewable resource, some concerns should be noted:

- Susceptibility to drought: South Africa is a water-stressed country, and very low river and dam levels are a regular occurrence. As with other countries in Africa, one cannot rely on many of the hydropower resources during dry periods.
- Large-scale hydropower projects that rely on large dams have significant environmental impacts, not only covering large areas of land, but also affecting the ecology of the rivers and the river basins downstream. For these reasons, several authors regard expansion potential for hydropower as being limited.

In the *progressive renewable* scenarios reviewed in this study, we have used only up to 70 percent of the 7.8 GW potential national capacity identified by Barta. This gives an upper limit of 5.5 GW, with a potential yield of 14.6 TWh at an average load factor of 30%. For the *high renewable* scenario we assume that additional large scale hydro imports of 6.5 GW would be available, taking the combined 'new hydro' totals up to 11 GW and 57.8 TWh (the imported supplies are assumed to have a higher load factor).

3.7 Biomass

3.7.1 Introduction to the resource

Biomass is a major indirect source of solar energy. It can be used in several forms - as a direct heating or cooking fuel or to generate electricity, with various technical options being available (e.g. direct combustion in boilers, gasification, fluidised bed gasification). It can also be used indirectly, such as using biological processes to produce methanol or ethanol, and creating a liquid fuel that can be used for transport or cooking applications. Ethanol gel is currently receiving considerable national and international attention as a possible household fuel. Crops that have high oil content can be used to produce biodiesel, which can be used directly, or blended with conventional diesel. Anaerobic bacteria produce methane from biomass, and this can be captured and used directly for thermal and power generation purposes. The methane could be sourced either from landfill sites (Section 3.8) or from specialised 'biogas' digesters.

In 2000, biomass was reported to be 8.7 percent of final energy consumption (DME, 2002c, referenced in EDRC, 2003). Co-generation by industry from bagasse contributes approximately another 1 percent (NER, 2002). WEC (2003, p. 23) indicates that biomass and other renewables (which are very small) contribute almost 15 percent to South Africa's final energy supply. Biomass data, however, needs to be treated with caution, since the data reported in the energy balances can vary by a factor of two from year to year. For example, household biomass for 1999 and 2000 is estimated at 190 PJ, whereas for 1993 to 1997 it was estimated at 370 PJ (EDRC, 2003). When considering potential contributions from biomass, it is critical to distinguish between resources that are used sustainably and those that are not. For example, in almost all rural areas of the country, biomass is the most important source of energy for cooking and space heating, with more than 70 percent of households using wood for cooking. However, while the supply/demand balance is reasonable in some areas, the wood is being used faster than it grows in other areas, with significant environmental and socio-economic consequences.

Given that biomass data is based on projections from household and industry surveys with small samples, details on the percentage of biomass energy that derives from sustainable resources are currently impossible to establish. Biomass is certainly a key renewable energy source, but the sustainability of its production needs to be clearly understood, especially in the context of a water-stressed country.

South Africa already has significant experience of power generation from biomass. Some sugar mills burn bagasse (cane residues and waste), and paper and packaging mills use waste biomass to generate process steam, and generating approximately 210 GWh of electricity per year (DME, 2003b). One of the first CDM projects to be developed in South Africa includes the integration of additional biomass waste into a paper mill's coal boiler feedstock.

Several biodiesel production facilities are in the planning stages, and Sasol has investigated the economic feasibility of building a 400 000 ton/year soybean to biodiesel plant (Creamer, 2004).

Although biomass energy may be regarded as Carbon neutral, and renewable, there are several concerns regarding the environmental impact of large-scale biomass-based energy production. Particular concerns include:

- Water requirements: South Africa is a water-stressed country and the well-known 'Working for Water' programme has actively sought to reduce water-hungry tree infestations in catchment areas.
- Biodiversity: Large-scale monoculture energy crops could have a significant effect on species diversity and land quality.
- Food security: If farmers start to plant energy crops instead of food crops, there is a greater risk of food scarcity, particularly in years of drought.

The German Advisory Council on Global Change suggests the following 'guard rail' for biomass energy:

> "Sustainable land use. 10–20 percent of the global land surface should be reserved for nature conservation. Not more than 3 per cent should be used for bio-energy crops or terrestrial CO_2 sequestration. As a fundamental matter of principle, natural ecosystems

should not be converted to bio-energy cultivation. Where conflicts arise between different types of land use, food security must have priority." (WBGU, 2003, p. 2).

3.7.1.1 Fuelwood

In a recent review of strategy options for fuelwood, Shackleton et al, (2004, p. 4) noted that:

- The national demand for fuelwood was estimated at 13 million m^3/annum in the mid-1980s and has never been updated since then.
- Fuelwood use is widespread, with over 95 percent of rural households using it to some degree.
- Demand is unlikely to grow from current levels in the light of (i) the HIV/AIDS pandemic which has stagnated population growth for the next 10 to 20 years, (ii) increasing urbanisation, and (iii) large-scale electrification programmes.
- Urban markets are a growing aspect of fuelwood demand.
- Newly electrified and /or urbanised households tend to continue to use fuelwood for a variety of reasons, including its low price or 'free' availability, cultural reasons, lack of cash to buy alternatives, lack of cash to buy appliances for other energy forms, general preference, etc. In the longer term, however, per capita consumption tends to decline.
- The gross annual value of demand to the national economy is estimated to be R3 – 4 billion.
- At the local level, demand is highly variable by location, but does tend to be greater in areas with larger biomass resources.
- Estimates of household consumption rates range from 0.6 tonnes per year to more than 7.5 tonnes per year, typically between 3 and 4 tonnes per household per year.

Shackleton's data indicates the critical importance of fuelwood to households. The contribution of biomass to household energy should therefore be included in planning scenarios. This will require an improved understanding of the longer term potential for sustainable resource harvesting.

3.7.2 Cost indications

The cost of generating electricity or producing liquid fuels from biomass depends very much on the source of the biomass. In many situations, biomass resources are waste products from agricultural or forestry processes, and the cost of electricity or liquid fuels is primarily related to conversion costs. In some situations, it is possible to find sources of biomass that have a negative cost, with the supplier paying the purchaser to take the material away. It is thus already economically and financially viable for some sugar mills to produce electricity from their bagasse waste streams, and some paper mills to burn biomass waste in boilers to produce energy. However, if biomass is to be used on a truly large scale for power generation or to make liquid fuels, then it will be necessary to plant crops specifically for energy purposes. Raw material costs would then increase significantly. Conningarth Economists (DME, 2004a, p. 118) estimated biomass generation costs in the range of R0.06/kWh to more than R0.80/kWh.

Sasol and other large groups in South Africa are already working towards the establishment of large-scale biodiesel production. This implies that costs will be of the same order as current diesel costs (about R3/litre), otherwise it would be extremely difficult for the product to enter the market. Government has indicated that a rebate on the applicable fuel taxes would apply for bio-fuels.

Ethanol and ethanol gel are currently more expensive than kerosene, but it is anticipated that costs of the order of R3/litre could be achieved – this would enable ethanol gel to compete as a household fuel.

The IEA (2003) indicates that biomass energy system costs are expected to decline by 5 percent per decade for the next two decades. This is a slower cost reduction rate than for other renewable energy technologies, reflecting the fact that biomass generation technologies are more 'mature'.

3.7.3 Potential

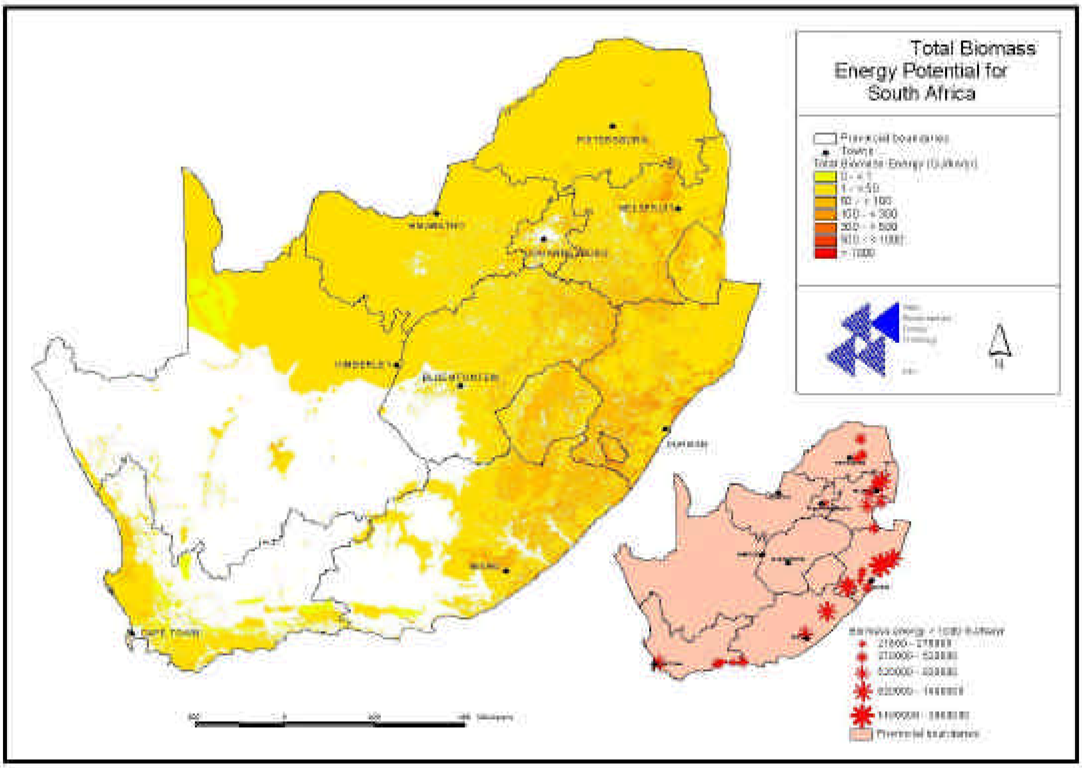
3.7.3.1 Electricity from biomass

As illustrated in Figure 3-6, the most productive biomass areas are in KwaZulu-Natal and the wetter parts of Mpumalanga. It will be noted that the energy potential per hectare extends as high as 1000 GJ/ha/annum.

There are currently 4 300 km^2 ha of sugar cane plantation and 13 000 km^2 of forestry plantation in South Africa (SMRI 2004). Existing sugar mills burn bagasse, and paper and packaging mills use pulp waste to generate process steam and approximately 210 GWh of electricity per year (DME, 2003b). The SMRI study indicates a total potential of 12.7 TWh per year from the existing sugar cane, forestry, sawmill, pulp and paper industries. If an additional land area equal to the current sugar crop were to be used for energy crops, then, with an average yield of 106 GJ/ha (3 GWh/km^2), it would be possible to produce a further 3.7 TWh of electricity as outlined in Appendix B. For the purposes of the *progressive renewable* scenario, we have used the combined total of 16.4 TWh.

However, Lynd et. al. (2003) estimate that the gross (prior to conversion) annual biomass energy production potential for South Africa is about 135 PJ per percent of available non-crop, non-forest, non-wilderness area used to produce energy crops. Thus their base case estimate entailing use of 10% of non-crop, non-forest, non-wilderness land gives an estimated production potential of 1350 PJ. This is the greatest potential of any country in Africa. Assuming a conversion efficiency of 25 percent for electricity, this could deliver almost 100TWh. If it were converted to liquid fuels at a conversion efficiency of 50 percent it would provide 675 PJ of liquid fuels equivalent (more than current transport fuel requirements). The high renewable scenario makes use of these somewhat higher resource assessments. Clearly a more detailed assessment is required, taking particular care to ensure that socio-economic and environmental issues are properly accounted for.

Figure 3-6 South African biomass resources



3.7.3.2 Biodiesel

Biodiesel is a vegetable oil derived from crops such as sunflower, soya and canola seed. It can be used in diesel engines and has a similar energy content to that of conventional crude oil-based diesel. It is estimated that the agricultural sector has the potential to produce more than 1.4 billion litres per annum of biodiesel (with an energy content of 45.7 PJ or 12.7 TWh) from various oilseed crops. In comparison, the national annual diesel consumption is 6.8 billion litres, with an energy content of 259 PJ (72 TWh) (DME, 2004c). The potential 45.7 PJ could be achieved in two ways:

1) Switching 6 500 km^2 of commercial maize production to oilseed crop production
2) Implementing an agricultural production revitalisation programme in disadvantaged rural areas.

The latter would make 23 000 km^2 of land available for oilseed crop production. Either option would make a contribution of more than 20 percent towards South Africa's diesel consumption (DST, 2003).

3.7.3.3 Ethanol

Table 3-1 indicates the potential contribution that ethanol from biomass could make towards energy supply in South Africa (adapted from Eberhard and Williams. 1988). Realisation of this potential would require substantial investments and significant changes in agricultural practices. The energy content of 1 litre of ethanol is approximately 23.6 MJ.

Table 3-1 Possible contribution of ethanol derived from biomass to energy supply in South Africa

Crop or biomass source	Energy content of potential annual ethanol production PJ (TWh)
Cassava	72.3 (20.1)
Sugarcane	11.1 (3.1)
Bagasse	5.6 (1.6)
Molasses	2.3 (0.6)
Maize	22.5 (6.3)
Sorghum straw	5.1 (1.4)
Wheat straw	7.0 (1.9)
Forest	3.4 (0.9)
Sawmills	0.7 (0.2)
Total	**130 (36.1)**

In considering land use for crop production for energy, it is worth noting that the current area under dryland cultivation in South Africa is 102 000 km^2 (DST, 2003). The competitive use of the same resource for both energy and non-energy products is an important consideration. In the longer term, it may be possible to extract energy from biomass grown in the ocean, where limitations of land area and water availability would naturally be far less.

For the *progressive renewable* scenario we have therefore assumed a maximum limit of 150 PJ (41.6 TWh heat energy) as the maximum allowable contribution of *biofuels*, including biodiesel, ethanol and others. This is in addition to the biomass for electricity generation maximum limit of 16.4 TWh described in Section 3.7.3.1. In the *high renewable* scenario we have used the higher Lynd et al estimates to justify a possible production of up to 43 TWh electrical energy from biomass, and 180 PJ biomass derived liquid fuels.

3.8 Landfill gas

3.8.1 Introduction to the resource and technology

Modern sanitary landfill operations involve the controlled spreading, compaction and covering of refuse. Landfill gas is the natural by-product of the decomposition of this solid waste in landfills and is comprised primarily of Carbon dioxide and methane. This gas can be extracted from well-managed landfills and is either burned to dispose of the methane (a wasteful process) or used to generate heat for the operation of landfill site equipment or for the generation of electricity. South Africa disposes of almost all its refuse in landfill sites.

3.8.2 Cost Indications

Production costs for landfill gas-based electricity generation are estimated to range from 17 to 30c/kWh (DME, 2004a). Costs depend primarily on the size of the generating unit, which range from 'micro', with a capacity of approximately 500 kWe, to 'large', with a capacity of 4 MW.

3.8.3 Potential contribution

South Africa has the potential to derive a substantial energy resource from landfill gas in its densely populated areas. Lombard de Mattos and Associates (2004) established that 453 landfill sites were operational or were in the process of being permitted. Fifty-three of these sites were analysed to determine the potential energy that could be extracted from the production of landfill gas. The sites were screened by size and by the nature of the wastes disposed on the sites. The possible production of methane (the largest component of landfill gas) and other gases can be estimated using various mathematical models that use information on the composition and quantities of the material deposited in the landfill.

Lombard de Mattos and Associates (2004, p. 34) estimated that South Africa has the potential for an installed capacity of 831 MWe of landfill gas-based electricity generation facilities which would produce an estimated 6.5 TWh of electricity annually at a load factor of 90 percent. In addition, the net realisable electricity available from sewage-derived methane in South Africa would be in the order of 0.8 TWh per annum, giving a total of 7.3 TWh for present resources. As urban populations grow and more people move into the middle or upper income bracket, so waste streams will grow. Furthermore, if waste resource streams are separated, there can be improved energy return. There is thus a potential for the landfill gas resource to grow over time. Assuming a 1 percent growth rate in this resource over 40 years, the final potential would be 10.8 TWh by 2045. The renewable energy resource potential from solid waste that has been considered in this study is therefore 10 TWh.

3.9 Wave, Ocean Current, Geothermal and Other Options

3.9.1 Wave energy

The ocean breakers crashing onto our shores have an average energy intensity of approximately 25 to 50 MW/km for about 900 km of coastline. If only 75 percent of this coastline was suitable for converter installation, then a total generating capacity of about 18 000 MW could be installed. Eberhard and Williams (1998) estimated that an annual average of 8000 MW could be generated, with a winter average of 10 000 MW. This could yield 70 TWh. This energy resource is therefore very significant.

Wave energy is currently receiving increased international attention, with several firms in the United Kingdom testing large-scale prototypes. A recent UK-based / Portugal implemented project by AWS has commissioned a 2 MW undersea unit, which is expected to be relatively secure under severe storm conditions. There are several other designs receiving international interest.

3.9.2 Ocean currents

Ocean currents are also an indirect source of solar energy since they are linked to the winds and surface heating processes. Harnessing the energy from these open-ocean currents requires the use of turbine-driven generators anchored in place in the ocean current streams. In one concept, large turbine blades would be driven by the moving water, similar to windmill blades being moved by the wind; and the blades used to turn the generators and thus harness the energy of the water flow. Another concept uses a barge moored in the ocean current stream fitted with a large cable loop to which parachutes are fastened. The current acting against the open parachutes would pull the cable. When the parachutes reach the end of the loop, they would turn the corner, close and be dragged back against the current. The continuous movement of the cable would be used to turn a generator to produce electricity. POEMS (2005) describes 'exciting technology, such as the rim-driven turbine, and the potential for further discovery and derived benefit from Newtonian and non-Newtonian process fluid mechanics, applied vortex hydrodynamics and linear implosion technologies in the future'.

There are many ocean sites world-wide with velocities of 2.5 m.s-1 and faster. Countries with an exceptionally high resource include the UK (E&PDC, 1993), Ireland, Italy, the Philippines, Japan and parts of the USA. Few studies have been undertaken to determine the total global marine current resource, although it is estimated to exceed 450 GW (POEMS, 2005). Currents such as the Agulhas current on the South African coast could have significant potential. This would entail a much lower risk than placing turbines in remote war-torn countries on the African continent.

3.9.3 Geothermal

In regions of volcanic activity, places where aquifers reach deep into the earth's crust and along fault lines, conditions can be suitable for the extraction of geothermal energy from the earth. Unlike the other discussed forms of energy, the sun's daily energy flux is not directly responsible for geothermal energy, which results from the flow of heat from the hot earth's core to the surface. According to estimates quoted by the German Advisory Council on Global Change (WBGU, 2003, p. 72), economic reserves of geothermal energy in 10 to 20 years time could be equivalent to current global primary energy use. However, if geothermal resources are to be used sustainably, then the heat extraction rate should not exceed the earth's natural heat flow. The Council conservatively estimated that, globally, 30 EJ could be extracted sustainably by 2100. This is equivalent to seven times South Africa's current total primary energy demand. Worldwide, approximately 8 000 MW of geothermal power is generated (International Geothermal Association, 2004). The United States has the largest geothermal installed base followed by the Philippines. Although the contribution of geothermal power generation to national energy supply is small in the case of the United States, it does represent 21.5 percent of national energy supply in the Philippines. Currently Kenya, with more than 100 MW of geothermal generation, has Africa's largest installed capacity (Engineering News, 2003a). Kenya and ten other East African states have committed to installing 1 000 MW by 2020 (Engineering News, 2003b).

Geothermal resources have not been reviewed in the recent DME strategy development processes, or in the series of Danida funded CaBEERE resource assessments. Little is thus known of the true potential. However, the Southern Cape Fold Mountains hold subterranean reservoirs of superheated water that some argue could be a source of cheap 'green' energy (Engineering News, 2003c). For the purposes of this study, we have assumed a maximum potential of 500 MW, which is important, but does not have a strong influence on the scenarios presented.

3.9.4 Other technologies

There are other 'future' technologies that could produce Hydrogen using renewable resources. Hydrogen can be stored and then used as needed for energy services or electricity production, thereby helping to overcome some of the disadvantages of intermittent renewable generation. The National Renewable Energy Laboratories in the USA are researching five main categories of Hydrogen production:

- Renewable Electrolysis: using electricity generated using any of the above renewable energy resources to split water using the electrolysis process

- Reforming of biomass and wastes: using pyrolysis or gasification of biomass resources to produce bio-oils or gas streams that can then be separated in valuable chemical and fuels such as Hydrogen
- Biological water splitting: using photosynthetic microbes to produce Hydrogen from water though their metabolic activities, the energy source being light
- Photoelectrochemical water splitting: using multijunction cell technology developed by the photovoltaic industry to generate sufficient voltage to split water, without requiring electrolysers
- Solar Thermal water splitting: using highly concentrated sunlight to generate temperatures that are high enough to drive thermochemical cycles that can be used to produce Hydrogen.

The potential for Hydrogen to contribute to future energy supply is discussed further in Section 4.3.

3.10 Summary of renewable energy potential

Table 3-2 lists estimations of renewable energy potential from several recent studies. The far right column indicates the maximum potential that we have used as an upper limit for scenarios in this study, based on the discussion above. It will be noted that there are significant differences in the estimates given by different parties. These differences result from:

- Uncertainty in resource estimates, particularly for wind, hydro and biomass
- Different assumptions regarding the financial and economic costs of harvesting the resource using different conversion technologies
- Different assumptions about the price that energy generated can be sold for.

In most cases, the figures determined for this study are higher than others and reasons for this are given in the relevant study sections. For wind, hydropower and biomass, further detail on our assumptions, and in particular on the reasons why different researchers have arrived at different conclusions, are listed in Appendix B.

From Table 3-2 it can be seen that the contributions of biomass, hydropower, and landfill sites, while very significant in the shorter term, are not adequate to meet more than about 20 percent of total electricity needs, and only 20 percent of current liquid fuel needs. If one uses the Lynd et al data for biomass, then far higher contributions could be achieved. Wind could contribute up to 50 percent of current electricity demand, but this is assuming maximum exploitation, at significant cost. On the other hand, the solar resource is far larger than required. In the longer term it will be necessary to focus attention on the solar energy conversion technologies (and associated storage technologies) if a more substantial renewable energy contribution is to be achieved.

Table 3-2: **Renewable energy potential -– assessments**

Resource	Draft Renewable Energy White Paper (referenced in EDRC 2003)	Renewable Energy White Paper (DME 2004)	CaBEERE studies and brochures	Economic Modelling Paper (DME 2004a)	Renewable Energy Market Transformation Study (World Bank 2004 (REMT))	Upper limits used for this study
	Potential contribution (in TWh electricity output unless otherwise stated)					
Solar water heating	.5	6 (urban residential only)		4.9 (domestic only) 2 (commercial)	43 in 2021	55 by 2050 (although not limited by supply)
Solar photovoltaic	40 000	-		-		not limited by supply / resource availability
Solar thermal electric	20 000	36				not limited by supply / resource availability
Wind	5.7	1.98	26	64	64	106
Bagasse	5	1.4 (electricity)	22.3 (total) 5.6 (electrical)	5.84		Biomass (general) Electricity: 16.4 liquid fuels: 150 PJ Lynd et al: 675 PJ @50% conversion eff.
Forestry, saw mill, pulp and paper	2.62 (wood waste)	12.1	7.1	0.1 (excludes forestry)		
Landfill gas and municipal waste	0.93	11 (total)	6.5	0.598		7.2 (growing to 10.8 by 2040)
Hydro (excluding pumped storage)	10 GW	7.8 GW	7.8 GW 14 TWh	3.4 GW 9.2 TWh	- 9.2 TWh	5.5 GW 14.6 TWh
Wave, tidal, geothermal, ocean						70

4 Energy Storage and Transport of Energy

4.1 Why is Storage Needed?

Renewable energy is not always available when required, particularly wind and solar electricity generation technologies that are dependent on an intermittent resource. The South African energy supply system relies on the storage of energy in fossil fuel stockpiles such as coal, liquid fuel storage depots and electrically charged pumped storage schemes. Enriched nuclear fuels can also be stored more-or-less indefinitely until the useful energy is required to be released in electricity generation facilities.

Although an extremely versatile energy carrier in terms of modern appliances and industrial applications, electricity is probably the most limiting carrier in terms of storage. It tends to be very expensive to store and electrical supply and demand must be continually and instantaneously balanced. This balancing act requires the provision of a so-called spinning reserve. This refers to the maintenance of power plants in a state whereby they are almost ready to be brought on-line should there be a change in electrical system demand or a failure of another electrical supply option elsewhere on the network. Typically, wind and solar resources cannot be managed in this way – and it is therefore necessary to identify other energy storage options, that can be used to top up the supply when demand peaks, or if intermittent resources reduce output.

4.2 Storage Options for Electricity

In South Africa, most electrically generated energy is stored in the three pumped storage schemes, with a combined capacity of 1580 MW. These plants can be brought on-line at very short notice in times of high demand or inadequate generation in the system. In times of low demand, excess generation capacity is utilised to fill the dams that provide the storage capacity. The greater the difference between maximum and minimum system demand, the greater the need for expensive plants that provide peak demand and/or storage capacity.

This is particularly important for renewable resource based electrical generation, as its output can be less readily predicted and therefore requires increased 'backup' generation and/or storage capacity. The increased need for electrical system storage capacity, in the form of pumped storage or other energy carrier storage, is therefore a limiting factor in any transition to a sustainable energy system. The potential for additional pumped storage schemes in South Africa has been estimated to be approximately 10.2 GW. Fortunately, as the variety of renewable energy technologies and generation sites increase, with different sources installed over a large area, the need for storage capacity begins to decrease again as the electrical network itself effectively becomes the storage pool. This type of argument forms part of the rationale for a more distributed generation system.

WBGU (2004) argues that, in the long term, transport and direct consumption of electricity in extended grids will probably remain less expensive than storage. Once the share of renewable energy sources has reached around 50 percent, the daily and yearly load curves will exhibit both excess power and shortages, despite best efforts at optimisation. This will necessitate additional energy storage.

There is a range of different technical solutions to meet short- and longer-term storage needs. The technologies can be roughly divided into relatively fast storage types with high output (e.g. capacitors, flywheels, superconductors) and slower types with high energy content (e.g. pumped storage hydroelectric plants, compressed air tanks, electrochemical storage). To keep costs down, pumped storage hydroelectric plants are most often used to provide large-scale grid support for mid- to long-term energy storage. Redox systems, especially those using Hydrogen, are being developed as future storage systems.

4.3 The Emerging Hydrogen Economy

An example of extremely high renewable penetration into a country's energy system can be seen in a study which simulated a 100 percent renewable energy supply to Japan (described online at www.energyrichjapan.net). This system is based on actual weather data with a real-time simulation of how actual demand is met by an entirely renewable resource base supply system. Since it is best to operate renewable generators whenever the sun is shining or the wind is blowing, excess power is used in this simulation to produce Hydrogen. The Hydrogen can then be used when needed to generate electricity. Descriptions of a Hydrogen economy envisage Hydrogen tankers or pipelines, rather than crude oil tankers, exporting energy from renewable systems to other countries.

Hydrogen is particularly attractive as a component of a transformed energy system because it can be produced from water (using energy), with almost no pollutants emitted when it is used to provide heat or electricity on demand. Emerging Hydrogen technologies would enable the long-term storage of large amounts of energy, with the gas being easily transported. In combination with renewable energy sources, Hydrogen thus has the potential to become a crucial energy carrier in a future sustainable energy system (WBGU, 2004).

Fuel-cells, which generate electricity using an electro-chemical process rather than a conventional combustion/heat-engine cycle, are likely to be available in a range of sizes. Small portable units can generate electricity for personal requirements (e.g. computers) while multi-megawatt systems that can feed power into the grid as required, or integrate into domestic energy systems as 'distributed generation' technologies.

Hydrogen has been proposed as a major energy carrier in the *'high renewable'* scenario below, with its contribution reaching 1450 PJ annually by 2050. To achieve this, the Hydrogen production/storage/transport and utilisation industry would have to grow at a very high rate from its current 'zero' base. It is worth noting that Hawaii for example has embarked on a path to become a net Hydrogen exporter, while the Pacific island Vanuatu has a goal of 100% renewable energy supply by 2020 (Dunn, 2001). Hydrogen is again set to play a central role in the energy supply system for Vanuatu with excess for export. The situation for larger economies is similarly pressing with a researcher at the United States National Renewable Energy Research Laboratory quoted by Dunn in the same year as saying that the United States could achieve a clean Hydrogen economy within ten years given an effort of similar proportion to their national space programme. Development of a large-scale Hydrogen contribution to the economy would be difficult, but it does seem possible!

4.4 Distributed Generation

The predominant themes emerging amongst visionaries on the future of the energy industry are that energy will be used more efficiently, electrical generation facilities will be smaller, planning will be decentralised and energy supply will become progressively more benign in terms of its impact on the natural environment.

Technology options to be considered in these smaller, finer grained solutions are wind power, solar thermal applications (both passive and active), photovoltaics, battery storage, generator sets, Stirling engines and fuel cells. These small, locally situated generation and storage facilities in the distribution network are collectively referred to as distributed generation (Schäffler, 2001).

In the scenarios discussed, time and space have not allowed for detailed discussion on what could be distributed generation, and what is likely to be centralised. One of the main advantages of distributed generation is that it reduces reliance on large-scale transmission lines. If properly applied, distributed generation can reduce substation loading and the need for substation/transmission line upgrades. Smaller scale generation options also typically require shorter lead times for construction, and construction programmes can be adapted more easily to changes in total demand. Large-scale centralised plant construction programmes carry significant economic risk, in that a slower than anticipated growth in electricity demand can result in expensive excess capacity (as happened in the late period from 1970 to early 1980's in South Africa). It is important to note that several of the large-scale contributions included in the scenarios would be made up of several hundred or thousand smaller distributed generators.

4.5 Energy Efficiency

Although renewable energy options are critical to achieving a more sustainable energy future, they only address supply-side issues. Often, the energy used to achieve a particular task or output is far more than is really needed, and energy efficiency measures can be used to reduce that demand. There are several energy efficiency interventions that can be summarised according to the various environments in which the options are implemented.

In the industrial, commercial, institutional and public sectors, efficiency improvements can be achieved through the provision of motive power for lighting and heating systems. For example, energy-efficient motors can be installed. Because the energy that the motor uses is usually many times more valuable than the motor itself, the extra expenditure on the capital cost of a more efficient motor is rapidly recovered in reduced energy bills. Variable speed drives allow for improved tailoring of the speed of the motor to the job that the motor is actually doing. Power factor correction equipment helps to improve the energy efficiency of electricity generation, distribution and consumption.

Lighting can be rendered more energy efficient by ensuring appropriate lighting levels, the introduction of compact fluorescent lamps (CFLs) and other more efficient lights, sophisticated lighting controls and more effective use of daylight. Space heating can be made more energy efficient with building insulation, heating controls and passive solar design. The efficiency of heating systems can be improved with the use of solar heaters, pipe and boiler insulation and system designs that incorporate sound thermodynamic principals. These systems are promoted by 'energy efficient' institutions such as the Rocky Mountain Institute (www.rmi.org).

Similarly, the residential sector offers a significant number of options for increased energy efficiency. These include space-heating interventions (e.g. building insulation and passive solar design), the use of more efficient light and lighting systems and improved insulation in hot water systems. Schäffler (2001) describes promising future technologies that are already being considered. For example, superwindows intelligently transmit or reflect radiation to optimise energy consumption for both heating and lighting in buildings. Intelligent building energy management systems are making previously futuristic ideas more plausible and widespread (e.g. lights switching on and off automatically as people enter or vacate a room).

Energy planners often consider energy efficiency goals in terms of 'negawatts' or explicit energy saving targets superimposed on the energy supply curves. In the scenarios below we have not done this, so as to simplify presentation. For all three scenarios we have assumed that very active energy efficiency programmes are underway, and that the electricity or total demand curves used therefore already include the energy efficiency gains.

5 Scenarios for Future Energy Supply

At present, the South African government policy is that renewable energy should contribute 10 000 GWH (cumulative) by 2013. An earlier draft of the white paper called for the renewable energy contribution to total final energy to increase from the current 9 percent to 14 percent by 2012, which was a more ambitious contribution[13]. The Sustainable Energy and Climate Change

[13] Note, there is considerable uncertainty regarding the contribution of biomass, some data indicating that it is already contributing almost 15% to final energy demand (WEC, 2003, p. 23). See Section 3.7.

Partnership has called for a target for electricity generation by renewable energy technologies target of 10 percent by 2012, and 20 percent by 2020. A recent study by the Energy and Development Research Centre has indicated a possible target of 15 percent for renewable electricity generation by 2020 that, with appropriate policies and measures, could be achieved with net cost savings over the period (EDRC, 2003, p.116). What is finally achieved depends heavily on the effort that government, industry and people are prepared to make.

In the following sections, we explore the implications of three broad scenarios:

- A *business as usual* low renewable target scenario, and
- A *progressive renewable* energy scenario, which does not focus on achieving a particular target, but rather explores the implications of focussing significant attention on renewable energy investments, particularly in the electricity sector
- A *high renewable* scenario that includes large scale Hydrogen production, and partial substitution of non-electricity fossil use with renewable energy generated electricity.

The recently completed National Integrated Resource Plan did not include renewables in the base case. However, the DME target of 10 000 GWh was included as a special addendum to the most preferred plan, with concentrating solar power and wind being the only two options investigated (NER 2004a, NER 2004b). Various parties (e.g. World Bank Renewable Energy Market Transformation Study, 2004) are exploring several other options for a short-term renewable energy contribution. As previously noted, landfill gas and biomass can easily provide 10 000 GWh of energy at reasonable cost. Solar water heaters could also meet this output, and options such as wind, solar and small hydro are also contenders.

In order to explore fully the impacts of future energy demand, the aging of existing power plants and the incorporation of new (fossil or renewable) power plants into the energy mix, it is customary to undertake a modelling exercise using tools such as MARKAL and LEAP. The resources available for this study were limited, however, and the authors chose to develop a relatively simple spreadsheet-based 'visualisation' model. This model illustrates effects from demand growth, the introduction of new technologies and the decommissioning of existing plants. More rigorous modelling will be required to validate the results presented here.

The visualisation model uses information from the preceding chapters to:

- Provide upper boundaries for the amount of a particular renewable energy that could be included in the energy mix
- Provide an indication of the cost of using different energy technologies
- Illustrate the contributions that each technology makes to:
  a) The total installed base (for each scenario studied, we have defined the installed capacity needed in MW)
  b) The energy production per year (for each technology, a typical load factor is assumed for a given year, and a net energy output is calculated in TWh)
  c) The ability of the system as a whole to meet peak demand requirements (based on the potential contribution that the technology can make to meeting peak demand power requirements)
- Allow the user to explore the effects of introducing different technology options into the electricity or total energy supply mix.
- Illustrate the role of large scale energy storage systems (or multiple distributed energy storage in meeting peak demand.

The model does not formally quantify the cost of supply, although it does produce indicative cost curves for each technology class. It also does not consider the costs and losses associated with transmission of energy. However, a reserve margin is provided to cover for this. Section 5.2.3 and 5.2.4 provide more information on strategies followed in populating the model.

The analysis is divided into two parts, a review of electricity generation options, followed by a review of the total energy supply situation.

5.1 Business as Usual – Electricity Generation

Figure 2-5 illustrates four electricity demand options for South Africa. As discussed in Section 2.2, we assumed for the purposes of this report that future demand will follow the 'energy conscious' curve. Figure 5-1 shows this demand curve (red line), and the existing generation capacity (in TWh) (blue block, includes existing coal and existing Nuclear). It should be noted that the existing equipment is scheduled for decommissioning, with the first plants going out of service by 2024 and relatively little of the existing capacity left by 2038. It is possible that generation plant life could be extended, but this has not been explored in this model.

By 2006, new generation capacity is required to allow an adequate reserve margin. The cream block shows the additional generation capacity (i.e. refurbished mothballed coal plant, new coal and fluidised bed coal plant) that is proposed in the NER Integrated Resource Plan 14 for the period up to 2022. From 2023, it would be necessary to add similar conventional power plant capacity, as required to meet energy requirements. The next band in the graph (light blue) is the contribution from peak generation plant, again as proposed in the NER IRP Plan 14 for the period up to 2022, and then with continued expansion as required.

The importance of peak plant is not readily apparent in Figure 5-1, as it contributes very little to energy supply., This is because the plant is only run for short periods when the total load on the system is high. However, Figure 5-2 shows the contribution of different technologies in providing an adequate reserve for peak demand periods. It can be clearly seen that new peak plant plays an important role from 2008 onwards.

Figure 5-1 Business as usual scenario: energy demand matching[14]

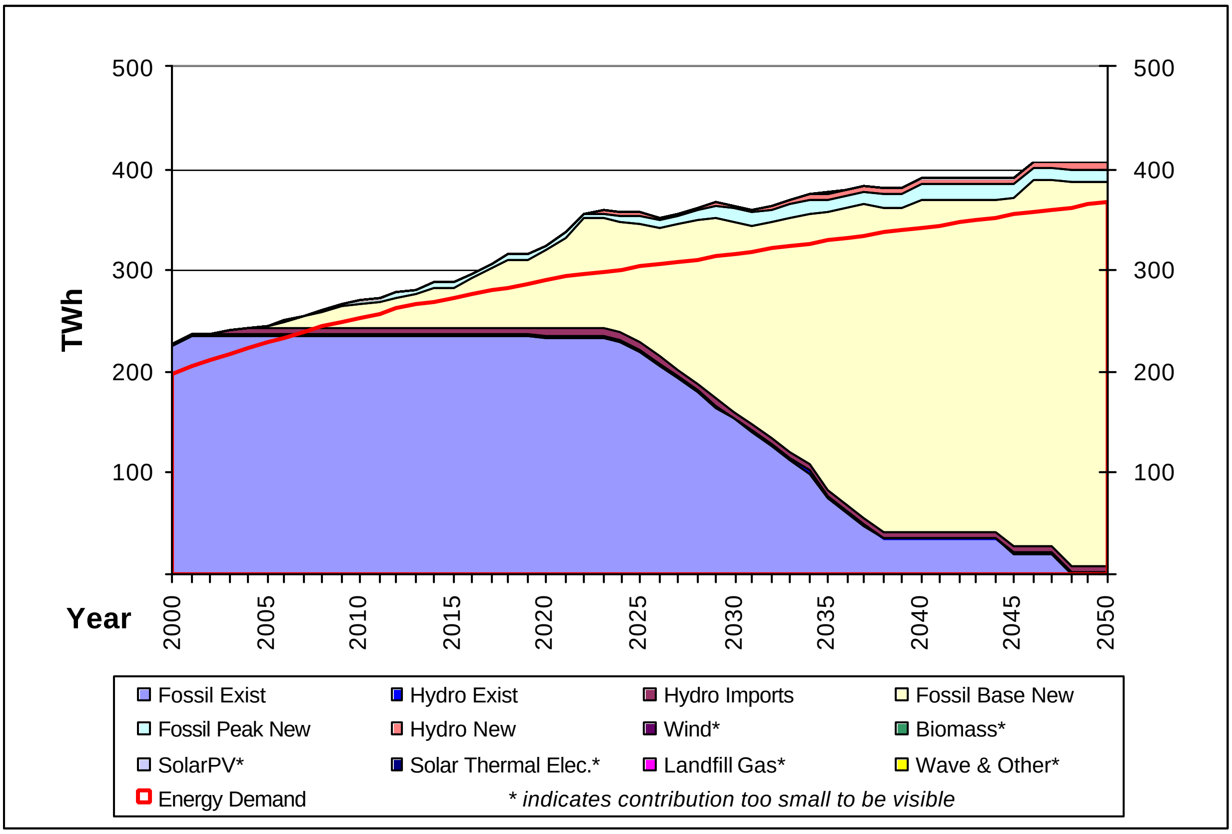
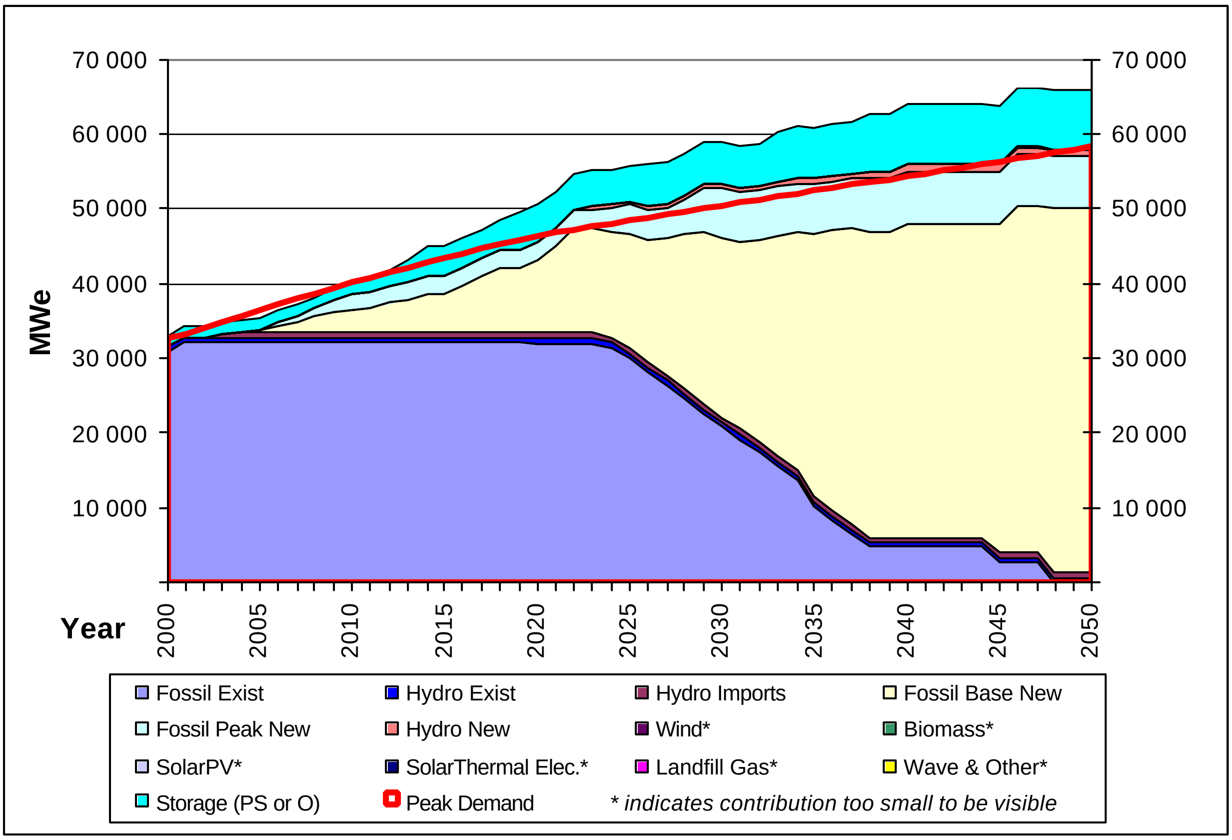


Figure 5-2 Business as usual scenario: peak demand matching



[14] Supply is shown as being higher than demand because of the need to provide extra or reserve capacity to deal with peak demand periods or generation plant shutdowns for maintenance. In practice some of the generation equipment would be turned off or run at reduced output so that supply matched demand.

New hydro capacity is not included in the NER IRP, but we have suggested that 500 MW be added in 2023, and a further 500 MW in 2034. The NER IRP Plan 14 also includes the addition of new pumped storage schemes, with 333 MW coming on stream in 2012 and a further 999 MW in each of 2013, 2014 and 2019. It will be noted that these do not contribute to energy supply, but do make a major contribution to the system's ability to meet the peak demand.

The NER IRP Plan 14 also includes 152 MW of energy efficiency/demand-side management savings. This has not been included, as the 'energy conscious' demand curve used for this exercise already assumes significant energy efficiency activity.

5.1.1 Observations on the business as usual scenario

The most critical observation concerning the 'business as usual' scenario is the concern in respect to the sheer volume of new conventional (or possibly nuclear) power plant capacity that would be required. As indicated, the current plants would all have to be replaced, and the total capacity almost doubled by 2050. Firstly, the current environmental impact of the coal power stations is well known. Secondly, to achieve such a growth rate (41 GW of new plant by 2036), would require the addition of an average of 1.4 GW per year, equivalent to adding one of Eskom's large 3.6 GW power stations every 30 months. This represents an very large capital investment, and would have extremely significant environmental and economic impacts.

In this scenario, the renewable energy contribution would be limited to a maximum of 4 percent.

5.2 The 'Progressive Renewable Scenario'

Figure 5-3 to Figure 5-5 illustrate a possible electricity supply scenario (*Progressive renewable* Scenario) that makes significant use of renewable energy resources. Figure 5-6 provides illustrative costs per unit electricity from each generation source for this scenario.

The scenario is moderately aggressive during the years 2005 to 2020, with about 13 percent of total electricity obtained from renewables by 2020. To achieve this, the installed capacities of the different technologies would be as given in Table 5-1. Note that solar water heating is not included in our supply curves, as this is not a direct electricity generation option, but rather displaces electricity generation. If the effective electricity contribution (saving) of a large-scale solar water heater programme was included in the mix (the approach taken for the White Paper Renewable Energy target), then the renewable electricity contribution could be more than 15 percent.

Figure 5-3 Progressive Renewable Scenario: - installed capacity

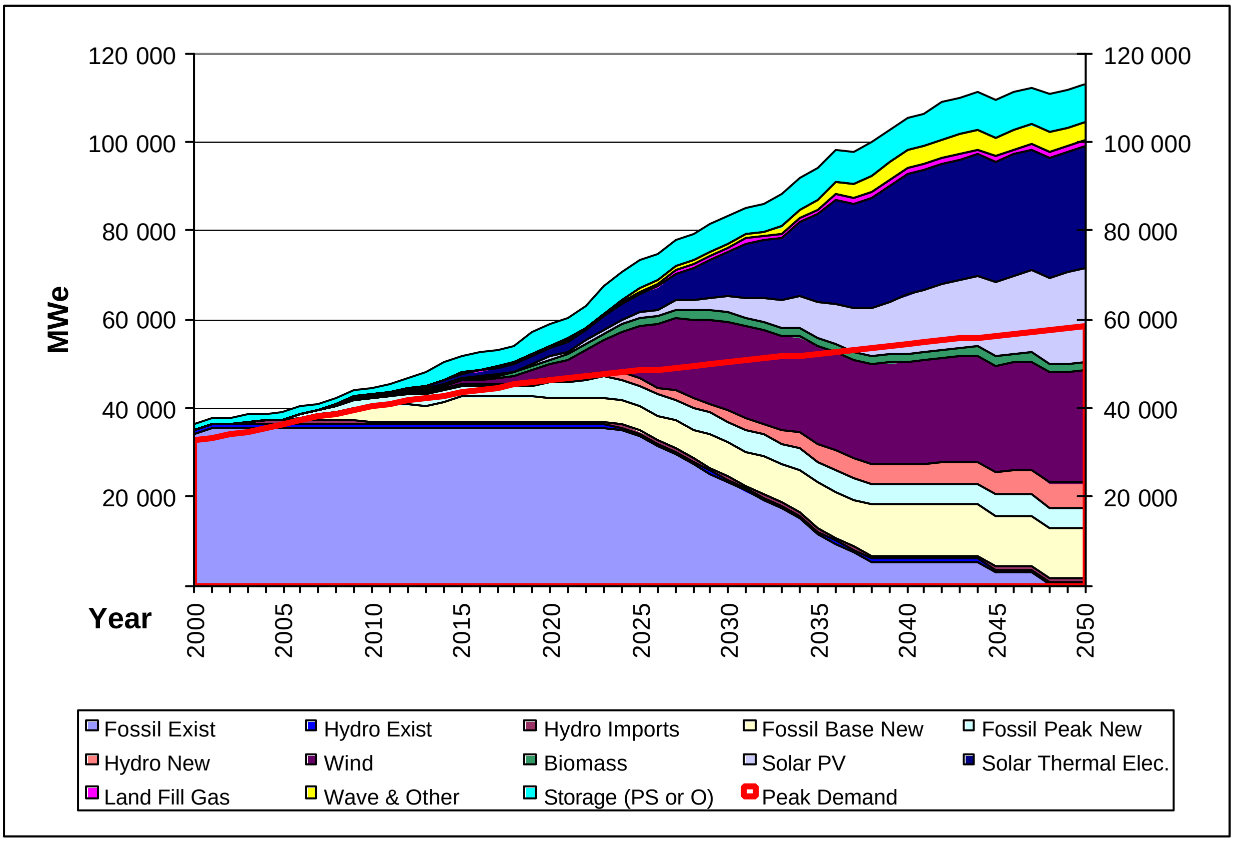


Figure 5-4 Progressive Renewable Scenario: Illustration of how the energy demand could be met

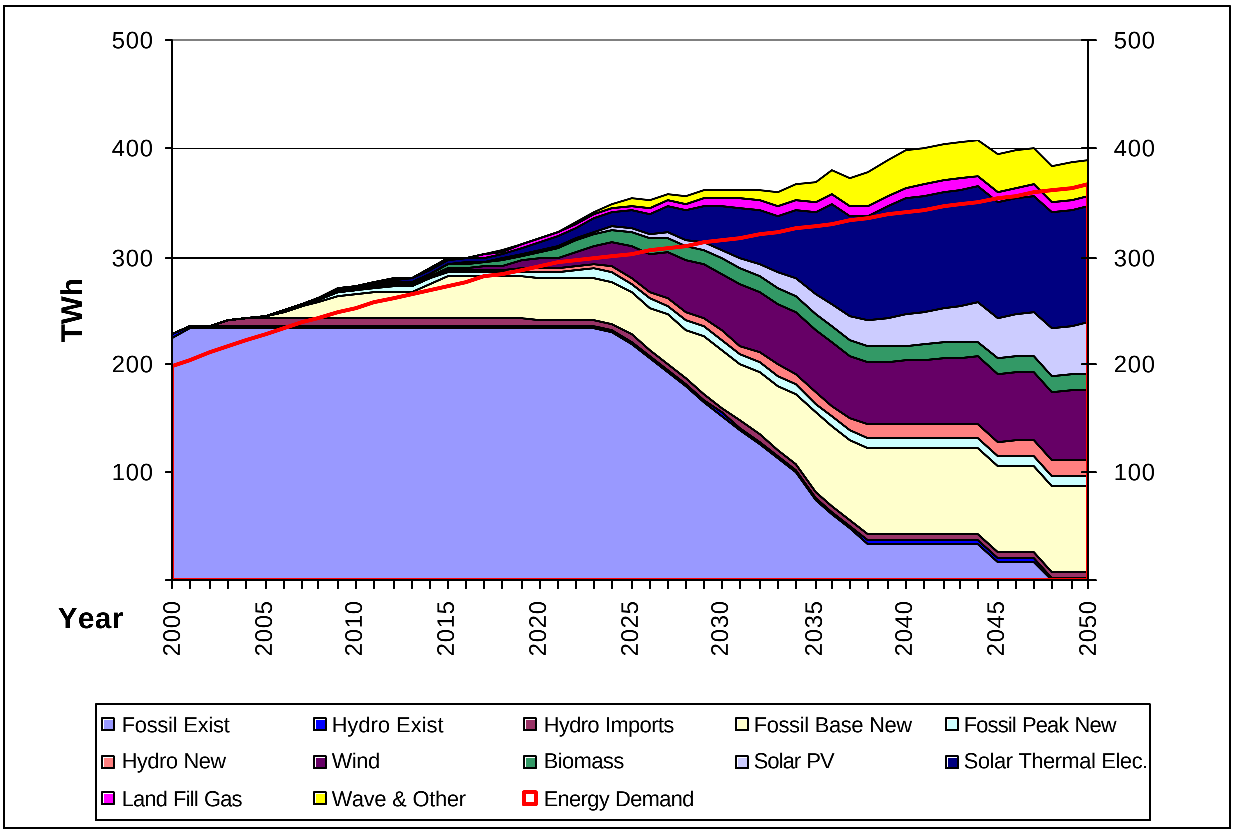


**Figure 5-5 Progressive Renewable Scenario:
Illustration of how the peak demand would be met**

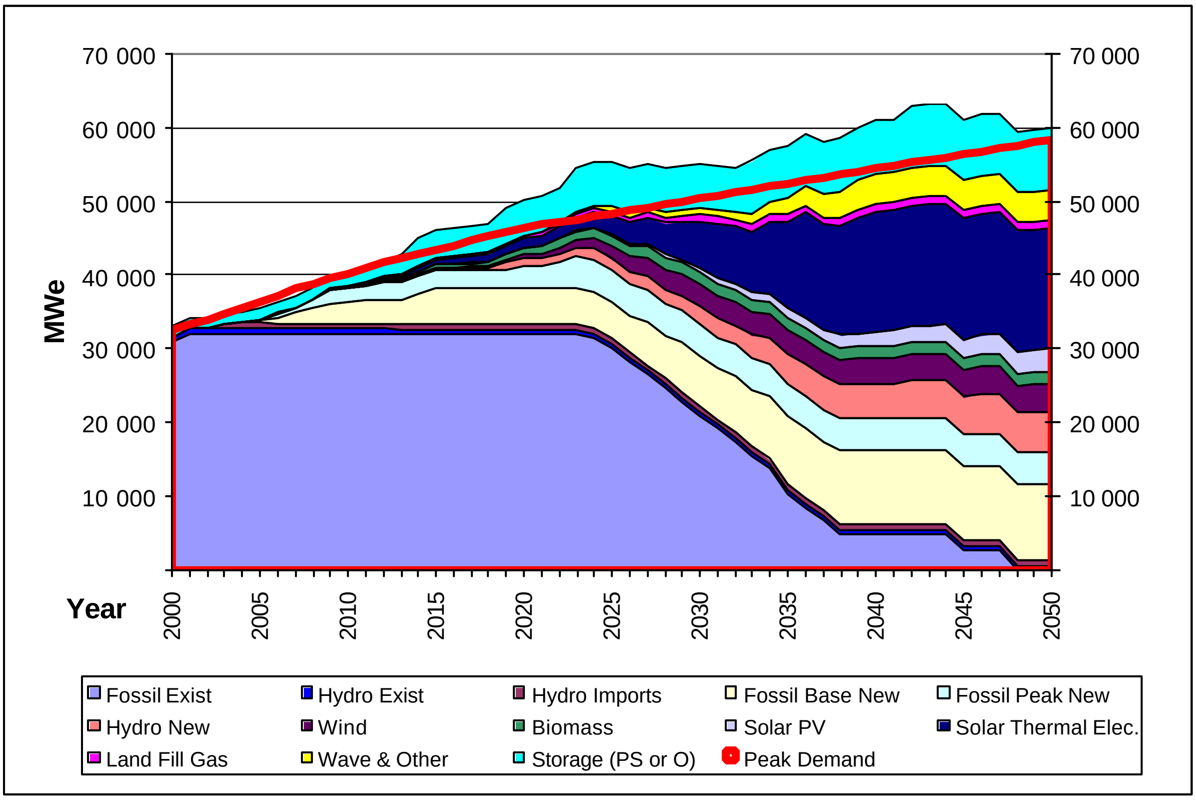


**Figure 5-6 Progressive Renewable Scenario:
Illustration of the possible changes in costs per unit energy over time**

Costs for renewable technologies tend to reduce over time as a result of experience and technical development. However, when particular lower cost resources are used up, prices show significant increases as higher cost resources are used (see section 5.2.3).

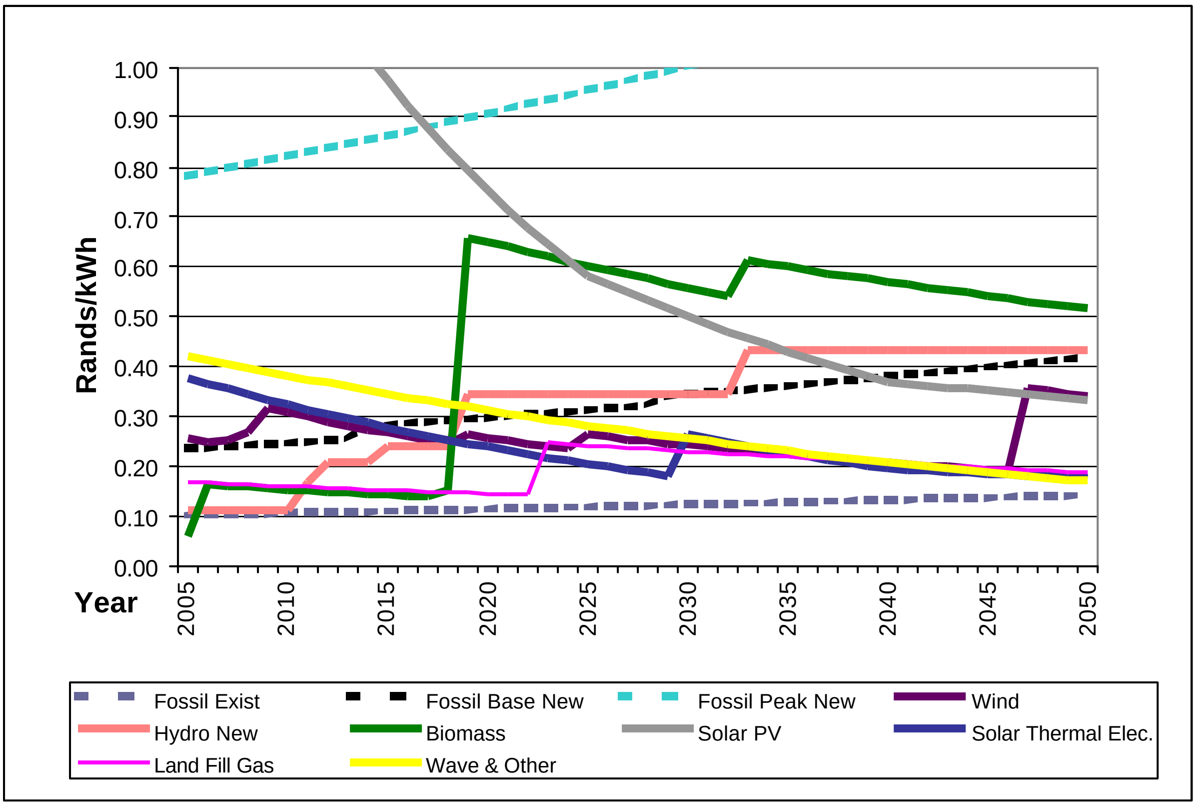


Table 5-1 Progressive Renewable Scenario: Illustrative generation technology capacities (in MW)

Year	Conventional and Nuclear Existing	Hydro existing	Hydro imports [15]	Fossil Base New	Fossil Peak New	Wind	Hydro New	Biomass	Solar PV	Solar thermal electricity	Landfill gas	Wave and Other generation	Storage (PS or Other)
2003	35 623	641	556						8				1 580
2004	35 623	637	781			4			12				1 580
2005	35 623	633	781	380[16]		4		8	14				1 580
2006	35 623	629	781	760	720	9		16	17		5		1 580
2007	35 623	625	781	1 518	720	29		30	21		35		1 580
2008	35 623	621	781	2 186	1 200	79	20	90	25		65		1 580
2009	35 623	617	781	2 953	1 920	179	34	150	32	100	72		1 580
2010	35 623	613	781	3 256	1 920	233	56	180	42	200	140		1 580
2011	35 623	613	781	3 559	1 920	303	82	210	55	300	154	1	1 580
2012	35 623	613	781	3 559	2 640	393	113	240	71	400	169	2	1 913
2013	35 623	579	781	3 559	2 640	511	150	276	92	600	186	4	2 912
2014	35 623	579	781	4 491	2 640	665	195	331	120	800	205	8	3 911
2015	35 623	575	781	5 423	2 640	864	230	397	156	1 000	225	12	3 911
2020	35 523	571	781	5 423	3 360	3 208	1 070	989	580	2 000	363	100	4 910
2025	33 423	571	781	5 423	4 800	11 911	1 570	1 649	1 443	4 147	585	800	6 110
2030	23 191	571	781	7 595	4 800	19 934	2 576	1 929	3 590	10 320	942	950	6 110
2035	11 391	571	781	10 391	4 800	21 781	4 076	1 929	8 188	19 660	1 143	2 250	7 310
2040	5 391	571	781	11 323	4 800	22 892	4 576	1 929	13 186	27 311	1 201	4 250	7 310
2045	2 891	571	781	11 323	4 800	24 059	5 076	1 929	16 829	27 311	1 238	4 250	8 510
2050		571	781	11 323	4 800	25 287	5 576	1 929	21 479	27 311	1 238	4 250	8 510

[15] This scenario assumes that new hyrdo imports are largely off-set (in energy terms) by power exports

[16] Early installations likely to be refurbished plant or natural gas turbines.

5.2.1 Installed capacity

As illustrated in Figure 5-3, the ratio between total installed capacity and peak demand for the period 2020 onwards increases significantly, because the renewable energy options run at far lower capacity factors than base-load fossil plants. During the period 2005 to 2020, renewable energy options such as biomass, wind and land-fill gas are emphasised, as these represent short-term lower cost opportunities (see Figure 5-6). However, it would be important during this period to start gaining experience with solar thermal electric technologies because, by 2020, these are likely to be the lowest cost options, provided that an adequate experience based is developed in South Africa. Although the graphs indicate that solar PV remains expensive, it should be noted that this technology can be installed almost anywhere – reducing transmission costs, is simple to operate, and is within the realm of individual purchase decisions. As a result, the total costs of PV use may compare more favourably than suggested by a direct generation cost comparison. We anticipate that PV technology will play a very important role in the electricity supply market (grid and off-grid).

5.2.2 Energy and peak demand matching

The projections show a reasonable margin for both the total energy requirement and the peak demand capability of the plants installed. With more sophisticated analysis, we anticipate that the resource margin could be reduced, with a lowering of total costs. It will be noted that, in later years, solar thermal electric generation is indicated as having a particularly significant role to play in peak demand. This is because both thermal storage options and the fossil hybrid options can be integrated with solar thermal technology. The indicated 'new' pumped storage options provide slightly more than 7 GW by 2033, but this may be an underestimation as the model cannot determine full storage requirements. There are however other emerging storage technologies which should be available in time. Storage is a critical component of peak demand matching, but does not contribute to meeting total energy needs.

The projections are obviously more speculative for the period 2025 to 2050, but it is of interest to note that South Africa has a unique opportunity to develop a very strong renewable component to its electricity supply from 2025 onwards. The two main reasons for this opportunity are:

1. Existing coal plant capacity is scheduled for decommissioning, starting around 2022
2. By that stage (see Section 5.2.3), solar thermal electric options (and other renewable energy options) will possibly be cheaper to build than new fossil plants.

It is thus possible that South Africa could make a rapid transition from strongly coal-based electricity generation to renewable energy-based generation, dominated by solar energy, during the period from 2023 to 2050 (see Figure 5-9).

5.2.3 Cost of energy

Figure 5-6 illustrates possible prices changes (R/kWh) for the different technology options. Assumptions regarding changes in technology costs are listed in Appendix C. Note that in this study, it was not possible to determine pricing with any degree of accuracy and Figure 5-6 is presented simply to show reasonable values and trends, drawn from the technology review in chapter 3.

The existing fossil plants obviously show the lowest costs, simply because large capital investments have already been written off. However, a gradual climb in price is indicated (one percent per annum), reflecting anticipated coal price increases due to Carbon taxes, environmental concerns and increased resource scarcity, as well as increased maintenance costs as the plant ages.

Small amounts of biomass energy can be generated at low cost in the early years. However, as biomass generation increases, low and zero cost resource options are fully utilised. Dedicated planting of energy crops will be required by 2020, with a consequent significant increase in the cost of biomass generated electricity.

Some hydropower resources are likely to be brought on stream at relatively low cost, although, similar to biomass, once the good sites have been used up, subsequent development will be more costly.

Landfill gas has a similar cost curve, with anticipated price increases as sites that are smaller and less favourable to exploit are brought on-line. A gradual drop in price is expected as technical improvements take place, particularly with respect to reductions in operation and maintenance of landfill gas generation plants.

The next cheapest options indicated (year 2005) are wind and new base-load fossil fuels. Internationally, wind farms are already competing favourably with new fossil fuel capacity. However, in the South African context, good wind sites have not yet been well documented, and it should be noted that, as more wind is brought on stream (e.g. in 2011), prices would increase. Provided that the use of wind is expanded over several years, then the price increases resulting from the use of poorer resource areas will be partially offset by global reductions in technology cost. Wind therefore remains a competitive option, within the total resource limitations as discussed in Section 3.5.3. It should be remembered that, as previously explained, the cost of new fossil capacity is expected to gradually increase (1 percent above inflation per annum).

Solar thermal electricity is indicated as the next cheapest option in the early years, starting at about R0.40/kWh. However, if costs decline at the indicated 3 percent per annum, then by 2012, solar thermal electricity could be cheaper to install than new base-load fossil plants, and by 2022, it could become the lowest cost option. This does not necessarily mean that all new capacity installed should be solar thermal generation plants, because generation and load demand fluctuations would cause difficulties. However, for illustrative purposes, we have included a 50 percent price increase for solar thermal electric power in 2030 in order to make provision for increased thermal or other storage capacity to be integrated with the solar thermal plants. Even then, the generation costs are indicated as being extremely competitive.

It should be noted that fossil peak plant is very costly, rising as fuels become more expensive. This is typical of peak plant, but its low capital cost and high flexibility mean that significant peak plant capacity will be installed.

The solar PV curve is the most expensive technology for the majority of the scenario period. However, we still regard this cost indication as highly uncertain. As discussed in Section 3.2, this industry is growing extremely fast and there have been ongoing price reductions and innovations. Furthermore, its simplicity of use and its versatility with respect to distributed generation mean that PV technology will almost certainly be a very important player.

5.2.4 Rationale for the choices made

The rationale in deciding which energy forms should contribute to the energy mix was to utilise the lowest cost resources fairly early, while still maintaining a 10 to 20 percent growth rate in the solar PV and solar thermal electric technologies. The latter technologies are seen to be critical for the later years, and it is thus important to build experience early. In all cases, specific industry growth rates were kept within reasonable limits to allow for a gradual growth of the industry. Typically growth was limited to a maximum of 30 percent per year, although, in some cases, installation of large plants resulted in a steep jump.

The allowable resource utilisation in each case was limited in line with the data in Table 3-2. In populating the model, we were surprised to find that it was difficult to achieve a high renewable contribution by 2020. All the technologies start from such a small base that even a 20 percent growth rate does not make significant progress in 15 years in terms of TWh. This is accentuated by the fact that there is significant existing fossil capacity. However, once each of the introduced technologies has reached a reasonable size, their contribution to the energy mix suddenly starts to grow faster, and we found it necessary to trim growth rates back to 5 percent per annum or less in later years.

The figures show a move to 70 percent renewable contribution by 2040. This is higher than most international long-term scenarios. We anticipate that more formal and detailed modelling will indicate the need to include a higher fossil contribution in order to provide greater peak load and base load reliability. It is of interest to note, however, that such a rapid shift is not without precedent. During the first half of the 20th century, there was a similar shift from wood, biomass, coal and animal power to oil. Similarly, in urban areas, electrification has brought about rapid changes in energy behaviour. Given our excellent solar resource base, if the conversion technologies (combined with storage) do become cheaper that fossil alternatives, a rapid shift will occur.

5.3 Energy Demand Other than Electricity

If the growth rates indicated in the Integrated Energy Plan up to 2022 are extended, total energy demand could triple by 2050 (as illustrated in Figure 2-3). In our opinion, this is not sustainable. Figure 5-7 illustrates a revision of energy demand by sector. In this scenario, energy demand growth rates for each of the sectors have been reduced, on the assumption that energy efficiency and energy conservation will play a very important role – the 'energy conscious' model. As with other outputs of this study, this graph is not the result of rigorous modelling, but rather an illustrative scenario to provide a basis for discussion. It still involves more than doubling the final energy demand and will place a huge burden on the environment.

Figure 5-7 Illustration of an 'energy conscious' total final energy demand scenario

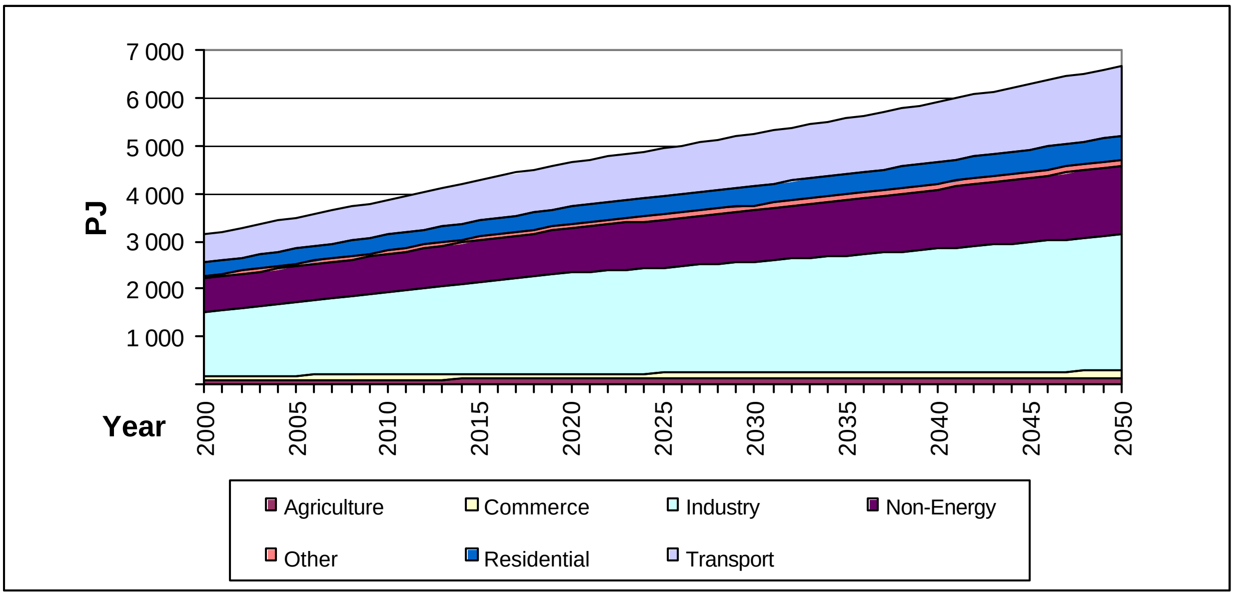


Figure 5-8 illustrates a possible resource supply selection for the 'energy conscious' scenario. Four main renewable energy components are shown, which together account for 35 percent of final energy consumption by 2050:

- Biomass is expected to continue to play an important role as a direct source of energy, although the continued growth indicated in the graph is possibly not sustainable with respect to the environment and food security. Note: the total energy scenario illustrations shown indicate that biomass currently contributes about 14% to final energy demand. If the biomass contribution is closer to the 9% indicated by some data (see section 3.7.1), then the renewable energy contribution to total energy will have to be reduced by about 5%.

- Solar water heaters are shown to contribute approximately 150 PJ per annum by 2030. This would entail significant growth of the solar water heater and process heat market (in line with the growth curve of Figure 3-3).
- Biofuels (biodiesel, ethanol and other options) are shown as an additional biomass contribution, also contributing about 150 PJ by 2030 (see Section 3.7.3.2 and 3.7.3.3). Note that this would have significant environmental impacts. At a production rate of 120 GJ/ha this would require a land area of 12 500 km^2. This is about 1% of the South African total land area, and about as large as current forestry plantations. Obviously if improved production rates can be achieved, less land would be required.
- Lastly, the renewable energy component of electricity supply is represented, using the totals derived in Section 5.2.

Figure 5-8 Progressive Renewable Scenario: Illustration of final energy supply (in PJ), expressed by resource

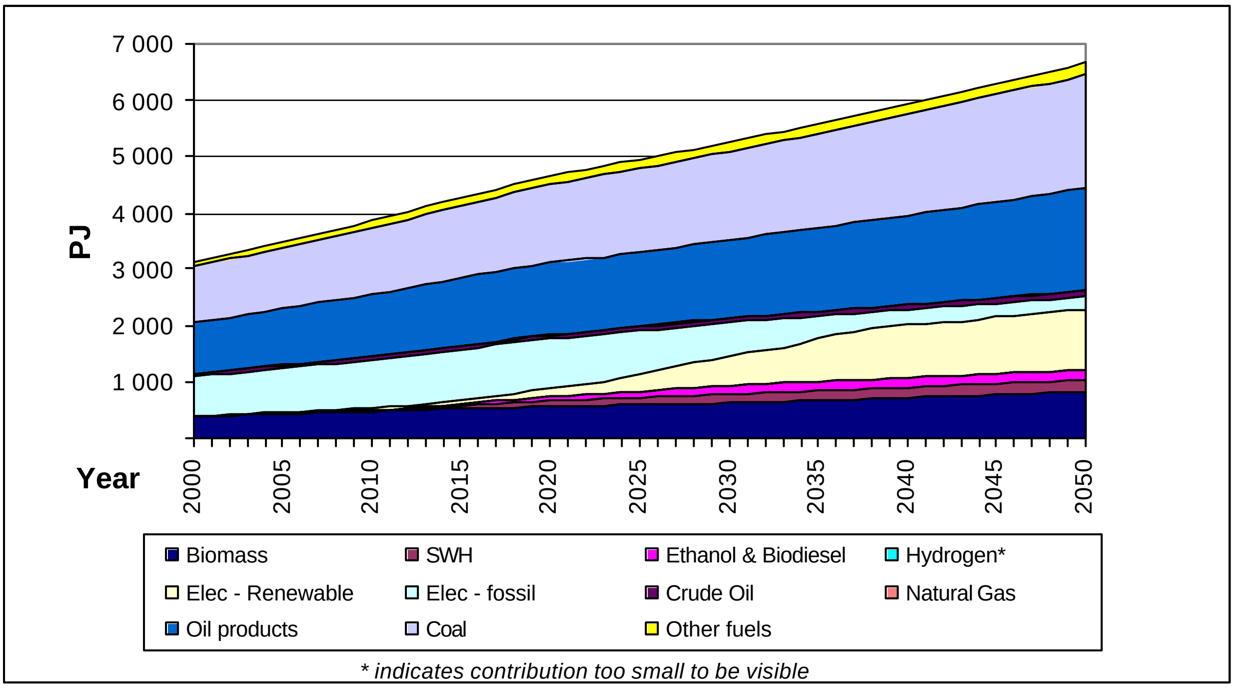
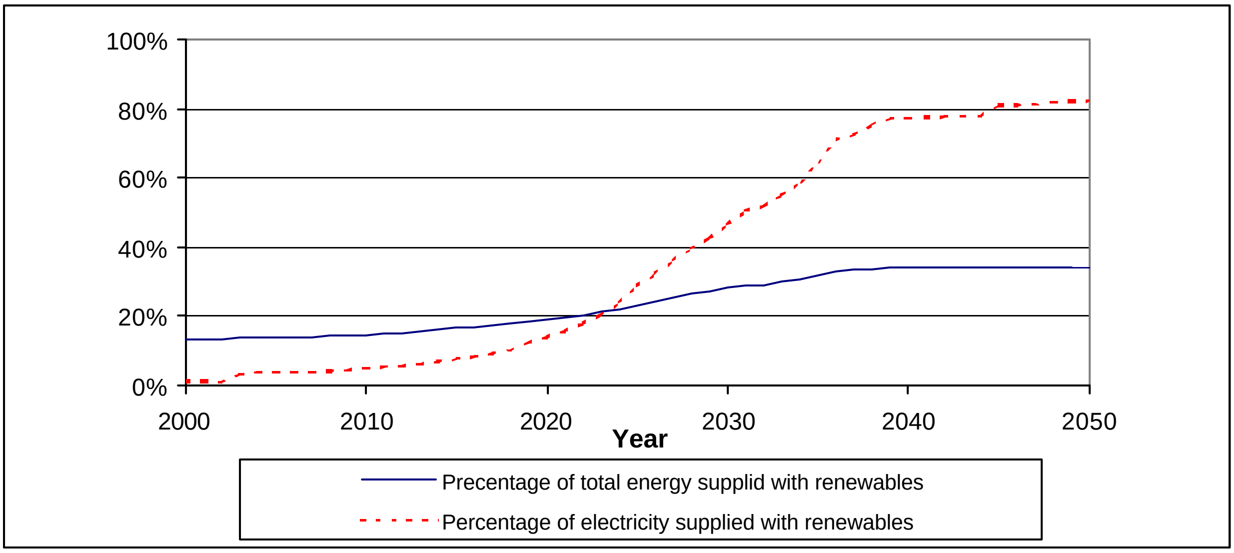


Figure 5-9 Progressive Renewable Scenario: Percentage renewable contribution to total final energy demand and to electricity supply



5.4 The 'High renewable' scenario

At present (2005), renewable energy is a very small part of the electricity supply sector, but biomass and hydropower together contribute about 10 percent to final energy. It is of interest to note that, in the scenarios presented, renewable energy increases its share of both electricity and of total energy supply, but the increase in electricity is far more marked. Indeed, it is rather disappointing to note that, despite a 75 percent contribution to electricity supply, the total contribution of renewable resources to total final energy is only 35 percent by 2050. Indeed, Figure 5-8 indicates that the amount of fossil fuel used per annum will continue to grow over the entire period. In other words, even the very significant investments made in renewable energy in the *progressive renewable* scenario are not sufficient to reduce overall green house gas emissions or fossil resource consumption. The main 'problem area' is in the non-electricity energy use in the economy.

How can South Africa convert more of the non-electricity demand to renewable resources? Biomass and national hydropower are unlikely to offer further contributions. We therefore anticipate that technologies such as solar and perhaps wave energy will need to be used to produce Hydrogen that can directly replace the large oil component of the final energy supply mix.

5.4.1 A possible way to meet the challenge

Figure 5-10 to Figure 5-13 illustrate a possible scenario to meet the challenge– the *high renewable* scenario. This involves two major structural changes to the energy supply situation: an *increase* in electricity production to 600 TW, *and* production of Hydrogen or some other portable fuel from renewable energy resources. The policy and economic effort involved to do this would be challenging. The rationale and methods needed to achieve this are explained below.

Electricity production has been increased to a 600 TWh per annum in 2050 (compared to the baseline demand of just under 400 TWh). This allows some of the current fossil fuels used for transport and industry to be replaced with renewably generated electricity. Examples of ways to achieve this include:

- significant use of electric vehicles and electric powered trains for personnel and goods transport
- greater use of electricity in manufacturing processes (rather than direct use of coal or oil) *provided that this electricity is sourced from renewable resources*. Obviously where biomass, solar or other renewable resources can be used directly, this is far preferable.

In order to produce the extra electricity, the following resources have been used (compared to the *progressive renewable* scenario):

- Additional conventional peak plant has been installed to help deal with the variability of the renewable contribution (total of 7 200 MW by 2050).
- Early stage growth of the wind industry is accelerated, and the final installed capacity is higher, with energy contribution by 2050 at 80 TWh. This is still less than the upper limit of 106 TWh identified in section 3.5.3.
- The hydro contribution has been increased to 11 000 MW, at a capacity factor of 60%, yielding 58 TWh. We assume that about 6 000 MW of this contribution would be imported - with the attendant risks of long distance lines through several countries.
- The biomass contribution has been increased to 43 TWh, which, although high, is only less than half the resource Lund et al identify (see section 3.7.3.1)
- The total installed base of photovoltaics is increased to 38 700 MW by 2050. This would require an exposed surface area of 386 km^2 for solar modules at an efficiency of 10%.
- The total installed base of solar thermal electric plant is increased to 47 000 MW by 2050.

- The installed capacity of wave or 'other' renewable energy resources is increased to 8 700 MW, yielding 68.5 TWh.
- Additional storage has been added to the system. The added storage may not all be pumped storage. Some storage capacity may be new technologies as discussed in section 4.2.
- Other generation options are as for the *progressive renewable* scenario.

Figure 5-10 High Renewable Scenario: Electricity energy supply mix

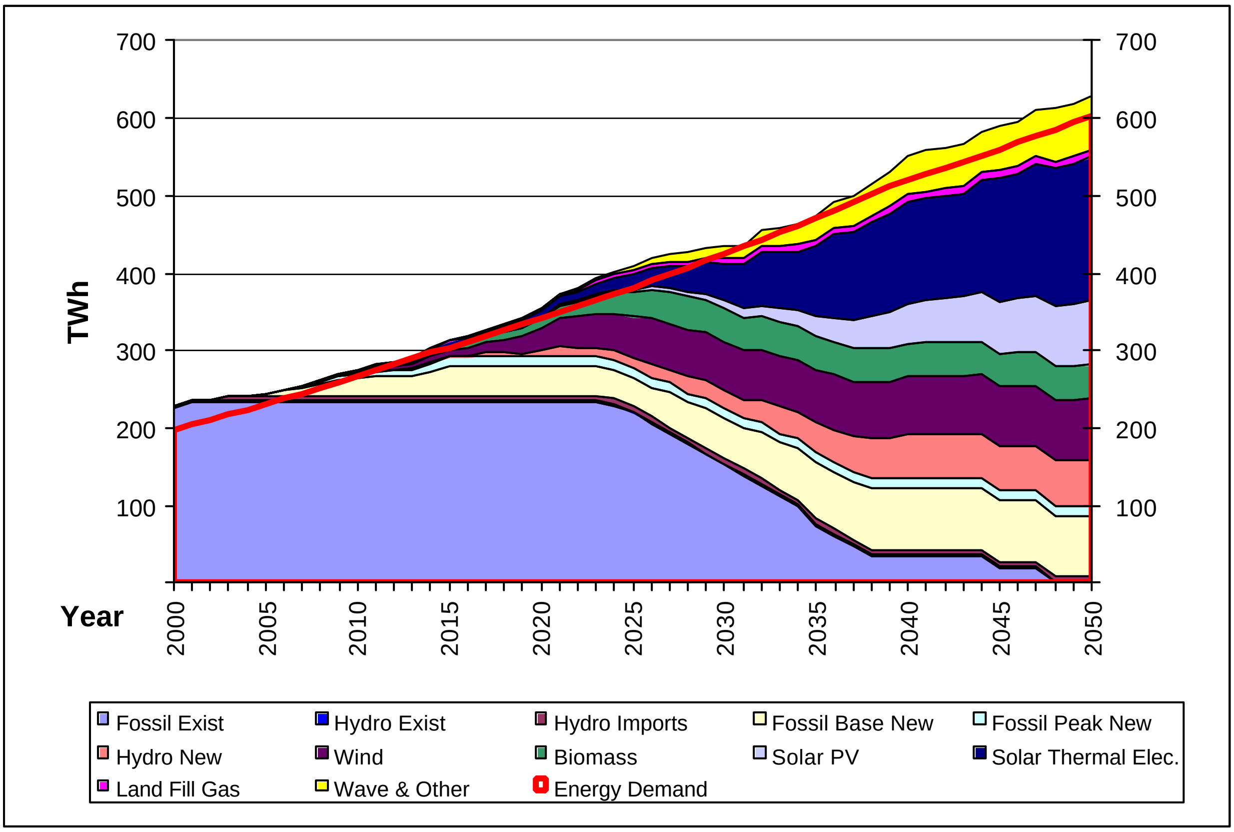


Figure 5-11 High Renewable Scenario: Total energy supply mix

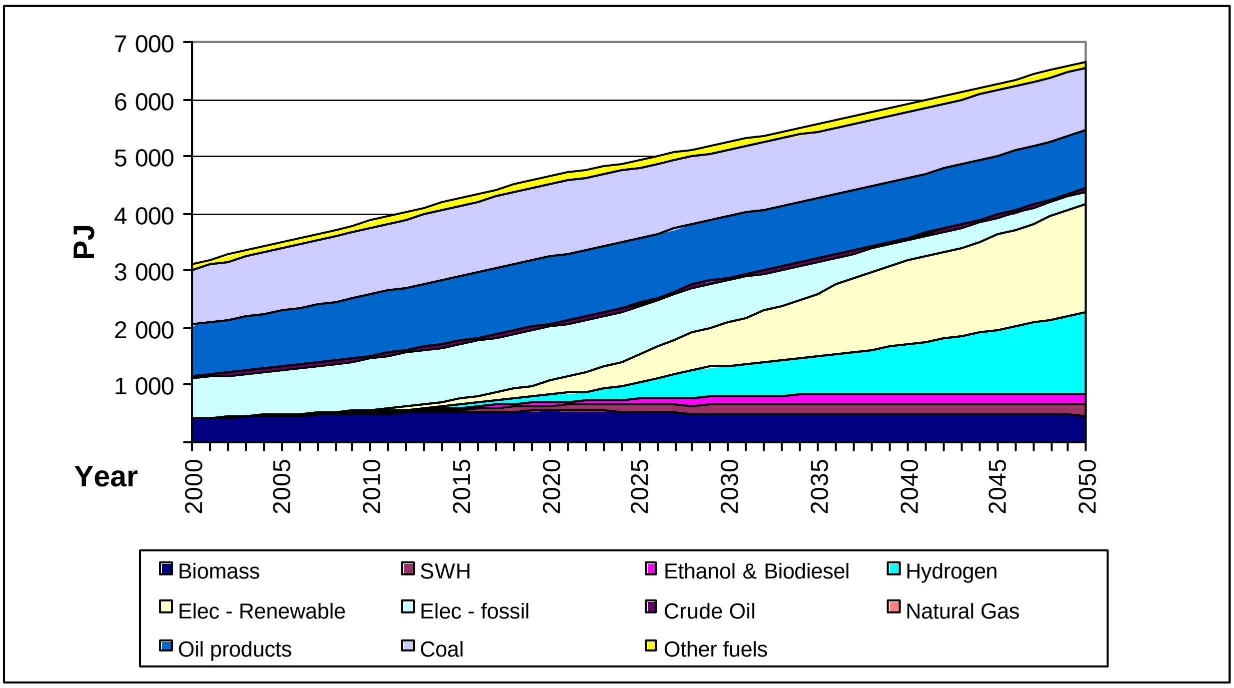
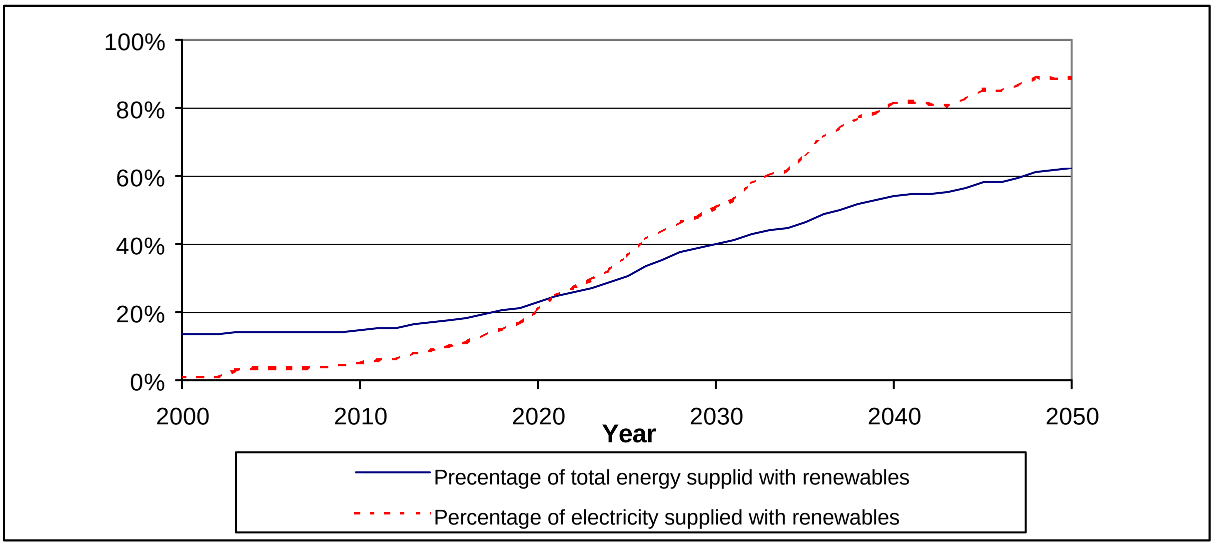


Table 5-2 High Renewable Scenario: Illustrative generation technology capacities (in MW)

Year	Conventional and Nuclear Existing	Hydro existing	Hydro imports (exist)	Fossil Base New	Fossil Peak New	Wind	Hydro New + new imports	Biomass	Solar PV	Solar thermal electricity	Landfill gas	Wave and Other generation	Storage (PS or Other)
2003	**35 623**	641	556						8				1 580
2004	**35 623**	637	781			4			12				1 580
2005	**35 623**	633	781	380		4		8	14				1 580
2006	**35 623**	629	781	760	720	20		16	19		5		1 580
2007	**35 623**	625	781	1 518	720	100		30	24		35		1 580
2008	**35 623**	621	781	2 186	1 440	150	30	90	32		65		1 580
2009	**35 623**	617	781	2 953	2 160	300	50	150	41	100	72		1 580
2010	**35 623**	613	781	3 256	2 880	600	90	200	53	200	140		1 580
2011	**35 623**	613	781	3 559	3 600	1 000	138	250	70	400	154	1	1 580
2012	**35 623**	613	781	3 559	4 320	1 300	196	300	90	500	169	2	1 913
2013	**35 623**	579	781	3 559	5 040	1 690	500	400	117	800	186	4	2 912
2014	**35 623**	579	781	4 491	5 760	2 197	500	500	153	1 100	205	8	3 911
2015	**35 623**	575	781	5 423	6 480	2 856	500	700	199	1 300	225	12	3 911
2020	**35 523**	571	781	5 423	7 920	10 604	2 000	1 742	737	2 400	363	100	6 908
2025	**33 423**	571	781	5 423	7 200	20 184	3 000	4 334	1 834	4 838	585	850	8 906
2030	**23 191**	571	781	7 595	7 200	24 032	5 000	5 795	4 564	12 039	942	1 950	10 904
2035	**11 391**	571	781	10 391	7 200	26 274	8 000	5 795	11 356	22 937	1 143	3 700	12 902
2040	**5 391**	571	781	11 323	7 200	27 614	11 000	5 795	23 744	33 456	1 201	6 200	12 902
2045	**2 891**	571	781	11 323	7 200	29 022	11 000	5 795	30 304	40 481	1 238	7 200	12 902
2046	**2 891**	571	781	11 323	7 200	29 313	11 000	5 795	31 820	40 981	1 238	7 200	13 902
2050		571	781	11 323	7 200	30 503	11 000	5 795	38 677	46 682	1 238	8 700	15 902

Figure 5-12 High Renewable Scenario:
Renewable contribution to electricity and total energy supply

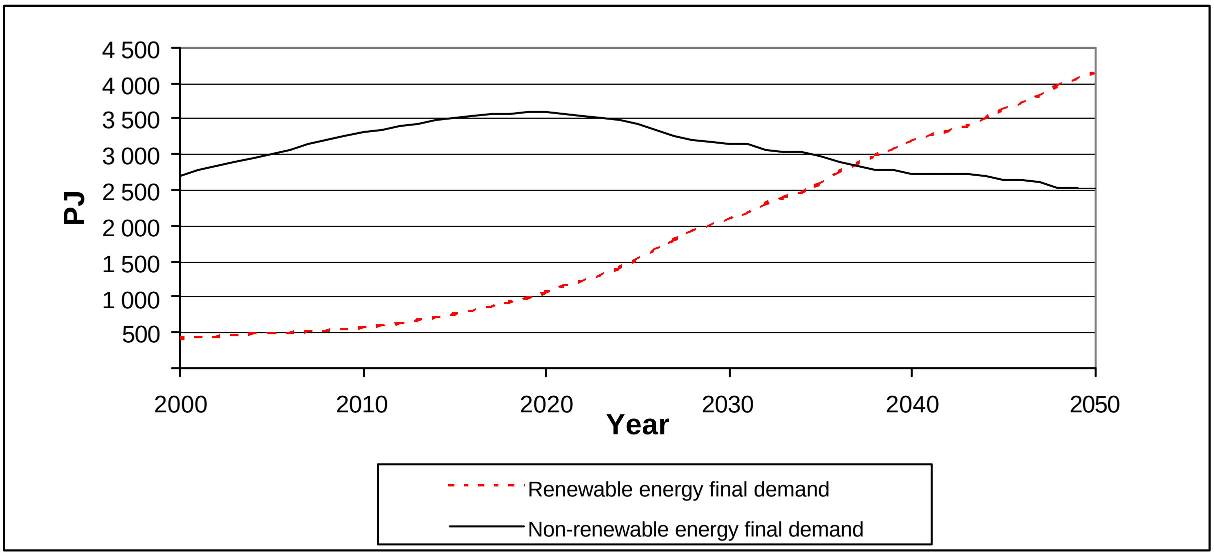


Given that the total energy required by the economy is assumed to be the same as for the *progressive renewable* scenario, the increased *electricity* contribution reduces the remaining contribution required by coal and other fossil resources for non-electrical demand. However, as the *total* demand for energy increases significantly over the period, fossil contributions would also increase unless significant non-electric renewable energy is utilised directly in the economy.

- To achieve this, Hydrogen production and storage has been postulated to contribute up to 1 432 PJ by 2050. This is slightly more than the current direct use of coal in industry.
- The proportional contributions of coal and oil products have been reduced accordingly, to keep the total energy utilized in the economy at the same level as for the other two scenarios presented in this study.
- The Hydrogen production methods have not been specified. In all probability they would require electrolysis, powered by solar thermal electricity, solar PV, or direct solar thermal Hydrogen production processes. Other alternatives include the use of the photosynthesis cycle using sea-based mariculture (see section 3.9.4). Off-shore wind turbines and wave plants could also contribute. To give some idea of the scale of such an endeavour, consider that solar to Hydrogen production at 10% overall efficiency would require approximately 1800 km^2 of solar energy collector area.

Figure 5-13 shows the final energy supply in PJ for all renewable contributions, and all non-renewable contributions. It is of concern to note that even in this *high renewable* scenario, the fossil energy component still rises to 3500 PJ, before declining again by 2050 to levels only slightly lower than the current levels.

Figure 5-13 High Renewable Scenario:
Renewable and non-renewable contributions to the energy mix



5.4.2 Energy efficiency – even more effort required!

The authors regard the challenge of achieving the *progressive renewable* scenario as huge. For South Africa to make the necessary shifts in the energy economy to achieve something like the *high renewable* scenario would be significantly more difficult. However, if the total energy requirement of the country is allowed to increase to 6 600 PJ over then next 50 years[17], then investments in energy supply will in any event be very large. If it is possible to develop the economy and people's quality of life using approaches that do not require such an increase in energy consumption, and if energy efficiency can be effectively promoted at all levels, then the average annual growth in energy demand could be reduced. This would obviously make it far easier to reduce the total fossil fuel contribution without stretching the renewable energy resources and technology production facilities to the extent indicated in the *high renewable* scenario.

6 Conclusion

6.1 Renewable Energy Resource

The investigations undertaken for this report provide clear evidence that there are sufficient renewable energy resources in South Africa to provide for about 13 percent of the electrical demand by 2020, and easily 70 percent or more by 2050 (*progressive renewable* scenario). From a total energy perspective, medium-term contributions of 15 to 20 percent by 2020 are quite feasible. However, in the longer term, it will be difficult to achieve more than a 35 percent contribution by 2050, unless Hydrogen generation becomes an economic prospect. If one incorporates a significant renewably generated Hydrogen component and an even more aggressive renewable electricity growth scenario, then the *high renewable* scenario indicates that renewables could provide up to 20% of electricity by 2020, and more than 60% of the total energy demand by 2050.

Although the scenarios assume far lower energy demand growth than the current national planning process, this demand growth still makes it very difficult for renewable resources to keep pace. As a result, total fossil/conventional contribution increases for the first few years in all scenarios. This confirms the importance of energy efficiency as a key strategy to reduce the growth of fossil fuel consumption.

[17] This is an average annual increase of only 1.5% over the 50 year period. Current National Integrated Energy Planning processes have energy demand growth rates in excess of 2.8% for some sectors – see Figure 2-3

6.2 Knowledge Status

Analysis of the resource base has been very difficult in many respects and, as illustrated in Table 3-2, studies over the past few years have produced several different results. In our opinion, there is a need for clear resource assessments that are undertaken using transparent, standardised methodologies. This would allow analysts and decision-makers to fully understand where the data comes from and how reliable it is.

It is important to provide detailed resource data as well as assessments of potential yields using particular conversion technologies. However, even the latter rapidly becomes dated. All too often, we believe that decisions have been made on the basis of current cost and technology information without due recognition being given to the rapid rate at which changes are taking place in the renewable energy industry. In selecting data for use in the scenarios, we have tried to balance more conservative estimates of renewable resources with more inclusive, yet realistic, estimates.

The research has also identified two key weaknesses of existing energy plans:

1) Very little long-range (50 or even 100 year) planning is being undertaken in South Africa. Given the possible large-scale changes in the energy supply system indicated in the scenarios, we feel that this is a critical oversight.
2) Although the recent NER IRP did take some account of large-scale renewable generation potential, it seems to have been done as an afterthought. It appeared to rely on a very limited range of technologies and cost/resource analysis that lacked detail. Electricity and energy planning should anticipate longer-term cost and policy trends, and seek to integrate sustainable energy planning more fully into the process.

6.3 Drivers for Change

This report takes a range of reasons for an emphasis on renewable energy technology as given, and policy issues have not even been reviewed (much is covered in other studies). However, fossil fuel scarcity and pricing, as well as climate change concerns (and the resulting Carbon-related costs/taxes) provide critical motivations for change. A brief review of fossil fuel pricing indicates that real price increases of between 0.6 and 1.5% percent per annum are plausible. Furthermore, the growing understanding of the threat from global climate change caused by continued CO_2 emissions provides an important indirect motivation for change. There are also direct incentives through Carbon taxes and other elements of the Kyoto Protocol.

As part of the resource review, we have also reviewed selected technologies. Of particular interest is, firstly, the historical data on the growth rates of the solar PV and wind industries (20 to 30 percent per annum), and secondly, the ongoing cost reductions which in some cases provide a clear indication that costs may decrease by 50 percent within ten years.

Cost data is provided in the resource chapter, as well as in Appendix C. The analysis undertaken indicates that costs of power from renewables are already less than those from conventional resources in some selected cases. In the future, there is likely to be a cost advantage even at a very large scale.

6.4 Implications of the scenarios

Three scenarios were reviewed for electricity generation. The ‘business as usual’ scenario assumes very little support for renewable generation technology from decision-makers. The scenario clearly illustrates the huge increase in capacity of fossil plants that would be needed between 2022 and 2038. This raises major environmental and economic warning flags. It also highlights the opportunity that South Africa has to prepare for the capacity crunch, and have in place alternative energy solutions for large-scale implementation.

The *progressive renewable* scenario shows how early efforts to include renewable energy, say, by seeking to achieve 15 percent by 2020, would place the country in a strong position to expand capacity rapidly from 2022 onwards. The expansion in capacity would coincide with the decommissioning of the coal plants. Such preparatory work would be important for local capacity development and job creation. However, it is also critical to secure the potentially realisable cost reductions offered by renewable energy technology.

The scale of energy infrastructure required to meet the longer-term energy needs is difficult to assess when one simply considers TWh or MWe installed. Some appreciation can be gained by considering the current SWH and PV industries in South Africa. Both industries already directly employ several hundred people, and there are several hundred thousand installations. Yet their contribution to electricity or total energy supply is not even visible on the graphs in 2005. By 2040, both have sizeable spaces allocated on the graphs, with installed capacity for SWH being about 100 times current capacity, and that for PV being more than 1000 times current capacity. The implications for job creation are clear.

Both scenarios illustrate how short time really is, particularly in the light of the required growth rates for emerging industries such as solar PV, wind and solar thermal electric. Effective large-scale industries will take time to develop. Even at a 20 percent annual growth rate, it will take several years before these industries can really start to add energy capacity to the grid on the scale required.

A significantly more aggressive scenario (*high renewable*) explores the implications of increasing the electricity component of the total energy mix (using renewable generation sources) *and* including a large scale Hydrogen/fossil fuel substitution process. Although challenges would be huge for this scenario, the solar resource and other renewable resources are available to meet the demand. This scenario allows the country to achieve a net reduction in fossil fuel contribution by 2050, with the renewable energy contributing 60% to the total energy mix by 2050.

There is an interesting development of the technology selection process in the scenarios. Initially, lower cost options, such as biomass, landfill gas and selected wind sites, are more attractive than solar and large-scale wind. However, because these low-cost options have a limited resource base, it is very important to balance development efforts - harvesting the lowest cost resources, but at the same time developing the necessary technical capacity to harness the larger scale solar and possibly wave technologies.

Figure 5-6, although speculative, highlights the potential for renewable energy options to be the most cost-effective options for energy supply in the future. Fossil fuel pricing is, of course, particularly difficult to predict (consider the oil price changes in 2004). However, if oil prices do continue to rise, it will not be long before solar thermal technologies, in particular, present a large-scale, economically viable power supply option.

6.5 Energy efficiency

Although not specifically explored in detail within this study, energy efficiency is clearly identified as a crucial element in energy planning. If the South African economy is allowed to grow in such a way that energy intensity per unit GDP remains similar to current levels, it will have adverse environmental and economic implications. Even the current growth rates used by the DME and the NER for planning (illustrated in Table 2-4 and Figure 2-3) would result in a tripling of energy demand if extended through to 2050. The scenarios explored in the report assume that total energy increases by slightly more than double by 2050. In our opinion, even this growth rate is too high, and it would be prudent to use energy efficiency measures that allow economic growth, but with more limited energy demand growth. Much depends on the way in which the economy grows, and on our ability to apply effective measures for energy efficiency and energy conservation.

List of References

Barta, B. (2002). Barta Bo: Baseline study: Hydro-power in South Africa. CaBEERE Project report, Department of Minerals and Energy, Pretoria.

Bennet, K.F. (1983). Alternative energy options. Conference on South African Energy in Perspective. Johannesburg: South African National Committee of the World Energy Council. pp 87-95.

Cawood, W., and Morris, G. 2002. Baseline study: Solar energy in South Africa. CaBEERE Project report, Department of Minerals and Energy, Pretoria.

Creamer, M, (2004). Sasol Projects Update: Biodiesel blueprint, Engineering News, 2004/05/21

Darroll, L. (2004). Northern Cape solar project to use 'power tower' system. African Energy Journal, 6 (5), 18-21.

Department of Minerals and Energy, CSIR, ESKOM. (2002). South African renewable energy database.

Department of Minerals and Energy. (2002). South Africa national energy balance, 2000. Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy. (2003a). Integrated energy plan for the Republic of South Africa. Department of Minerals and Energy.

Department of Minerals and Energy. (2003b). Business opportunities in South Africa for renewable energy Independent Power Producers, Pretoria.

Department of Minerals and Energy. (2004a). Economic and financial calculations and modelling for the renewable energy strategy formulation. Prepared for DME by Conningarth Economists for CaBEERE project, Pretoria.

Department of Minerals and Energy. (2004b). White paper on renewable energy policy of the Republic of South Africa. Government Gazette, 14 May 2004.

Department of Minerals and Energy. (2004c). National Energy Balance, 2001.

Department of Science and Technology, 2003. Investigation into the role of biodiesel in South Africa. Prepared by CSIR Transportek. Pretoria.

Diab, R. D. (1985). Possible contributions of wind power to South Africa's energy needs. South African Journal of Science, 81(8), 460-463.

Diab, R. D. (1995). Wind atlas of South Africa. DMEA, Pretoria.

Dunn, S. (2001). Hydrogen Futures: Toward a sustainable energy system. WorldWatch Institute Paper 157. WorldWatch Institute. Washington. August 2001.

Eberhard, A, and Williams, A. (1988). Renewable energy resources and technology in southern Africa. Cape Town: Elan Press.

Energy and Development Research Centre. (2003). Policies and measures for renewable energy and energy efficiency in South Africa. Prepared for the Sustainable Energy and Climate Change Partnership, University of Cape Town.

Engineering News (2003a, April 18) Ten African countries mull geothermal power, Engineering News, Martin Creamer Publications

Engineering News (2003b, July 18). Kenya is set to commission third geothermal plant. Engineering News. Martin Creamer Publications.

Engineering News (2003c, February 25) Southern Cape. Engineering News. Martin Creamer Publications.

Health Systems Trust. (2005). Project population figures are based on various projections models attempting to quantify the expected effects of HIV/AIDS on population growth. [On-line]. Available Internet: http//new.hst.org.za/indic/indic.php/1/?mode=data

International Energy Agency. (2003). Renewables for power generation: status and prospects. Paris.

International Energy Agency. (2004). International Energy Outlook 2004. IEA, Washington, DC. Available Internet: www.eia.doe.gov/oiaf/ieo/index.html.

International Geothermal Association. (2004). Available Internet: http://iga.igg.cnr.it/geoworld/geoworld.php?sub=elgen

Jones, J. (2004). Onward and upward. trends in BTM's world market update Renewable Energy World. July-August, 60.

Kenny, A. R. (2002, January). Preliminary energy outlook for South Africa. Energy Research institute, University of Cape Town.

Lombard de Mattos & Associates. (2004). Landfill gas resource for power generation in South Africa. CaBEERE Project report, Department of Minerals and Energy, Pretoria.

Lynd, L. R., von Blottnitz, H., Tait, B., de Boer, J., Pretorius, I. S., Rumbold, K. and van Zyl, W. H. (2003). Converting plant biomass to fuels and commodity chemicals in South Africa: a third chapter? South African Journal of Science 99, November/December 2003.

Manders, P. T., and Venter, G. P. N. (2004). Energy scenarios for Africa. CSIR Energy Thrust / CSIR Environmentek, Pretoria.

Marketbuzz. (2004). Annual world solar photovoltaic market report. [On-line] Available Internet: http://www.solarbuz.com.

National Electricity Regulator. (1998). Electricity supply statistics for South Africa, Pretoria

National Electricity Regulator. (2002). Electricity supply statistics for South Africa 2000. Pretoria

National Electricity Regulator. (2004a). National integrated resource plan, 2003/4: Reference case. Compiled by ISEP Eskom (Resources and Strategy), Energy Research Institute (University of Cape Town), National Electricity Regulator.

National Electricity Regulator. (2004b). National integrated resource plan, 2003/4: Stage two: Risk and sensitivity analysis. Compiled by ISEP Eskom (Resources and Strategy), Energy Research Institute (University of Cape Town), National Electricity Regulator.

NREL (2005). Hydrogen production & delivery. Available Internet: www.nrel.gov/hydrogen/proj_production_delivery.html

Olivier, H. (1986). Hydro-electric potential in Southern Africa. In Eberhard, A, and Williams, A. (1988). Renewable energy resources and technology in southern Africa. Cape Town: Elan Press.

POEMS. (2005, February 7). Practical ocean energy management systems. [On-line]. Available Internet: http://www.poemsinc.org/FAQcurrent.html..

Refocus. (2004, November 3). Global production of solar cells increases 32 percent. Refocus Weekly, Washington DC.

Schäffler, J. L. (2001, July). Energy alternatives for the future. Talking Energy 2001. South African National Energy Association, Johannesburg.

Scholes, B. (2004). International trends in climate change. Johannesburg Plus 2 Conference. CSIR Division of Water, Environment & Forest Technology. 3 September 2004.

Shackleton, C. M., Buiten, E., Annecke, W., Banks, D., Bester, J., Everson, T., Fabricius, C., Ham, C., Kees, M., Modise, M., Phago, M., Prasad, G., Smit, W., Twine, W., Underwood, M., von Maltitz, G., and Wenzel, P. (2004). Fuelwood and poverty alleviation in South Africa: Opportunities, constraints and intervention options. Prepared for Department of Water Affairs and Forestry, Pretoria.

Solar Paces. (2005). CSP technology. [On-line]. Available Internet: http://www.solarpaces.org.

SolaSure (2004). Market Survey of Solar Water Heating in South Africa, and Capacity Building. Prepared for the Energy Development Corporation of the Central Energy Fund. Revision 1

Sorenson, B. (1979). Renewable energy. Academic Press.

Stassen, G. 1996. Towards a renewable energy strategy for South Africa. PhD Thesis. University of Pretoria. p164.

Sugar Milling Research Institute. (2004). Assessment of commercially exploitable biomass resources, bagasse, wood and sawmill waste and pulp, in South Africa. Prepared for the Department of Minerals and Energy by CaBEERE, Pretoria.

Tripod Wind Energy & Oelsner Group (2003). Baseline study on wind energy in South Africa. CaBEERE Project report, Department of Minerals and Energy, Pretoria.

WBGU. (2003). World in transition towards sustainable energy systems. German Advisory Council on Global Change (WBGU), EARTHSCAN, Berlin.

Winkler, H. (2004). Renewable energy policy in South Africa: Policy options for renewable electricity. Energy Policy, 33, 27–38.

World Bank, 2004. South Africa: Renewable energy market transformation (REMT) project: Economic and financial analysis due diligence. Prepared by Conningarth Economists, Pretoria.

World Energy Council. (2003). South African energy profile. WEC and South African National Energy Association, Johannesburg.

Appendix A Glossary

Biomass	All Carbohydrate material produced during photosynthesis in plants
Capacitor	An electrical device for storing charge. As electric current is essentially charge flowing through a conductor, a capacitor can therefore serve as an electrical storage device.
CDM	Clean Development Mechanism. This is the most commonly discussed method for providing a financial incentive to developing countries to reduce greenhouse gas emissions.
Energy	The ability to do work, usually measured in Joules, or sometimes in Watt-hours.
Energy carrier	A fuel or form in which energy is 'carried' to where it is needed (e.g. petrol, paraffin, electricity).
Energy demand	The demand from consumers for energy at the point of end use.
Energy mix	A generic term for the range of energy sources and carriers contributing to energy supply. It is usually used in referring to the mix of electrical generation technologies and energy resources from which that electricity is converted making up the electrical supply on the national grid.
Greenhouse effect	A large proportion of the radiation that strikes the earth from the sun is simply radiated back to space and does not warm the earth up. 'Greenhouse' gases, such as methane and carbon dioxide, absorb some of this escaping energy and trap it in the earth's atmosphere. This extra energy results in a warming of the earth's atmosphere.
Flywheel	A heavy wheel that can be 'charged' by using energy to increase the rate at which it is spinning. This energy can then be stored in the low-friction spinning wheel and discharged using the flywheel to turn a generator or other energy conversion device.
Heat engine	A mechanical device that converts heat energy to mechanical work. Typically used in a conventional power plant or a solar thermal power plant to drive electricity generators. Examples include steam turbine power plants, gas-driven power plants, reciprocating engines and Stirling engines.
Joule	The System International unit of energy. 1 Joule is roughly equivalent to the energy required to lift 98 g up 1 metre against the force of gravity on earth (1 Newton metre).
kWh	Kilowatt hour. The most commonly used unit to measure electrical energy sold; equivalent to 3 600 Joules.
LRMC	Long Run Marginal Cost. Usually refers to the cost of electricity produced using the technical options required to meet expanding demand.
Net Discount Rate	The annual rate by which future benefits and costs are 'discounted' or reduced to allow calculation of an equivalent 'present' value
Piezo-electric	An electronic process whereby pressure is converted to an electrical current. Piezo electric elements are pressure sensitive electronic devices. When pressure is applied to the device, it generates an output voltage and current.
PJ	Petajoule. Equal to 10^{15} Joules, or 277 777 777 kWh – an enormous amount of energy.

Primary Energy	The energy entering any energy conversion process. In the sense of economic analysis it refers to all primary energy resources from which useful energy is extracted and transferred to the point of end use.
Redox Systems	Refers to the chemical reactions reduction and oxidation. Redox systems convert chemical energy to electrical current.
Scenario	A possible sequence of future events.
Superconductor	A material that exhibits no resistance to electrical charge under special circumstance of temperature and pressure. In this way electrical energy can be transferred without incurring losses and a closed loop of superconducting material can potentially store electricity for long periods.
TWh	Terawatt hour. Equal to 3.6 PJ or 1 000 000 000 kWh – an enormous amount of energy.
W, kW, MW, GW	1 Watt is the basic measurement of power or the rate of doing work. 1 Watt = 1 Joule/second; 1 kilowatt (kW) = 1000 W; 1 megawatt (MW) = 1 000 000 W; 1 gigawatt (GW) = 1 billion W.
Wp	Watt-peak. PV modules are usually rated according to their Watt output under standard radiation conditions (effectively full sunlight).

Appendix B Renewable Energy Resource Estimates

This appendix provides more information on the renewable energy resource estimates for hydro, wind and biomass reviewed and used in this study. The appendix should be read in conjunction with the main report.

B.1 Wind

Documented efforts to get to grips with the South African wind resource have been ongoing since probably 1980s. Estimates of the total theoretical wind resource range from 3 GW (which could generate about 4 TWh) (Eberhard and Williams 1985) to approximately 60TWh per annum (DME, 2004a).

Table B1: Summary of wind resource assessments

Study Name	GW	TWH	Source: Comments
Diab, 1985	3 **3000**	26 '-	There seems to be an error in Diab's application of her stated calculation method, see below. Our revision of her calculation yields the **Bold** numbers
DME, 2004b, p. 30	3	1.98	This seems to be based on Diab's work, and excludes off-shore potential
DME, 2004a	33	64	This calculation is discussed in more detail below
This study	50	106	See below

Diab (1985) states that it is generally accepted that between 1.5 and 2.5 percent of the radiant solar energy which reaches the earth is constantly being converted into kinetic energy. Using 2 percent as the average dissipation rate and a value of 350 $W.m^{-2}$ as the average insolation (over 24 hours) in South Africa, a figure of 7 $W.m^{-2}$ is obtained for the total rate of solar input to wind energy. However, since it is possible to extract only that portion of the energy in the boundary layer close to the surface of the earth, this value must be further reduced. Thirty-five percent of the total wind energy dissipation occurs within 1000 m above the earth's surface, hence application of this factor to 7 $W.m^{-2}$ gives 2.5 $W.m^{-2.}$ This can then be multiplied by the total surface area of South Africa (1 223 803 km^2) to yield the maximum potential. Diab's calculation based on this methodology yielded 3 GW (Diab, 1985, p. 461). However, on rechecking the calculation we obtain a 3 000 GW. Diab suggests that only 10 percent of this be extracted to avoid alteration of global circulation patterns. This would yield up to 300 GW, almost ten times current installed coal generation capacity.

The DME renewable energy policy document (DME, 2004b) states that the upper limit of wind energy available to be captured in South Africa is estimated at 3 GW. Taking a conservative estimate of 30 percent conversion efficiency and 25 percent capacity factor, it is estimated that wind power could supply about 1 980 GWh per annum. However, as far we can see, this is based on the calculation set out by Diab, and is a significant underestimate.

Another illustrative calculation is to assume that, if we were able to place existing technology turbines at maximum practical density along a strip 1km wide by 1000 km long of western Cape Coastline, this could yield 50 TWh of electricity (about 25 percent of the 2002 demand).

A recent economic analysis undertaken to help develop the renewable energy strategy (DME, 2004a), used a more detailed assessment of wind energy potential, based on:

- Using modelled wind speed probability distribution functions to estimate the energy available per km^2 in particular resource regions
- The regions were then divided into wind regime classes, and the area of land available in each class was determined
- Using information on standard wind turbine technology, it is then possible to determine the potential energy generation per turbine in each wind regime, and then, using information on the possible density of turbines per square km, to work out the total resource in each wind class area.

Practically suitable land was defined by considering proximity to roads, the electrical distribution network and land which lies outside incompatible land use zones such as designated conservation areas. This takes into account one of the primary considerations for successful implementation of wind, namely transport infrastructure, availability of engineering services and resources and access to remote locations. Offshore wind energy potential was excluded from the study based on the expected high cost of installation offshore beyond a steep and narrow continental shelf. (Off shore wind technology is receiving increasing attention internationally.

Table B2 is adapted from the DME (2004a) study.

The authors were, however, conservative regarding land availability. Of the 900 000 km^2 exposed to wind speeds of 5.5 $m.s^{-1}$ or more, they assumed that only 2800 km^2 could be allocated to wind farms. Even in these allocated areas, the turbines themselves would only take up about 1 to 2 percent of the land area (56 km^2 or about 0.003 percent of the total resource area) and farming could continue under and around the plant. If one only allocates 2 percent of the 900 000 km^2 in the resource-rich areas to wind farms (which still allows farming or related activities to continue underneath the turbines), then a resource of the order of 400 TWh could be available.

For the purposes of this study, we have assumed that 1 percent of the land area in each of the first five wind class zones assessed in the DME (2003) study could be allocated to wind farms. This gives a land area of up to 4 100 km^2, and a resource potential of about 50 GW, yielding 106 TWh at capacity factors of between 24 and 37 percent. To this could be added a coastal area. This resource level is, for the scenarios discussed, more than could feasibly be taken on to the grid (due to concerns about storage and peak load management). Furthermore, as discussed in Appendix B, it may result in some effect on weather patterns.

For comparative purpose, note that Denmark, with a total land area of only 16 000 km^2 (less than the area covered by Classes 1 to 4) has 7 000 turbines which account for 18 percent of its installed electricity generation capacity, and currently generates 5.9 TWh.

Table B2: Wind resource assessment, adapted from DME 2004a. The bracketed data is own assessment using the stated revised land areas

Resource	Key data	Area of land exposed (km^2)	Useable area (practical considerations (km^2)	Output per 1.5MW turbine annually (GWh)	Total installed MW	Total available GWh	Capex per MW installed (R/KW)	R/kWh
Wind								
Wind Class 1	Mean wind speed >8.5 m/s	680	2 (7)	4.9	20 (82)	63 (265)	7 700	0.38
Wind Class 2	Mean wind speed 8.0 to 8.5 m/s	860	2 (9)	4.6	26 (103)	78 (316)	7 700	0.40
Wind Class 3	Mean wind speed 7.5 to 8.0 m/s	2 040	5 (20)	4.1	62 (245)	167 (664)	7 700	0.45
Wind Class 4	Mean wind speed 7.0 to 7.5 m/s	60 700	180 (607)	3.5	2 160 (7 282)	5 109 (17 224)	7 700	0.51
Wind Class 5	Mean wind speed 6.5 to 7.0 m/s	345 700	985 (3 458)	3.2	11 815 (41 494)	24 841 (87 237)	7 700	0.58
Wind Class 6	Mean wind speed 6.0 to 6.5 m/s	503 000	1 481 (5 031)	2.6	17 774 (60 367)	31 139 (105 763)	7 700	0.70
Wind Class 7	Mean wind speed 5.5 to 6.0 m/s	50 500	151 (505)	2.2	1 817 (6 064)	2 705 (9 030)	7 700	0.82
Total		**963 480**	**2 806 (9636)**		**33 674 (115 636)**	**64 102 (326 203)**		

B.2 Hydropower

Table B3 summarises several studies which have been reviewed in determining the size of the resource to be included in the scenarios considered in this study.

Table B3: Summary of national hydro resource assessments

Study name	GW	TWh	Source / Comments
Stassen 1996, referring to Bennet 1983	8.36	73.23	This is the estimated theoretical hydro potential for the country. Stassen (1996) contends that this number be limited to a more conservative estimate of the realisable hydro potential of nearer to the 15% of this maximum potential, i.e. approximately 11TWh, in line with the other studies. The limiting factors include high run-off variability from year to year, limited reservoir storage sites, losses by spillage during floods and the uneconomical scale of some sites.
Barta,2002	7.841	14.04	Baseline study on hydro-power prepared for CaBEERE – a detailed study
DME, 2004a	3.4	9.244	This study, commissioned by the CaBEERE project and also undertaken by Barta, modelled small hydro (and some larger) projects only. It differs from the 7.8 GW outlined in Barta (2002) (the hydro baseline study) as no schemes smaller than 1 MW and several larger schemes have not been incorporated.
DME, 2004b	7.8	-	This study referenced the baseline study.
World Bank, 2004	-	9.244	This study was undertaken as a due diligence in preparation for the renewable energy market transformation initiative, sought to identify actual projects suitable for receipt of the World Bank subsidy. The methodology was based largely on that of DME, 2004a.
This Study	5.5	14.6	This study has considered the inclusion by 2050 of no more than 70% of the resource described by Barta in the 2002 baseline study. The load factor that has been assumed to decrease from 55% to 30% by 2050.

The 2002 Baseline study on Hydro in South Africa, conducted by Barta, and based on reliable input sources and extensive research, is considered by many in the industry to be the first real attempt to consolidate existing hydro resource assessments. As outlined by Barta in that study the theoretical hydro-power potential of South Africa had previously been estimated to be as high as 8 360 MW or 54 925 GWh per annum at a 75 percent loading or even higher. As can be seen from Table B4 the estimate of firm potential for hydro-power development in South Africa, stands at 12 160 MW, which is about 45 percent higher than any other previous estimate of the total capacity. The major component of that estimate is the potential for development of seven pumped storage sites investigated as firmly feasible by Eskom.

Table B4: Current and potential hydro capacity in South Africa

Hydro-power category (Power output range)	Installed capacity (MW)	Potential for development	
		Firm (MW)	Long-term (MW)
Pico (up to 20 kW)	0,02	0,1	60,2
Micro (20 kW to 100 kW)	0,10	0,4	3,8
Mini (100 kW to 1 MW)	8,10	5,5	5,0
Small (1 MW to 10 MW)	25,70	63,0	25,0
Subtotal for pico/micro/mini and small hydro	33,92	69,0	94,0
Large conventional hydro-power (> 10 MW):			
• Run-of-river (e.g. direct intake or weir)	-	1 200	150
• Diversion fed (e.g. pipe, canal or tunnel)	-	3 700	1 500
• Storage regulated head (e.g. barrage or dam)	653	1 271	250
Total for renewable hydro-power in SA	**687**	**5 160**	**1 994**
Large pumped storages (> 10 MW)	**1 580**	**7 000**	**3 200**
Grand total for all hydro-power in South Africa	2 267	12 160	5 194
Imported macro hydroelectricity (> 10 MW)	**800**	**1 400**	**35 000 (+)**

Source: Baseline Study (CaBEERE, 2002).

The long term total potential for renewable hydro-power is thus the sum of existing, firm and 'long-term', being 7.841 GW. The total pumped storage potential is 11.78 GW.

This study has not included pumped storage as part of the hydro resource category, only as a storage option. Furthermore, we have assumed that some sites identified in the Barta study would not be possible to implement on environmental grounds. We have therefore sued a maximum of 5.5 MW installed capacity. At a 30% load factor this could yield 14.6 MW by 2050.

B.3 Biomass

There are currently 4 300 km^2 of sugar cane plantations and 13 000 km^2 of forestry in South Africa. The waste streams from this industry could generate approximately 6 TWh and 7 TWh of electricity per annum respectively at a conversion efficiency of 25 percent (SMRI 2004).

The average energy yield per hectare assumed for a generic energy crop covering an additional area approximately equal to that under sugar cultivation was obtained by using calorific values for sugarcane and forestry wastes as in SMRI 2004. The energy content of the waste from sugar production is 5.2 GWh/km^2 and that of waste from the sawmill, pulp and paper and forestry industries collectively is approximately 2.2 GWh/km^2. If we use a weighted average of 3 GWh/km^2 as the energy content of a generic energy crop (before conversion to electrical energy), and an electrical conversion efficiency of 25%, then an additional 5000 km^2 of energy crops would yield a further 3.7 TWh electricity..

Table B5: Potential electrical energy from Biomass resources

	Land Aread cultivated (Km2)	Energy Content (TWh)	Conversion Efficiency to Electrical (%)	Equivalent Electrical Output annually (TWh)
Sugar Cane	4 300	22.3	25	5.6
Forestry	13 000	10.85	25	2.7
Sawmill		7.51	25	1.9
Pulp and Paper		10.17	25	2.5
Generic Energy Crop	5 000	14.7	25	3.7
Total	22 300			16.4

Lynd et. al. (2003) estimate that the gross (prior to conversion) annual biomass energy production potential for South Africa is about 135 PJ per percent of available non-crop, non-forest, non-wilderness area used to produce energy crops. Thus their base case estimate entailing use of 10% of non-crop, non-forest, non-wilderness land gives an estimated production potential of 1350 PJ. This is the greatest potential of any country in Africa. Assuming a conversion efficiency of 25 percent for electricity, this could deliver almost 100TWh. If it were converted to liquid fuels at a conversion efficiency of 50 percent it would provide 675 PJ of liquid fuels equivalent (more than current transport fuel requirements).

Appendix C Scenario assumptions and methodology

The model used for the scenario visualisation in this study was developed by RAPS Consulting with the primary purpose of *illustrating* the technology choices made by the project team. It is not a formal long-range energy modelling tool and in its current form is not suitable for use by other parties. Other specialist products such as LEAP and MARKAL are more suitable for detailed analysis.

The model has four main components: an electricity demand model, and electricity supply model, a total energy demand model, and a total energy supply model.

- The electricity model allows users to select from several demand scenarios and several supply scenarios. In each case, the individual contributors to the supply scenario should be manually adjusted so that the total energy output and the ability of the generation equipment to contribute during peak periods are sufficient to meet the demand scenario. The model thus illustrates choices made by the authors regarding what generation capacity it would be feasible to install when.

- The total energy model also allows the users to select one of several specified sectoral demand growth scenarios. The total energy supply model uses the results of the electricity model as one of its supply inputs, draws on all available renewable energy supply options (such as hydrogen and biodiesel/ethanol) and then decreases the energy drawn from conventional (fossil) supply options so that the total energy requirement is met.

It is obviously critical that the model users remain with realistic renewable energy resource constraints, as identified in chapter 3 and Appendix B. For each renewable energy resource, an appropriate method must be used to identify the maximum potential contribution.

C.1 Demand Scenario Methodology

The demand scenario uses the year 2003 as a base, and all scenarios therefore have the same electrical energy demand for 2003, being 217 TWh. The following input table is then used to define the increase in electricity consumption over time.

Table C1: **Average growth in demand over intervals.** (**Source**s: **Un-shaded cells** = **NER**, **2004a, p. 13**; **shaded cells** = **RAPS Consulting projections**

Year	NER NIRP (High) % growth	NER NIRP (Medium) % growth	NER NIRP (Low) % growth	Energy conscious %growth	Electricity substitution % growth
2003 – 2008	4.30	3.20	1.60	2.40	3.00
2008 – 2013	3.10	2.30	1.00	1.80	4.00
2013 – 2018	2.60	1.80	0.90	1.40	2.50
2018 – 2022	2.50	1.80	0.80	1.20	2.30
2022 – 2030	2.50	1.80	0.80	0.80	2.20
2030 – 2040	2.50	1.80	0.80	0.80	2.10
2040 – 2050	2.50	1.80	0.80	0.70	1.50
Scenario Code	AA	AB	AC	BB	BC

The rationale for the assumptions in Table C1 are included in the main report.

The model allows for the peak demand to change at a different rate to the energy demand. However, for the purpose of the analysis presented here, we have assumed that the ratio of peak demand to total energy demand (effectively the demand load factor) remains constant. This is likely to be conservative, as ongoing efforts by government, Eskom, the NER and other parties seek to move loads from the peak periods in the day/year to off-peak periods, thus reducing the (peak demand)/(annual energy demand) ratio.

The total energy demand model uses a similar strategy, as described in section 2.2.

C.2 Existing Generation Capacity

Existing generation is divided (for the purposes of this report only) into three categories: conventional, existing hydro and imported hydro. Conventional includes all plant currently installed, including peak, coal and nuclear. The NER IRP data on installed capacity and planned dates of decommissioning are then used to provide annual figures for total installed capacity. This plant is assumed to be able to run at an 80 percent load factor if required. It is also assumed to be able to contribute 90 percent of its available capacity to meeting peak load requirements (a simplified spinning reserve).

Similar assumptions, as indicated in Table C2, are used for existing hydro and imported hydro.

Table C2: **Input data for existing generation capacity**

	Existing conventional base	Existing hydro	Imported hydro
Load factor	75%	40%	90%
Availability for peak generation	90%	98%	98%
Maximum allowable capacity (MW)	35 600, reducing to 0 by 2048	641, reducing to 571 by 2050	781 and for high renewables 6 700
Cost change over time	1% per annum	-	-

C.3 New Generation Capacity

C.3.1 Conventional plant

Two categories are illustrated, conventional base load and conventional peak plant. Key data used is provided in Table C3. These plants are assumed to include all fossil fuel options, such as pulverised coal, fluidised bed coal, open cycle gas turbines, etc. In the 'business as usual' scenario (CC), we have assumed that the costs of generation using these technologies would increase at a rate of 1 percent per annum, as a result of increased climate change concerns and of increased fuel scarcity. In the progressive renewable scenario (EE), we do <u>not</u> assume such a high cost increase, as the significantly reduced use of these fossil resources will mean that concerns regarding scarcity are less serious, and prices may even drop. Further, given that South Africa would be meeting its CO_2 reduction targets, Carbon penalties or taxes would be lower.

Table C3: **New conventional plant data**

	New Conventional base	New conventional peak plant
Load factor	80%	20%
Availability for peak generation	90%	90%
Cost change over time :	1% increase/year	1%

C.4 New renewable energy capacity

Table C4 provides a summary of the key data used for renewable energy modelling. Assumptions are explained more fully in Appendix B and the main report.

Table C4: Key data for new renewable energy capacity

	Wind	New Hydro	Biomass	Landfill	Solar PV	Solar Thermal electric	Other (wave, ocean current, new technologies)	Pumped Storage (or other large scale storage)
Load factor	30% (up to 2007) 35% (2008 onwards)	(Scenario EE[18]) 55% (up to 2018) 40% (2019 to 2033) 30% (2033 – 2050) For scenario FF[19], up to 60% load factor as imported	80%	90%	25% (6h/day)	45% (includes some thermal storage)	90%	0%
Availability for peak generation	15%	98%	85%	85%	15%	60%	95%	98%
Cost change over time	-25% per decade up to 2023 (IEA 2003), then 15% per decade, but with resource linked increments	No change	-1%/year, but with increments because of resource	-1%/year	5%/yr to 2025 3%/yr to 2040 1%/yr to 2050	4%/yr to 2015 3%/ yr to 2040 1%/yr to 2050		'-
Max allowable	150 TWh	14.6TWh	16.4 TWh 100 TWh[20]	10.8 TWh (in 2045)	No practical limit	No practical limit	70 TWh	10.3 GW
Used in scenario EE	66 TWh	14.6 TWh	14.5 TWh	10 TWh	47 TWh	107 TWh	33.5 TWh	8.5 GW
Used in scenario FF	80 TWh	57.8 TWh	43 TWh	10 TWh	84 TWh	184 TWh	68.5 TWh	16 GW

[18] EE=Progressive renewable

[19] FF= High Renewable

[20] See section 3.7.3.1 to see why two figures quoted.